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POSITION PAPER
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FROM ENGLISH TO THE MOTHER TONGUE: ARTIFICIAL INTELLIGENCE AND A NEW PARADIGM OF ACADEMIC PUBLISHING

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ABSTRACT

For decades, English has served as the dominant language of scholarly communication. While this dominance has facilitated global dissemination of knowledge, it has also created significant barriers for researchers whose native language is not English. This article argues that recent advances in artificial intelligence, particularly in machine translation and language understanding, make it possible to reconsider one of the fundamental assumptions of contemporary academic publishing: that scientific work must be written in English to be internationally relevant. Rather than requiring authors to adapt their ideas to a foreign language, a new model may emerge in which scholars write in their native language while readers, editors, and reviewers access AI-assisted translations in the language of their choice. The paper discusses the historical origins of English-language dominance, the advantages of native-language authorship, the implications for editorial and peer-review processes, and the broader consequences for scientific diversity, inclusion, and knowledge production. This approach could also help broaden access to publication for scholars working in underrepresented linguistic communities.

1 INTRODUCTION

If the purpose of scholarly writing is to make ideas accessible and testable, then language should be treated as a medium of communication, not as a condition of scientific value. The globalization of science has also brought globalization of language. Over the past several decades, English has become the dominant medium of academic communication. Researchers seeking international visibility are expected to publish in English regardless of their linguistic background. This convention has undoubtedly facilitated international exchange, yet it has also produced a system in which linguistic proficiency often becomes a prerequisite for scientific participation.

For many scholars, particularly those from smaller linguistic communities, writing in English represents a substantial burden. The challenge

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extends beyond grammar and vocabulary. Scientific writing requires precision, nuance, rhetorical sophistication, and the ability to communicate complex ideas effectively. Even highly qualified researchers may struggle to express subtle arguments in a foreign language. As a result, scientific quality and linguistic quality are frequently conflated, despite being fundamentally different dimensions of scholarly work.

The rapid development of artificial intelligence invites a reconsideration of this model. Modern AI systems are capable of translating complex texts with a level of fluency unimaginable only a few years ago. Recent discussions in scholarly publishing suggest that AI translation technologies may fundamentally transform multilingual scientific communication (Amano et al., 2025). More importantly, they increasingly understand context, terminology, and discipline-specific language. These developments raise an important question: if readers can access high-quality translations instantly, why should authors be required to write in a language other than their own?

2 THE COST OF WRITING IN A FOREIGN LANGUAGE

The current publishing system imposes hidden costs on researchers. Authors invest substantial time and resources in language editing, translation, and proofreading. In many cases, professional language editors improve grammar but lack expertise in the relevant scientific field. This can lead to modifications that improve style while inadvertently altering meaning.

The problem is particularly evident in the social sciences and humanities, where arguments often depend on subtle linguistic distinctions and cultural context. Researchers may simplify ideas, avoid complex formulations, or abandon culturally specific concepts because they are difficult to communicate in a foreign language. The result is not merely a linguistic compromise but a potential reduction in intellectual diversity (Amano et al., 2025).

Native-language writing allows scholars to communicate with greater confidence, precision, and originality. Concepts can be developed within their natural cultural and linguistic framework, preserving nuances that might otherwise be lost.

3 ARTIFICIAL INTELLIGENCE AS AN ENABLING TECHNOLOGY

The emergence of large language models and AI translation systems changes the technological landscape of academic publishing. Readers already use translation tools routinely when accessing news, technical documentation, and scholarly literature. Increasingly, the distinction between a text originally written in English and one translated into English becomes less significant from the reader's perspective (Translayer Team, 2026).

AI does not simply replace traditional translation. It enables a multilingual publishing ecosystem in which the original language remains central while multiple translated versions become available simultaneously. Under such a model, the authoritative version of a paper remains the author's original text, while readers interact with dynamically generated translations adapted to their linguistic preferences.

This shift has implications far beyond convenience. It challenges the assumption that linguistic standardization is necessary for scientific communication. Instead, technology enables communication across languages without requiring the elimination of linguistic diversity.

4 IMPLICATIONS FOR EDITORS AND REVIEWERS

The greatest challenge of a multilingual publishing model is not the reader but the editorial process. Editors must evaluate submissions, communicate with authors, select reviewers, and ensure publication quality. Traditionally, this requires a shared language.

However, editorial work is already increasingly supported by digital tools. AI can assist editors in generating preliminary translations, checking formatting requirements, identifying missing references, verifying citation consistency, and summarizing manuscript content. Recent analyses suggest that AI-assisted editorial workflows may significantly reduce language-related barriers in scholarly publishing (Gordon, 2024). Rather than replacing editorial judgment, AI can augment it.

The same principle applies to peer review. Reviewers frequently encounter manuscripts written in imperfect English and already devote effort to interpreting unclear passages. AI-assisted translation could allow reviewers to evaluate manuscripts in their preferred language while preserving access to the original text when necessary. In this model, peer review becomes focused more directly on scientific merit and less on linguistic conformity.

Such developments may be especially valuable for smaller journals with limited editorial resources. AI tools can function as editorial assistants, reducing administrative burdens and enabling broader international participation.

5 SCIENTIFIC DIVERSITY AND KNOWLEDGE EQUITY

Language is not merely a communication tool; it is also a repository of culture, history, and ways of thinking. The dominance of a single language inevitably privileges certain intellectual traditions while marginalizing others.

A multilingual publishing model could contribute to greater equity in global science (Amano et al., 2025). Researchers from developing countries and smaller linguistic communities would face fewer barriers to publication. Local knowledge, region-specific concepts, and culturally grounded perspectives could enter international debates without being filtered through a single linguistic framework.

Such a transformation would also benefit readers. Instead of forcing all participants into one language, scientific communication could adapt to individual linguistic preferences. AI translation makes this vision technically feasible for the first time in history.

6 REMAINING CHALLENGES

The transition toward multilingual publishing is not without obstacles. Technical standards must be developed for metadata, indexing, citation practices, and version control (Gordon, 2024). Publishers must establish policies defining which version of a manuscript constitutes the official record. Quality assurance procedures for AI-generated translations will also be necessary.

Equally important is the question of academic prestige. English-language publication remains deeply embedded in evaluation systems, rankings, and institutional expectations. Changing these perceptions may take years, even if technology is already available.

Nevertheless, many historical transformations in scholarly communication initially faced resistance. Digital journals, open access publishing, and online peer review were once considered unconventional. Today they are widely accepted. The same may eventually occur with multilingual publishing supported by artificial intelligence.

7 CONCLUSION

Artificial intelligence offers an opportunity to rethink one of the foundational assumptions of modern scholarly publishing. Rather than requiring all researchers to write in English, future publishing systems may allow authors to write in their native language while readers, reviewers, and editors access high-quality translations generated by AI.

Such a model would not eliminate English, nor would it diminish international communication. Instead, it would reposition English as one language among many within a technologically connected ecosystem. The result could be a more inclusive, equitable, and intellectually diverse scientific community.

The future of academic publishing may therefore be defined not by a single global language, but by a global conversation conducted through many languages and connected through artificial intelligence.

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CASE STUDY
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EMPLOYING AI TO IMPROVE SUSTAINABLE GROWTH INDICATORS IN FINTECH PLATFORMS: ZEST-AI

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ABSTRACT

With the rapid spread of advanced digital technologies in financial services, this study examines how artificial intelligence can improve the effectiveness of sustainable-growth indicators on FinTech platforms, treating these indicators as strategic levers for operational efficiency and service quality. The American AI platform Zest-AI is used as a case study because of its success in developing AI-based credit-assessment solutions that expand customer reach and accelerate lending decisions at banks and financial institutions. The study finds that integrating generative AI, machine learning, and deep learning into digital financial platforms enables the creation of intelligent lending models that strengthen the financing capacity of banking and financial institutions. Results from the Sustainable Growth Index show that the Zest-AI platform attains a very high level of sustainable growth, indicating economic efficiency, promotion of social equity, and an orientation toward environmentally conscious digitalization. This performance is classified as a high degree of sustainability maturity.

1 INTRODUCTION

In light of the rapid digital transformation experienced by global economies, reliance on advanced technologies has become one of the fundamental instruments reshaping mechanisms of work and innovation across various economic sectors, including the financial technology (FinTech) sector. This technological progress has brought about a profound transformation in the delivery of financial services, enhancing operational efficiency, improving the quality of decision-making, and strengthening the competitive capabilities of financial institutions

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within contemporary digital environments (Gomber et al., 2017, p. 537).

Digital platforms face increasing challenges manifested in intensified competition, rising customer expectations, and the need to deliver innovative and secure financial services. In this context, artificial intelligence (AI) emerges as a key strategic factor that enables these platforms to improve their business models, enhance their ability to adapt to rapid changes in digital markets, and achieve higher levels of operational efficiency and flexibility (Vives, 2019, pp. 243-246), thereby ensuring their sustainability and continuous growth.

Customer creditworthiness assessment platforms represent one of the most prominent domains of digital transformation in which artificial intelligence can exert a tangible impact. This is due to the superiority of AI technologies over traditional financing methods in improving decision accuracy, risk prediction, and the provision of more secure and effective services through the exploitation of large volumes of data and their more comprehensive and objective analysis (Lessmann et al., 2015, p. 124). Moreover, issues of transparency and fairness in credit decisions are gaining increasing importance in light of growing regulatory and ethical requirements, which contributes to enhancing the reliability of automated decisions and ensuring their interpretability by both financial institutions and customers alike (Bussmann et al., 2020, p. 215), in addition to improving the quality of credit portfolios and reinforcing financial stability.

Among the prominent practical models in this field is the American platform Zest AI, which represents a leading example of the application of artificial intelligence in creditworthiness assessment. The platform uses advanced technology to build better credit models which result in improved customer satisfaction and risk management efficiency and responsible lending practices that support sustainable digital financial growth (Zest AI).

The research importance stems from its investigation into how artificial intelligence systems enhance sustainable growth indicators through their operational credit assessment applications which result in improved economic performance and financial sustainability for modern digital financial platforms.

1.1 Study Problem

The problem addressed by this study is summarized in the following main research question:

RQ: How do artificial intelligence technologies contribute to improving the effectiveness of sustainable growth indicators for the American financial technology platform “Zest-AI”?

In order to comprehensively examine all aspects of the topic and adequately answer the research problem, the following sub-questions emerge from the main question:

SQ1: What are the theoretical concepts associated with artificial intelligence technologies and financial technology platforms?

SQ2: What are the foundations of the relationship between artificial intelligence technologies and sustainable growth indicators in financial technology platforms?

SQ3: What are the most prominent artificial intelligence–based innovations of the financial technology platform “Zest-AI”?

SQ4: What is the level of performance of the sustainable growth indicators of the “Zest-AI” platform?

1.2 Study Hypotheses:

In light of the proposed research problem, the sub-questions, and the objectives of the study, the following hypotheses were formulated:

H1: Artificial intelligence constitutes a catalytic factor in enhancing the effectiveness of sustainable growth indicators for financial technology platforms by improving the efficiency of credit decision-making, strengthening financial inclusion, and reducing operational risks.

This main hypothesis is supported by the following sub-hypotheses:

H1.1: The fundamental concepts and technologies of artificial intelligence—such as machine learning, deep learning, and big data analytics—positively affect the performance of financial technology platforms by fostering innovation and advancing digital business models;

H1.2: There is a positive relationship between the adoption of artificial intelligence technologies and the improvement of the effectiveness of sustainable growth indicators for financial technology platforms across three main dimensions: economic efficiency, technological continuity, and social responsibility and governance;

H1.3: The platform "Zest" achieves its competitive advantage through a set of artificial intelligence–driven innovations, including advanced credit scoring models, fraud prevention systems, and the analysis of customers' financial behavior;

H1.4: The artificial intelligence solutions implemented by the "Zest" platform contribute to improving the performance of its sustainable growth indicators through a three-dimensional framework that integrates economic, social, and environmental dimensions.

1.3 Study Objectives

After addressing the previously stated research problem and the related research questions, this study aims to achieve the following objectives:

- To provide a review of the literature related to the applications of artificial intelligence in financial start-ups;
- To highlight the role of artificial intelligence in supporting the sustainability of financial technology platforms;
- To examine the applications of artificial intelligence within the American platform "Zest" as a practical model for assessing creditworthiness;
- To offer practical recommendations regarding best practices that financial platforms can adopt to enhance the effectiveness of sustainable growth indicators.

1.4 Study Significance

The significance of this research lies in identifying the vital role that artificial intelligence plays in enhancing the sustainability and competitiveness of financial technology platforms. The study seeks to provide an analytical framework illustrating how platforms can leverage artificial intelligence technologies to improve their operational processes, manage risks, and deliver innovative financial services—such as creditworthiness assessment—in order to meet the growing demands of the digital market and achieve continuous development. Furthermore, examining the model of the American platform *Zest* offers a practical experience that can be utilized in the development of specialized smart lending platforms in Algeria, thereby contributing to the expansion of both academic and applied knowledge concerning the relationship between digital innovation and indicators of sustainable growth in the financial sector.

1.5 Study Methodology

This study adopts the descriptive–analytical approach, as it is an appropriate method for clarifying the conceptual framework of the study variables and the relationships among them, through the examination and analysis of a pioneering experience in the field of financial technology represented by the American platform *Zest AI*.

2 THEORETICAL FOUNDATIONS OF THE STUDY

Financial technology platforms, in general, are showing increasing interest in employing the latest technological innovations to develop services capable of improving their understanding of customer needs, thereby enhancing their competitiveness and increasing their market share. Consequently, these platforms strive to operate within a modern institutional framework that keeps pace with developments in the technological environment—particularly in the field of artificial intelligence—in order to achieve sustainable growth.

2.1 Concept of Artificial Intelligence (AI)

Artificial intelligence is considered one of the most important pillars upon which modern financial technology is based, as it represents a driving force behind innovation and digital transformation across various financial services. Through its capabilities in learning, analysis, and prediction, artificial intelligence can bring about a qualitative shift in functions such as financing, risk management, and service personalization, making it a central element in the development of intelligent and sustainable financial systems.

2.1.1 Definition of Artificial Intelligence

Artificial intelligence has become a central component of the rapid development of financial technology, as it has reshaped methods of service delivery, risk analysis, and decision-making. Accordingly, defining artificial intelligence within the financial sector is of particular importance for understanding its role in building more innovative and sustainable solutions.

Artificial intelligence in the financial technology sector can be defined as "the integration of advanced computational models and machine learning algorithms to automate, enhance, and personalize financial services and decision-making processes" (Arner et al., 2020).

It is also understood as "the development of intelligent systems capable of learning from data to enhance risk management, fraud detection, credit scoring, and customer service on digital financial platforms" (Gai et al., 2018, pp. 262-273).

It is further defined as "the application of cognitive computing, predictive analytics, and automation to deliver smarter financial services based on data and digital innovation" (Badmus et al., 2024, pp. 616-618).

Based on the preceding definitions, artificial intelligence in the financial technology sector may be defined as "the deployment of advanced computational models, machine learning techniques, and predictive analytics within digital financial platforms and services, with the aim of automating processes, improving risk management, detecting fraud, and personalizing financial services, thereby contributing to enhanced operational efficiency and the achievement of sustainable digital innovation within the financial system."

Artificial intelligence can be employed in the innovation of financial services as follows (bigmedia, 2024):

- Assessing customer creditworthiness;
- Early fraud detection and risk management;
- Customer communication through chatbots and virtual assistants;
- Evaluating and enhancing the performance of banking and financial institutions;
- Improving the accuracy of financial decision-making;
- Supporting innovation and the development of new financial products.

2.1.2 Artificial Intelligence Techniques in the FinTech Sector

The use of artificial intelligence techniques across their various practical applications related to the financial technology sector is summarized in Table 1.

Table 1. *Key Artificial Intelligence Techniques in the Financial Technology Sector*

Technology	Concept
Big Data Analytics	Gartner defines it as "high-volume, high-velocity, and high-variety information assets that require economically viable and innovative processing methods in order to enhance insights and support decision-making." (Najem et al., 2025).
Natural Language Processing (NLP)	A subfield of artificial intelligence, which itself stems from computer science, and which significantly overlaps with linguistics that provide the linguistic descriptions required for computers. This field enables the development of software capable of analyzing and simulating the understanding of natural languages. It is used to analyze texts and conversations, such as loan application analysis, chatbots, document analysis, or financial news analysis.
Machine Learning (ML)	It is the science through which machines are able to translate, execute, and verify data using algorithms developed through complex mathematical capabilities and encoded in a language understood by machines, with the aim of overcoming certain problems faced by humans.
	It includes supervised learning, unsupervised learning, and reinforcement learning algorithms, which are used for data analysis, prediction, classification, and pattern recognition (Kou & Lu, 2025).
Deep Learning (DL)	A branch of machine learning that uses deep neural networks to process large volumes of complex data, such as images, audio, or text. It is applied in text analysis, document image recognition, and user behavior analysis. (Lee et al., 2024, pp. 460-478).

Technology	Concept
Reinforcement Learning (RL)	Primarily used in trading and asset management, where the model learns from experience and rewards to make optimized decisions over time.
Generative AI	New technologies such as large language models (LLMs) or generative models that produce content or exhibit interactive intelligence. These technologies are beginning to enter the financial domain in areas such as analytics, recommendations, and the generation of financial content (Lee et al., 2024).
Explainable AI (XAI)	In the financial sector, it is important that artificial intelligence decisions be explainable, as financial institutions and regulatory bodies require transparency. Consequently, research on explainable AI (XAI) in finance has become increasingly prominent (Roy et al., 2025, pp. 1-26).

Source: Prepared by the researchers

2.2 The Concept of Sustainable Growth in the Financial Sector

Sustainable growth is an economic concept that refers to achieving a continuous increase in production, income, and wealth without compromising the ability of future generations to meet their needs. In other words, it represents long-term economic growth that balances economic, social, and environmental dimensions.

2.2.1 Definition of Sustainable Growth

The term *sustainable growth* was introduced by the American economist Robert Higgins, who defined it as "the annual rate of increase in sales consistent with a given financial policy that can be achieved in light of a firm's profitability, asset utilization, dividend policy, and debt ratio." This concept provides a comprehensive financial framework and an equation for each firm to estimate its sustainable growth rate (Higgins, 1977, p. 08).

With regard to sustainable growth within organizations, it extends beyond merely achieving a certain level of financial growth. The pursuit of "sustainable" growth within institutions is not limited to improving financial indicators; rather, it encompasses a broader perspective that includes environmental, social, and governance factors. Sustainable growth aims to create long-term value without depleting natural or social resources and is characterized by environmentally sound practices, social responsibility, and economic viability (agn International, 2024).

In the field of financial technology, sustainable growth may be defined as "growth that reflects the ability of digital financial platforms to expand their operations and market reach while maintaining long-term economic viability, social responsibility, and environmental stewardship."

Based on the preceding definitions of sustainable growth, sustainable growth in the financial technology sector can be understood as "a process of digital and financial development that seeks to achieve a balance between technological innovation, economic stability, and social and environmental responsibility, thereby ensuring the platform's continuity and competitive capacity in digital financial markets over the long term."

2.2.2 Dimensions of Sustainable Growth in the Financial Sector

In light of the profound transformations taking place in the digital economy, financial technology has become one of the principal drivers of sustainable growth due to its cross-cutting impact on the economic, social, and environmental dimensions, as outlined below:

- *Economic Dimension:* Financial technology contributes to enhancing operational efficiency, reducing transaction costs, and improving capital allocation in ways that support the continuity of long-term growth (OECD, 2022, pp. 59-60).
- *Social Dimension:* It constitutes a central instrument for expanding financial inclusion and empowering vulnerable groups by facilitating transparent and equitable access to financial services and protecting consumers from digital and credit-related risks, thereby reinforcing social justice and social stability (CPMI, 2020, p. 51).
- *Environmental Dimension:* Green financial technology applications (*Green FinTech*) play a prominent role in supporting the transition toward a low-carbon economy by tracking

emissions and developing digital platforms for financing small-scale and green projects that are capable, in real time, of detecting and monitoring the remediation of imbalances in the environmental ecosystem—such as waste management—and of improving environmental disclosure through the use of advanced technologies. Through this integration of the three dimensions, financial technology is transformed into a supportive infrastructure for a more resilient, equitable, and sustainable financial system, capable of responding to the challenges of contemporary growth and achieving the Sustainable Development Goals in an effective and innovative manner (Padhiar & Christiaen, 2024, pp. 9-12).

2.2.3 Calculating the Sustainable Growth Index (SGI)

The methodology for calculating the Sustainable Growth Index is based on an approach derived from the Organisation for Economic Co-operation and Development (OECD) guidelines for constructing composite indicators. Initially, the values of each operational indicator over the study period are transformed into standardized scores within a range of 0–100 points, using the relative rescaling equation commonly applied in measuring sustainability indicators with different units (percentages, quantities, monetary values, etc.). The relative rescaling formula is expressed as follows:

$$Relative\ rescaling\ equation = \frac{operational\ value\ -\ minimum\ value}{maximum\ value\ -\ minimum\ value} \times 100$$

The maximum values are determined based on the results of the best published studies and the highest performance levels reported by financial institutions. Subsequently, the overall index score is calculated by aggregating the weighted scores of the indicators that constitute each dimension of sustainable growth in the financial sector (OECD/European Union/EC-JRC, 2008, pp. 27-28). This methodology enables the construction of a credible composite index that reflects the extent to which artificial intelligence technologies enhance the effectiveness of sustainable growth indicators for financial technology platforms by improving the economic, social, and environmental dimensions.

2.3 The Nature of Financial Technology Platforms

The financial technology (FinTech) sector is experiencing rapid development in parallel with the economic and social transformations brought about by the Fourth Industrial Revolution and financial globalization. Since the early formation of the financial system, a series of financial innovations has emerged, contributing to the improvement and advancement of financial services. The twenty-first century, in particular, has witnessed a qualitative surge in the pace of innovation and the application of advanced digital technologies in the financial domain, giving rise to a new form of activity known as financial technology platforms. These platforms represent the outcome of the integration between modern technology and financial services.

2.3.1 Definition of Financial Technology Platforms

A digital platform is defined as “a technology-based business model that creates value by facilitating exchanges between producers and consumers” (Mothibi & Lazaridis, 2021, p. 4).

The Financial Stability Board (FSB) defines financial technology as “technology-enabled financial innovation that may result in new business models, applications, processes, or products with a material effect on financial markets, financial institutions, and the provision of financial services” (Basel Committee on Banking Supervision, 2018, p. 05).

Based on the foregoing, it can be concluded that financial technology platforms rely on the use of advanced technologies to create innovative business models that enable the delivery of products and services in simpler ways to broader segments of users at lower cost.

Financial technology platforms (FinTech platforms) aim to achieve a set of strategic and operational objectives that enhance the efficiency and quality of financial services. The most prominent of these objectives can be summarized as follows (Croxson et al., 2022, pp. 07-08)

- Improving operational efficiency and reducing costs;
- Achieving more efficient market access;
- Enhancing customer experience;
- Promoting financial inclusion;
- Supporting innovation and the development of new financial products.

2.3.2 Types of Financial Technology Platforms

There are numerous approaches that can be adopted in the operation of financial technology platforms. The most notable of these are presented in Table 2.

***Table 2**. Types of Financial Technology Platforms*

Application	Concept
Crowdfunding Platforms	Crowd funding stands as a revolutionary method which transformed how people borrow money and make investments. The term describes a group effort which depends on trust and established relationships between people who combine their resources through online platforms to fund cost-effective project support. Start-ups and small to medium-sized businesses find their funding needs fulfilled through crowdfunding platforms which also support project financing for events and activities and scientific and engineering developments and website and mobile application creation and product design and film production and charitable and social initiatives. The four main types of crowdfunding platforms include reward-based crowdfunding and donation-based crowdfunding and equity crowdfunding and real-estate crowdfunding.
Peer-to-Peer (P2P) Lending / Direct Financing Platforms	Peer-to-peer (P2P) lending platforms function as online marketplaces which connect individuals who need loans with those who want to lend money. These platforms allow users to obtain loans through various financial products which include loan tranches and investment stakes and credit packages. The process of loan preparation occurs through P2P platforms that divide and organize loans, yet some platforms enable lenders to pick their own loan opportunities. The electronic platforms help borrowers obtain quick funding at reasonable interest rates and they enable investors to build diversified investment portfolios through dependable monthly payment generation.
Digital Wallet Platforms (Digital Wallets / E-Wallets)	A digital or electronic wallet functions as an electronic platform which organizes financial transactions and stores encrypted user data. The software functions across computers and mobile devices and smartphones and web platforms. Users can save their information in digital wallets which enables them to complete digital transactions. Software applications known as cryptocurrency wallets function to hold private keys which grant access to Bitcoin addresses and other cryptocurrencies while providing users with management tools for buying selling and exchanging their digital assets.
Cryptocurrency Platforms (Digital Currency / Cryptocurrency)	A digital or electronic currency is a virtual, intangible currency with no physical existence. The system operates through instant transactions which allow customers to buy products directly from digital platforms without using any middlemen. The system operates worldwide through Bitcoin, which serves as its leading example because it commands the highest recognition and most active trading activity. Cryptocurrencies operate through decentralized systems which enable users to make protected payments and keep their funds secure without revealing their real identities or visiting bank institutions. The blockchain technology functions as a distributed ledger system which tracks every transaction made by users of cryptocurrencies.

Source: Prepared by the researchers, based on:
(Basel Committee on Banking Supervision, 2018, pp. 15-17).

3 AI-DRIVEN SUSTAINABLE GROWTH METRICS IN FINTECH

Artificial intelligence is considered one of the most important factors contributing to the achievement of sustainable growth for financial technology platforms, not only through enhancing economic performance, but also by supporting social and environmental objectives related to sustainability. This relationship can be analyzed by examining how artificial intelligence applications contribute to the fields of payments, financing, investment, and insurance, and by assessing their impact on the economic, social, and environmental dimensions of sustainability.

3.1 The Role of AI in Achieving the Sustainability of Digital Payment Platforms

Digital payment services have witnessed significant development due to artificial intelligence technologies, which have enabled FinTech platforms to deliver fast, secure, and low-cost services. These technologies play a pivotal role in improving customer experience through machine learning–based fraud detection systems that monitor transactions in real time and accurately identify abnormal patterns, thereby reducing the risks of financial crime and enhancing trust in the financial system.

Artificial intelligence also contributes to promoting financial inclusion by providing mobile payment services to populations that lack access to traditional banking accounts. This enables individuals to store money, conduct transfers, and access basic financial services, thereby improving financial well-being and reducing poverty. These transformations support social sustainability by integrating vulnerable groups into the economic cycle and enhancing their ability to withstand financial shocks (Gautam, 2019, pp. 91-108).

At the economic level, reliance on intelligent payment technologies leads to lower operational costs and increased transaction efficiency, which enhances platform profitability and strengthens their capacity for growth and continuity. Moreover, the transition to digital payments contributes to reducing cash usage, thereby limiting financial crimes and corruption, which in turn supports the institutional framework of financial sustainability systems (Mhlanga, 2020, p. 45).

3.2 Application of AI in Smart Lending Services

Artificial intelligence has brought about a transformative shift in the lending sector through the development of credit assessment algorithms based on big data, digital footprints, and deep learning models. These technologies make it possible to obtain a more accurate representation of customers' financial behavior, thereby reducing information asymmetry, which had long constituted a major obstacle for traditional banks. Consequently, financial technology platforms have succeeded in expanding the borrower base to include segments that were previously excluded (Berg et al., 2020, pp. 2846-2850).

This development contributes to the achievement of economic sustainability through:

- Supporting small and medium-sized enterprises in obtaining the necessary financing to launch projects;
- Creating new employment opportunities as a result of the expansion of economic activity;
- Encouraging innovation and entrepreneurship.

From the perspective of social sustainability, artificial intelligence–based lending enables low-income groups to access financing at lower costs and under more flexible conditions, thereby helping to improve quality of life and reduce disparities among social groups.

Furthermore, artificial intelligence–enabled crowdfunding platforms offer innovative financing models that facilitate direct connections between investors and entrepreneurs, helping to channel financial resources toward sustainable projects such as environmental initiatives, social ventures, and circular economic activities. This, in turn, enhances their capacity to achieve long-term sustainable growth (Suryanto et al., 2020, pp. 1-9).

3.3 The Role of AI in Developing Investment Platforms

Artificial intelligence is considered one of the most important transformative tools in the field of investment, owing to its applications in robo-advisors, which provide portfolio management

services at lower cost and with a high degree of customization. Machine learning algorithms assist in analyzing market trends, identifying appropriate investment strategies, and delivering automated recommendations that support investors with limited expertise, thereby enhancing their capacity for saving and long-term investment (Schwinn & Teo, 2018, pp. 451-461). These models contribute to strengthening economic sustainability by increasing savings rates and improving the allocation of financial resources at both individual and institutional levels. They also support social sustainability by enabling middle- and low-income groups to invest small amounts, thereby reducing inequality in access to wealth-building instruments.

Moreover, some investment platforms, enabled by the analytical capabilities of artificial intelligence, provide opportunities to finance projects related to environmental and social governance, encouraging the direction of capital toward environmentally and socially sustainable activities. This, in turn, reinforces the environmental dimension within the comprehensive sustainability framework (Arner et al., 2015, pp. 5-35).

3.4 Application of AI in InsurTech Services

Insurance technology companies (InsurTech) have developed remarkably through the use of artificial intelligence in risk assessment and the provision of innovative insurance products, such as on-demand insurance, usage-based insurance, and microinsurance. These models offer low-cost insurance coverage targeting segments that were previously excluded from traditional insurance services (Abdikerimova & Feng, 2021, pp. 735-749).

Artificial intelligence enhances actuarial accuracy by integrating data related to climate conditions, geographic location, the Internet of Things, and individual behavior. This integration facilitates the development of effective insurance solutions against climate-related disasters and social risks, thereby strengthening the ability of households and small businesses to withstand economic shocks and contributing to the construction of adaptive communities—one of the core pillars of sustainability (Volz et al., 2020, pp. 05-07).

4 ZEST-AI AS A MODEL FOR SUSTAINABLE AI LENDING

The Zest AI platform represents one of the most prominent emerging models in the field of artificial intelligence–driven financial technology. It has succeeded in reshaping the traditional lending function by deploying advanced algorithms capable of analyzing financial data with a high degree of accuracy. The platform's rise reflects the profound transformations occurring within the financial sector toward the adoption of intelligent solutions in lending, credit risk management, and the expansion of financial inclusion.

In 2025, Zest AI was ranked among the world's top financial technology companies in the annual list published by CNBC, a prestigious global ranking compiled in partnership with Statista (Zest AI, 2025). It was also ranked in 2024 at position 318 on the Deloitte Technology Fast 500™, an annual ranking that includes 500 of the fastest-growing technology companies in North America over a three-year period. During the period 2020–2023, the platform achieved a growth rate of 368% (Zest AI, 2024).

Its rapid development constitutes clear evidence of the capacity of artificial intelligence to improve the quality of financial decision-making and reduce biases in credit allocation. In the context of intensifying competition within financial technology markets, Zest AI emerges as a leading platform that combines technological innovation with social impact, making it a suitable model for examining the role of artificial intelligence technologies in achieving sustainable growth for financial technology platforms.

4.1 Definition of the U.S.-Based Zest AI Platform

Founded in 2009 under the name Zest Finance, the company is headquartered in Los Angeles, California, United States. Its initial objective was to employ machine learning to enhance the lending capabilities of credit unions and make them more fair and transparent. In 2019, it transitioned from being merely a provider of financial solutions to a specialized artificial intelligence platform under the name Zest AI (Hurst, 2019).

The platform currently operates as a business-to-business software-as-a-service (B2B SaaS)

partner for banks, credit unions, and specialized lending institutions by providing innovations and developing models based on artificial intelligence technologies to facilitate access to consumer loans in a more efficient and effective manner. It has developed more than 600 models for creditworthiness assessment and automated decision-making and holds over 50 patents, including both registered and pending patents, in areas such as automation, accuracy, performance, and model interpretability. These capabilities enable the platform to reduce risk and maximize growth opportunities throughout the lending process.

As a leading platform in intelligent and innovative lending solutions that span areas such as marketing, credit analysis, fraud detection, loan policies, and related functions, Zest AI manages assets with a value exceeding USD 5.6 trillion (Zest AI, 2025).

4.2 Foundations of the Zest AI Business Model

In light of the ability of artificial intelligence to penetrate various financial and banking functions, the Zest AI platform's business model is based on providing intelligent, analytically driven solutions in the lending function. The key pillars of this model can be outlined as follows:

- *Big Data:* The platform collects and analyzes vast amounts of data from multiple sources, including banking data, credit reports, and even digital usage patterns related to mobile phones or internet activity, in order to construct an accurate and comprehensive profile of the customer.
- *Machine Learning Algorithms:* Artificial intelligence algorithms identify and analyze recurring patterns to predict an individual's credit behavior. As the volume of data increases, the accuracy of the models correspondingly improves.
- *Interpretability and Transparency:* The platform provides full transparency regarding how decisions are made, which assists institutions in complying with regulatory requirements.
- *AI-Automated Underwriting (May 2021):* Customized machine learning models are developed for each lender to enhance credit decision-making through fair and accurate assessments. These models contribute to higher approval rates for creditworthy borrowers and a reduction in non-performing loans.
- *Fraud Detection System – "Zest Protect" (August 2024):* This system offers advanced protection against fraud in loan applications through artificial intelligence technologies by enhancing comprehensive risk visibility and improving the ability to control risk levels, while reducing friction in customer interactions (Zest AI, 2025).
- *Intelligent Lending Platform – "LuLu Lending Intelligence":* Launched in February 2024, this platform is based on generative artificial intelligence (GenAI) technologies and enables lenders to obtain instant analytical insights into their credit portfolios and the broader market. The platform supports faster strategic decision-making based on a broader dataset, while facilitating the identification of business opportunities, the detection of performance gaps, and the improvement of credit portfolio health. It includes the following two modules:
  - *"LuLu Pulse" Module:* Launched in February 2025, this generative AI–based module allows financial institutions to use natural language to submit queries and obtain performance and market analyses without the need for complex dashboards.
  - *LuLu Strategy Unit:* This unit represents the second phase of the credit intelligence platform, developed by the platform beginning in May 2025. It provides advanced analyses of loan performance through simulations based on generative artificial intelligence and actionable data, as a strategic step toward integrating public sectoral data with institution-specific data. *LuLu Strategy* focuses on consolidating information derived from multiple sources within a unified, reliable, and customizable platform tailored to the needs of each client. With the launch of the *LuLu Strategy* unit, financial institutions can benefit from the features shown in Figure 1.

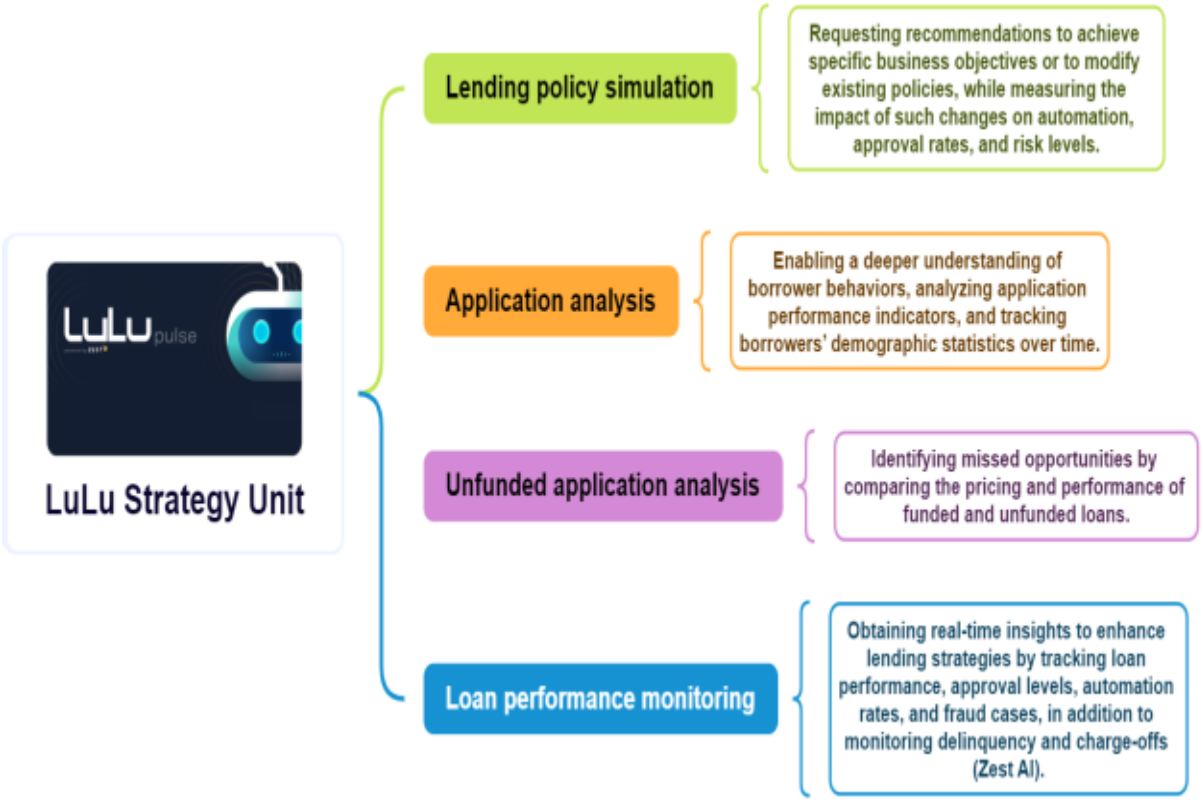


Figure 1*. Features of LuLu Strategy Unit*
Source: By the researchers based on a review of the Zest AI website on November 14, 2025, https://www.zest.ai/

Building on its intelligent solutions, the benefits for financial institutions in using the *Zest AI* platform can be summarized as follows:

- *Improved assessment accuracy:* The platform relies on comprehensive analytical decision-making, which reduces instances of incorrect loan approvals and helps enhance the quality of the credit portfolio;
- *Enhanced financial inclusion:* It enables lenders to reach new customer segments that may be rejected under traditional systems due to insufficient credit history, thereby increasing access to financing;
- *Reduction in loan default rates:* Through precise analysis, the platform allows for better prediction of borrowers' repayment capacity, thereby improving overall financial performance;
- *Processing speed:* The platform accelerates the evaluation process, positively affecting the customer experience and reducing waiting times.

4.3 Measuring AI Impact on Zest-AI Sustainable Growth

Despite variations in lending policies among lenders, the assessment of the use of artificial intelligence technologies in achieving the effectiveness of sustainable growth indicators for the *Zest AI* platform is based on a three-dimensional framework that reflects the comprehensive concept of sustainable growth in the financial technology sector. This framework integrates the economic, social, and environmental dimensions, and the following methodology was adopted:

- *Economic dimension:* improving operational efficiency through the automation of credit decision-making and reducing application processing time; increasing profitability by lowering default rates through accurate risk assessment models; and expanding the customer base as a result of broadening loan approval coverage.

Table 3. *Indicators for Measuring the Performance of Zest AI Platform Products Based on Artificial Intelligence Technologies*

Dimension	AI Technique Used	Growth Indicator	Value Before Use AI (2019)	Value After AI Use (2020–2024)	Impact Rate on Growth
Economic	Credit scoring models using machine learning techniques	Number of credit applications	Very low	Over 600,000 applications per year	Significant growth
		Value of granted loans	Limited scope	USD 250 billion	Considerable increase
		Customer growth rate	Very limited (approximately 10%)	50% per year	50%
		Increase in approvals / reduction of risk	—	25% increase in approvals	25%
	Fraud detection models	Loss reduction	—	20% reduction after system integration	20%
	Risk assessment models using machine learning techniques	Default rate	—	Reduced by between 30% to 40%	Average rate default 35%
	Decision automation models using machine learning techniques	Decision automation	Large-scale manual review	Increased automation from 60% to 80%	Average automated decisions: 70%
		Accuracy of decisions	—	Highly accurate decisions	—
Social	Bias reduction models	Financial inclusion expansion; increase in approvals for protected groups	—	Latinos: 49%. African Americans: 41%. Hispanics: 31%; women: 40%. older: 36%;	Average expansion of financial inclusion: 39.4%
	Bias correction techniques using AI	Fairness	Legal challenges	More than 62 million individuals approved: +271%	—
	Explainable artificial intelligence (XAI)	Balance across groups	Verity	Improvement in fairness indicators	Significant improvement in equity rates
	Generative artificial intelligence analytics; interpretable prediction models	Customer satisfaction analysis; customer loyalty	—	100% customer retention; increased customer satisfaction; Net Promoter Score (NPS): 81 points	High loyalty and satisfaction

Source: Prepared by the researchers based on a review of the Zest AI website on November 17, 2025, https://www.zest.ai/

- *Social dimension:* enhancing financial inclusion by accepting new segments previously excluded from the traditional credit system; promoting fairness in lending; and reducing racial bias through evaluation models that rely on Explainable AI techniques, which minimize exclusionary decisions.
- *Environmental dimension:* reducing paper consumption through the transition to fully digital assessment models; lowering carbon emissions by decreasing travel and manual procedures; and promoting the shift toward green operations (*Green FinTech*) through the integration of artificial intelligence tools that support operational sustainability.

Following a comprehensive electronic survey conducted to collect the necessary statistical data, the environmental dimension was excluded due to the unavailability of relevant data. Table 3 highlights the main indicators used to measure the performance level of the platform's smart lending solutions and their impact on achieving sustainable growth, through a comparison between the periods before and after the adoption of artificial intelligence technologies.

4.3.1 Calculation of the Sustainable Growth Index (SGI)

Based on the results presented in the table, the indicator values were initially converted into standardized scores (ranging from 0 to 100 points) using a simplified relative rescaling formula, due to the unavailability of minimum values representing conditions prior to the adoption of artificial intelligence technologies, as required in the original model methodology:

- *Average increase in credit approvals (25%):* By selecting the maximum possible increase observed in Zest AI's experiences, estimated at approximately 30%, the score is calculated as follows: $(25/30) \times 100 = 83 points$.
- *Average reduction in risk (20%):* The maximum achievable reduction in certain cases is estimated at 40%. A study by McKinsey & Company indicates that machine learning technologies can reduce risk by between 20% and 40% in lending models (Dash et al., 2021). The score is therefore calculated as: $(20/40) \times 100 = 50 points$.
- *Reduction in default rates (assuming an average rate of 35%):* With a maximum reduction of 40% observed in Zest AI's experiences, the score is calculated as: $(35/40) \times 100 = 87.5 points$.
- *Rate of credit decision automation (average automation rate of 70%):* The maximum level observed in Zest AI's experiences is 83%. The score is calculated as follows: $(70/83) \times 100 = 84.5 points$.
- *Fairness / inclusion of protected groups (average growth of protected classes at 39.4%):* The maximum level is approximately 49% (Zest AI's Credit Models Proven to Increase Loan Approvals for Every Protected Class, 2024). The score is calculated as: $(39.4/49) \times 100 = 80.41 points$.
- *Customer satisfaction / customer loyalty*: The Net Promoter Score (NPS) equals 81 points out of 100 (PR Newswire, 2024).
- *Selection of dimension weights*: Due to the lack of official data for the environmental dimension, the Sustainable Growth Index is calculated based solely on the economic and social dimensions, assuming a weight of 0.5 for each dimension.

4.3.2 Calculation of dimensional averages:

- *Economic dimension average:* increase in approval rate + risk reduction + default reduction + automation $(83 + 50 + 87.5 + 84.5)/4 = 76.25 points$.
- *Social dimension average:* fairness + customer satisfaction $(80.41 + 81)/2 = 80.70 points$.
- *Approximate Sustainable Growth Index score for the platform:* $(76.25 \times 0.5) + (80.70 \times 0.5) = (38.12 + 40.35) = 78.47 points$.

4.3.3 Analysis of Results

The application of the three-dimensional measurement model to the Zest AI platform reveals a set of significant results that reflect the ability of artificial intelligence technologies to enhance sustainable growth across the following dimensions:

A. Analysis of the Economic Dimension

The data indicate that the Zest AI platform has achieved substantial economic improvement across several indicators:

- *An increase in loan approval rates by 25% without raising risk levels:* This reflects the ability of predictive machine learning models to expand the pool of creditworthy customers by analyzing thousands of variables, including non-traditional data. This outcome translates into increased revenue flows without a corresponding rise in loss rates, thereby reinforcing the institution's sustainable growth.
- *A tangible reduction in credit losses by 20%:* This suggests that machine learning–based risk assessment models have enhanced the accuracy of borrower classification, thereby reducing default cases. This contributes to lower operational costs, improved credit portfolio quality, and the support of sustainable growth through capital protection.
- *A significant decline in default rates (ranging from 30% to 40%):* This reduction reflects the effectiveness of algorithms in predicting credit behavior, enabling early risk detection and more proactive decision-making.
- *High levels of decision automation, ranging between 60% and 80%:* Automation leads to shorter application processing times, lower operational costs, improved productivity, and the provision of faster and more reliable services to beneficiaries.

Overall, the results of the economic dimension demonstrate that artificial intelligence serves as a fundamental driver of enhanced efficiency and profitability, in addition to reducing risk.

B. Social Dimension Analysis

The indicators of the social dimension point to the following results:

- *Significant increases in approval rates for protected groups:* Latinos: +49%, African Americans: +41%, women: +40%, older adults: +36%, and Americans of Asian descent and Pacific Islander populations: +31%. These results demonstrate that the Zest AI platform has succeeded in correcting biases inherent in traditional lending models, thereby enhancing social justice and achieving broader financial inclusion.
- *Credit fairness:* The Verity Credit Union recorded substantial increases in lending to the following groups: Asian populations: +375%, older adults: +271%, and women: +194%. This constitutes strong evidence of the use of artificial intelligence models equipped with bias-mitigation algorithms and *Explainable AI* techniques that reduce exclusionary decision-making.
- *Very high levels of customer satisfaction* (Net Promoter Score = 81 points and customer retention rate = 100% for credit unions): Satisfaction and retention reflect the credibility of the model, the clarity of credit decisions, the high level of trust in the accuracy of assessments, and the improvement in the lending experience resulting from automation and transparency.

It is evident that the Zest AI platform not only supports economic growth, but also strengthens fairness and expands access to equitable financing opportunities for groups that were previously marginalized.

C. Environmental Dimension Analysis:

Although no officially published statistical data are available regarding the environmental dimension, the following indicators can be inferred:

- Transition toward full digitalization of credit underwriting: Decision automation at a rate of 80% indicates a reduction in the need for paper-based files, a decrease in meetings and manual interventions, and a reduction in travel and wasted time. This represents a direct contribution to lowering the carbon footprint and supporting green financial practices (Green FinTech).
- Integration with high-efficiency cloud data centers: Operating through modern cloud platforms reduces reliance on heavy infrastructure and enhances energy efficiency.

Despite the limited availability of data, the environmental dimension demonstrates a clearly positive outcome through the use of artificial intelligence technologies.

Based on the recorded results, the study shows that the sustainable growth index outcome, calculated using weighted averages, reveals that the Zest AI platform achieves a very high level of sustainable growth, scoring 78.47 points out of 100, representing a rate of 78.47%. This indicates that the platform exhibits strong economic efficiency, achieves social justice, and is environmentally oriented toward sustainable

digitalization. This level of performance is classified as high maturity in AI-supported sustainability.

5 CONCLUSION

Artificial intelligence has evolved from a technological phenomenon into a primary force which now drives the operations of the financial technology industry. It has become a fundamental pillar for innovation, the enhancement of operational efficiency, and the strengthening of early risk detection capabilities. The financial industry has undergone a major transformation because of AI technology implementation which allows institutions to deliver better financial solutions through digital platforms that support their transition into new banking models for the digital era.

The intelligent solutions function as a driving force which helps financial technology companies to enhance their sustainable growth indicators during the worldwide digital transformation. The American platform Zest AI shows how artificial intelligence integration into financial operations enhances system performance and service quality and expands financing options through sustainable and equal methods which proves technology enables a smarter financial future.

5.1 Study Results

Based on this study, the following conclusions can be drawn:

- Theoretical analysis shows that artificial intelligence drives sustainable development in financial technology platforms through improved decision accuracy and risk reduction and expanded financial access.
- Financial technology platforms achieve sustainable growth through artificial intelligence systems which extend beyond technical aspects because they affect economic elements and social structures and environmental sustainability. Modern businesses need to create regulatory systems and digital solutions which enable this type of integration.
- Artificial intelligence technology implementation in lending and investment and insurance platforms creates fair financial resource distribution which improves access to financial services for marginalized populations.
- The Zest platform analysis shows that artificial intelligence technologies which include machine learning and deep learning and generative intelligence serve as fundamental tools for developing new creditworthiness assessment systems and fraud prevention mechanisms and fast financing decision support.
- It is observed that the application of artificial intelligence technologies within the Zest platform enhances the financing capabilities of its partner banking and financial institutions;
- Machine learning enables the creation of models which focus on operational efficiency enhancement and cost reduction and credit decision accuracy improvement to achieve platform profitability and ongoing growth.
- The platform uses interpretable machine learning models which adapt to individual lenders to create fair and precise credit decisions that result in more approvals for qualified borrowers and fewer loan defaults.
- The credit services powered by artificial intelligence can process vast amounts of data at speeds and accuracies that surpass human abilities which enables banks to generate exact operational decisions for marketing and credit and risk management and other functions.
- The sustainable growth indicators show that the Zest AI platform achieves excellent sustainable growth performance because it combines economic efficiency with social equality and environmentally sustainable digitalization practices. The system demonstrates advanced artificial intelligence-based sustainable performance.

5.2 Study Recommendations

Based on the positive results achieved by the financial technology platform Zest in the field of artificial intelligence, and with the aim of developing the financial technology sector in Algeria, the study proposes the following recommendations:

- Working toward the development of similar platforms capable of supporting banking and financial institutions in enhancing the financing function;

- The financial sector needs to improve education and training programs which will help professionals learn how to operate artificial intelligence technologies at their best.
- Public banks along with other financial institutions should start using advanced artificial intelligence technologies according to the recommendations.
- Banking institutions must create an environment of permanent innovation which treats artificial intelligence as a core development element for future growth instead of a temporary solution.
- The financial sector needs to add environmental factors to its applied research activities which currently focus on three dimensions of sustainable growth.

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CASE STUDY
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DEVELOPMENT AND MODERNIZATION OF PORT INFRASTRUCTURE IN ALGERIA A CASE STUDY OF THE PORT OF SKIKDA

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ABSTRACT

This study examines the evolution of port systems and analyzes the modernization strategies of the Skikda Port Authority (Entreprise Portuaire de Skikda, EP Skikda) as a case study. The research aims to assess the extent to which the authority's strategy aligns with contemporary port models. Methodologically, the study employs a qualitative case study approach, based on the analysis of official port documents and technical reports. The findings reveal that the Skikda Port Authority is successfully functioning as a modern strategic logistics hub, transcending its traditional role in transit shipping operations. Its integrated administrative approach—combining advanced infrastructure with a focus on digitalization, safety, and stakeholder integration, ports as a competitive actor within global supply chains. The study concludes that EP Skikda offers a replicable model for other port authorities seeking to enhance both competitiveness and sustainability. By bridging traditional port operations with contemporary logistical demands, the case of Skikda provides valuable insights for emerging economies aiming to modernize their maritime infrastructure.

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1 INTRODUCTION

A port is a designated area located at the edge of oceans, seas, rivers, or lakes where vessels undertake loading and unloading operations for cargo or passengers. Ports can be categorized functionally as cargo ports (handling freight exclusively), passenger ports (handling passengers exclusively), or multi-purpose ports (managing both cargo and passenger traffic). Commonly, ports are cargo-oriented, dealing with general and bulk shipments. (Kuhn et al., 2021)

General cargo (non-bulk dry goods) refers to merchandise of varied sizes and weights, shipped either as loose, break-bulk items (packaged or unpackaged) or in standardized units, primarily via containers. In contrast, bulk cargo consists of homogeneous commodities—such as grains, ores, or liquids—loaded directly into a vessel's holds through specialized systems without intermediate packaging or containerization.

The concept of a port extends beyond maritime facilities in many contexts. The term may encompass airports and intermodal hubs such as rail terminals. Modern ports are not merely interchange points between sea and land but also function as integrated logistics and production centres. Additionally, ports may serve specialized roles, such as fishing harbors or naval bases. Activities not directly linked to maritime transport also fall under a broader definition of ports; for example, dry ports—inland logistics centres without direct water access—act as interfaces between land transport and seaports, providing multimodal distribution and logistics services. (Herath et al., 2026)

The maritime industry in general, and maritime transport in particular, constitute the cornerstone of global economic growth and development. These sectors are closely linked to the function of ports, which serve as vital infrastructure for economic expansion. Consequently, academic attention to port-related topics has increased, particularly in fields centred on issues of sustainability, development, and maritime policy (Diniz et al., 2024).

This paper will seek to examine the strategy of port development and modernisation in Algeria by highlighting the case of Skikda Port, considered one of the most significant ports in the country.

2 THE EVOLUTION OF COMMERCIAL PORTS

Thus, a port integrates three fundamental, interrelated elements: (Zaucha & Matczak, 2018)

- The Geographic Factor: The physical area and water space occupied by the port.
- The Administrative Factor: The governing body responsible for managing the port as a public facility.
- The Economic Factor: The port's role as a commercial and maritime gateway, providing shelter for vessels and facilitating trade.

In its simplest conceptualization, a port is a water area adjoining a coastline or riverbank, specially equipped with infrastructure and services to ensure the transfer of cargo between ships and other transport modes and to assist in passenger embarkation and disembarkation.

Scholars have proposed various classifications for ports. Talley (2009), for instance, categorizes ports based on the cargo handled:

General Cargo Ports: These ports handle non-containerized, break-bulk cargo loaded and unloaded directly to/from ships using slings, cranes, or similar equipment. Examples include steel, timber, logs, automobiles, and heavy machinery. It is noteworthy that before the advent of containerization, most cargo was handled as general cargo. Due to the operational efficiencies of containers, there has been a significant global shift towards containerized freight.

Bulk Cargo Ports: These ports handle unpackaged, homogeneous commodities poured or pumped directly into vessel holds. Some researchers include bulk cargo under the general cargo umbrella. Bulk ports are further subdivided into:

Dry Bulk Ports: Handling granular or particulate dry commodities such as grains, sand, wood chips, or iron ore, typically using pneumatic suction or conveyor systems.

Liquid Bulk Ports: Handling liquid commodities such as crude oil, petroleum products, chemicals, or edible oils, transferred via pipelines and loading arms.

Container Ports: Representing the modern, secure method for freight transport, these ports are dedicated to handling standardized shipping

containers. Due to the overwhelming reliance on containerization for goods movement, many traditional general cargo ports have developed specialized container terminals with dedicated berths and handling equipment. Container handling involves specific operational protocols and equipment tailored to various container sizes and types.

This typology reflects the primary operational specialization of ports within the global supply chain, highlighting the evolution from conventional break-bulk handling to highly mechanized bulk and containerized operations.

Ports have undergone significant evolution, corresponding with advances in operational methods, management practices, and technological development, profoundly impacting global economies. This evolution can be distinguished into distinct generational models (Haidine, Ait-Allal, Aqqal, & Dahbi, 2021)

- **First Generation Ports (Traditional Ports)**

Encompassing all ports established prior to the advent of containerization in the 1960s, these traditional ports are characterized by the following: The port is considered an independent unit with minimal commercial integration, primarily functioning as a point of origin and destination for goods and a node for modal transfer (a link between sea and land transport) ; Investments are heavily concentrated on basic quay infrastructure; Cargo handling relies on conventional, labor-intensive break-bulk methods using semi-standardized equipment; Information systems are localized, suitable only for internal port operations, resulting in superficial relationships between the port and its users; Consequently, the value-added generated by the port for the supply chain is relatively low.

- **Second Generation Ports (Industrial Ports)**

Emerging after 1960 following the introduction of containers and specialized container vessels requiring non-standardized handling equipment, these ports are distinguished by key features: They function as integrated centers for transport, trade, and industry, expanding beyond classical logistics activities (loading, unloading, storage) to include manufacturing and processing services; The port footprint expands significantly compared to first-generation ports, extending into the hinterland to accommodate related industries such as refineries and logistics zones; There is a shift towards higher capital intensity and a corresponding decrease in reliance on labor-intensive operations; A closer relationship develops between the port and its users, leading to an increase in the economic value-added generated by port activities (Helling & Poister, 2000).

- **Third Generation Ports**

By the late 1980s, third-generation ports emerged, driven by increasing vessel sizes, the expansion and diversification of container types (e.g., refrigerated, tank containers), and the rise of intermodal transport.

The port becomes a link within a broader transport chain, rather than merely an endpoint; Significant investment is made in creating and providing diverse transport linkages connecting ports to markets, mines, quarries, and oilfields; Port activities expand to include transit trade, free zones, supply chain centers, and integrated logistics services.

This period coincides with the adoption of advanced information technology and specialized cargo-handling equipment.

This rapid development opens avenues for multifaceted investments and value-added activities, such as automotive industries, processing and packaging, re-export businesses, container manufacturing and maintenance, thereby stimulating economic growth and employment.

- **Fourth Generation Ports (Information Technology Ports)**

Emerging in the early 2000s, fourth-generation ports are characterized by their reliance on modern technology to manage operations. Key features of this generation include the adoption of advanced information systems and fully integrated internal transport networks encompassing both road and rail infrastructure. Fourth-generation ports focus on meeting user needs and expectations through the use of sophisticated technologies (Heilig, Lalla-Ruiz, & & Voß, 2017), while improving service speed and performance at a reasonable cost.

- **Fifth Generation Ports (Local Integration)**

This generation of ports has emerged to support sustainability in the relationship between the port and the local community, with a focus on the integration of hub and feeder ports. These ports are distinguished by the involvement of global management companies in their operations and governance. (Hall & Jacobs, 2010)

This generational framework illustrates the port's transformation from a simple cargo interchange point to a complex, integrated logistics and industrial node within global supply chains. (Heilig et al., 2017)

Maritime transport constitutes an integral and indispensable component of international logistics, accounting for approximately 80 percent of global trade volume by tonnage. While the physical movement of goods necessitates multimodal transport systems, maritime shipping remains the backbone of international commerce. (Haidine et al., 2021)

Maritime transport activity complements other economic sectors—industrial, agricultural, services, and tourism—by supplying them with essential inputs and facilitating the distribution of their outputs to global markets. It contributes to increasing rates of both physical and human capital formation. By facilitating the transfer of technological knowledge, maritime services enhance productivity and stimulate economic growth, thereby strengthening a key determinant of economic development. Moreover, countries that own significant fleets or port infrastructure can generate substantial revenues by leveraging these assets through high operational efficiency or by leasing capacity to other nations. (Helling & Poister, 2000)

Furthermore, maritime transport improves a nation’s balance of payments by boosting export capacity and earning foreign exchange for the national treasury. It also supports import substitution by supplying raw materials to export-oriented industries and by offering alternatives to certain imports.

Characterized by its ability to transport thousands of tons of cargo per voyage—such as crude oil, bulk commodities, and containerized goods—maritime shipping is essential for the smooth flow of a country’s foreign trade, both in exports and imports. The availability of efficient maritime transport services is a prerequisite for unimpeded trade, promoting not only commercial exchange but also technological diffusion, which in turn raises productive capacity and supports long-term economic development. (Zaucha & Matczak, 2018).

3 MARITIME PORTS IN ALGERIA

Algerian maritime freight transport serves as a vital artery and a principal medium for the country’s international trade exchanges.

To oversee this strategic sector, the Directorate General of Merchant Marine and Algerian Ports (DGMAP) was established, with its key responsibilities encompassing:

- Proposing merchant marine and port-related policies, as well as implementing legislative and regulatory texts within its jurisdiction.
- Developing and executing a comprehensive strategy to apply international maritime regulatory mechanisms.
- Establishing quality management systems within the merchant marine and port sectors.
- Defining the modalities for managing and operating ports and auxiliary activities, and ensuring their oversight.
- Formulating the national program for maritime and port security.
- Regulating, supervising, and promoting trades and professions related to the merchant marine, ports, and port logistics.
- Monitoring the activities of bodies and institutions under its purview and preparing related reports, while negotiating bilateral and multilateral international agreements concerning the merchant marine and ports in coordination with relevant bodies.
- Digitalizing maritime and port activities.
- Ensuring compliance with and implementation of quality audit programs within its domain.
- Monitoring the activities of the Maritime Safety and Security Information Center, participating in the promotion of the blue economy in liaison with relevant ministerial departments, and managing a centralized database pertaining to the merchant marine and ports.

4 CASE STUDY OF SKIKDA PORT

This case study analyzes the Skikda Port Enterprise (Entreprise Portuaire de Skikda – EP Skikda), a key Algerian public economic entity managing the commercial and industrial port infrastructure in the Skikda region. Established by Decree No. 82-284 of August 14, 1982, and restructured as a joint-stock company on March 21, 1989, EP Skikda operates under the sole ownership of the port services group SERPORT Spa, with a registered capital of 9,000,000,000 Algerian dinars.

Table 1 Infrastructural Comparison: Skikda's Old and New Commercial Ports

Feature	Mixed Port (Old Port)	New Port
Access Channel	120 m wide, 15 m deep	250 m wide, 18 m deep
Turning Circle	360 m diameter	550 m diameter
Sheltered Water Area	43.3 ha	61 ha
Quay Length	2,180 m	240 m (general cargo), plus specialized berths
Berthing Positions	14 general cargo berths, 3 oil berths	1 general cargo berth, 7 oil/gas berths, 2 offshore SPMs
Protective Structures	Main jetty: 1,625 m; Secondary: 300 m	Main jetty: 1,875 m; Secondary: 650 m

Source: (Port of Skikda, 2025)

The enterprise holds multiple international certifications, including ISO 9001:2015, ISO 14001:2015, OHSAS 18001:2007, and ISPS Code compliance, reflecting its commitment to quality, environmental management, safety, and maritime security.

EP Skikda's core missions encompass the comprehensive management of port operations, including:

- Stevedoring, handling, and storage of goods;
- Towing, piloting, and mooring services;
- Port police and security operations;
- Maintenance and development of port superstructures;
- Collaboration with relevant authorities on port infrastructure projects;
- Passenger terminal services.

The company's territorial jurisdiction covers two main facilities: the Mixed Port of Skikda (the older multi-purpose port) and the New Port of Skikda, which primarily serves hydrocarbon exports.

4.1 Port Infrastructure and Technical Capabilities

4.1.1 Physical and Operational Characteristics

This section provides detailed comparative data for the two ports:

The New Port is designed to handle very large tankers, with two Single Point Mooring (SPM) buoys capable of servicing vessels over 320,000 DWT.

Both ports are equipped with modern navigational aids, including lighthouses and channel markers.

- **Cargo Handling and Storage Capacity**

Annual Throughput Capacity:

- General cargo: 4.5 million tons
- Hydrocarbons: 30 million tons
- Storage Areas:
- Open storage: 54.5 hectares (within port) + 37 hectares (extra-port zone)
- Covered storage: 2 hectares (warehouses & hangars)
- Specialized Facilities:
  - Grain silo (20,000 tons capacity)
  - Animal feed storage (35,000 tons)
  - Public weighbridges (80–120 tons)
  - Passenger terminal (1,200 passengers)
  - Roll-on/roll-off facility with three dual-lane gates
  - Fishing boat slipways (3 units)
  - Railway network: 2,660 m of tracks (7 lines), with a station 100 m from the Mixed Port

Detailed table outline berth lengths, drafts, and compatible cargo types for both ports, highlighting

flexibility in handling containers, bulk grains, hydrocarbons, metals, rolling stock, and specialized products such as liquefied natural gas (LNG), aromatics, and petroleum derivatives. Hydrocarbon berths are equipped with high-capacity loading arms (250–6,500 m³/h) and pipelines ranging from 6 to 16 inches in diameter.

4.2 Port Management and Operational Framework

EP Skikda positions itself as a vital link in national trade, striving for recognition based on performance, professionalism, and corporate citizenship. Its strategic policy is built on five pillars:

- Human Resource Development – Continuous training, HSE competency enhancement, and staff motivation.
- Client and Stakeholder Satisfaction – Adherence to regulatory, safety, and environmental standards while improving service quality.
- Operational Performance Improvement – Infrastructure optimization, market share growth, and modernization of equipment.
- Internal and External Communication – Enhanced communication channels with port community and stakeholders.
- Professionalism and Civic Responsibility – Commitment to worker safety, pollution prevention, and community relations.

The enterprise explicitly commits to legal and regulatory compliance, resource allocation for management systems (QHSE), pollution prevention (marine, soil, atmospheric), and regular management reviews.

EP Skikda maintains substantial anti-pollution and emergency response resources, including:

- 8 tugs equipped with anti-pollution and fire-fighting gear;
- 3 additional fire-fighting tugs;
- Oil spill containment booms (over 2,000 m total length);
- Skimmers, absorbents, storage caissons, and high-pressure cleaners;
- Two waste recovery barges.

This reflects a proactive approach to environmental stewardship and operational safety in a high-risk industrial port setting.

4.3 Port Digitalization and Customer Services

- Single Window Service (Guichet Unique): A centralized administrative office for container-related procedures, staffed by 32 agents working in two shifts to expedite cargo release.
- Intranet and Information System: The integrated port management system SIGNE supports real-time operational coordination and offers external client interfaces via a dynamic website.
- Reception Office: Located at the main entrance of the Mixed Port to assist clients and visitors.
- Access Protocols: Structured procedures for trucks, regular/occasional clients, and visitors, involving coordination with the Port Facility Security Officer (PFSO) and the Maritime Border Police.

It serves as a dematerialised data exchange platform, facilitating seamless logistics for the flow of goods from the moment a vessel is announced until the cargo is evacuated by its owner. It is defined as a facility that allows parties involved in trade and maritime transport to submit information and documents through a single-entry point in order to complete all official formalities related to import, export, and transit. The system aims to ensure high reliability in import and export procedures while reducing cargo clearance times within the port.

At the Skikda Port Enterprise, the Single Window has been operational since August 2021 and is equipped with human and material resources that meet the needs of all stakeholders. In line with this vision, the Port Services Group (SERPORT) has provided its subsidiaries with a value-added telecommunications network through the implementation of the Algerian Ports Community System (APCS). This system enables all port sector professionals and the customs administration to exchange data and messages in complete confidentiality and security. It manages the physical, administrative, commercial, and customs tracking of goods, allowing for the dematerialised completion of administrative, customs, and fiscal formalities related to port operations.

This community system, which functions as an interfacing platform federating the other systems of port stakeholders, is operational at the Skikda Port Enterprise. It is fed with real-time information via an Internet connection from the port enterprise's systems, the customs administration, shipping agents, freight forwarders, and other administrations operating within the port area (including trade, phytosanitary, veterinary services, etc.). This electronic portal simplifies and facilitates the provision and sharing of information necessary for completing all trade-related formalities, for both commercial operators and public authorities. Furthermore, the system ensures improved service quality and a reduction in document management costs.

Based on data, total cargo traffic reached 23,691,031 tonnes, marking a slight decrease of 0.1% compared to previous year. General (non-oil) cargo remained stable at 4,015,618 tonnes, although this represented a substantial increase from previous year levels. In contrast, dry bulk cargo declined by 17%, while liquid bulk (primarily hydrocarbons) continued to dominate overall activity, accounting for 19,675,413 tonnes. Container traffic exhibited notable growth, rising by 15% in volume and 18% in total weight. A clear dual structure characterises the port's trade flows: imports (2,718,003 tonnes) are dominated by China, Argentina, Russia, France, and Turkey, which together supply nearly 45% of incoming general cargo, including agricultural products, metallic materials, and transport equipment. Exports (19,150,771 tonnes), by contrast, are overwhelmingly hydrocarbon-based, with national coastal shipping (cabotage) playing a prominent role, followed by the United States, France, South Korea, and China as leading destinations (Port of Skikda, 2024).

5 CONCLUSIONS

The Port of Skikda represent a critical infrastructure node in Algeria's economic landscape, combining multi-purpose cargo handling with specialized hydrocarbon export capabilities. EP Skikda demonstrates a structured, certification-driven approach to port management, emphasizing safety, environmental compliance, and customer service. Its dual-port system allows for functional specialization—the Mixed Port serving general cargo and containers, and El Djedid Port focusing on energy exports, supported by deep-water berths and offshore loading facilities.

The development of port infrastructure can facilitate the improvement of transport routes and port connectivity, as well as the recovery of ancillary services and related activities (Peričin & Grbić, 2025) .

The enterprise's commitment to continuous improvement, stakeholder engagement, and risk management positions it as a model of public port governance in the region. Future challenges may include capacity expansion, digital transformation, and adapting to global energy transition trends, but the existing framework provides a solid foundation for sustainable growth.

The hydrocarbon sector dominates export activities at the Port of Skikda, with shipments directed primarily towards major American, Asian, and European markets, alongside a significant role played by national coastal shipping (cabotage). In contrast, imports via this port consist mainly of agricultural products (notably cereals), metallic materials, and transport equipment, with China, Argentina, and Russia ranking as the leading supplier countries. Furthermore, a marked growth in container traffic is observed, which may reflect a gradual shift towards the diversification of trade routes.

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CLIMATE–TECHNOLOGY INTERACTIONS AND THEIR IMPACT ON AGRICULTURAL PRODUCTION IN ALGERIA

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ABSTRACT

This study examines the impact of climatic and technological changes on agricultural productivity in Algeria during the period 1999–2023 using the ARDL model. The results confirm the existence of a long-run equilibrium relationship between agricultural value added and its climatic, technological, and structural determinants. Productive inputs, particularly fertilizers and water resources, positively affect agricultural performance, whereas rising temperatures and inefficient irrigation management exert negative effects. The findings also show that technological development contributes to strengthening the sector's capacity to cope with climate-related challenges. In addition, persistent structural constraints, including low labor productivity and the prevalence of traditional production practices, continue to limit productive efficiency. The error correction mechanism confirms the sector's ability to adjust toward long-run equilibrium following short-term shocks. Overall, the results highlight the importance of improving resource-use efficiency, promoting technological modernization, and strengthening climate adaptation policies to support sustainable agricultural development in Algeria.

1 INTRODUCTION

In recent decades, the global environment has been experiencing accelerated climate change, whose impacts are increasingly evident on both ecological and economic systems. Rising temperatures, recurrent droughts, and noticeable disruptions in rainfall patterns have posed new

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challenges to various productive sectors. The agricultural sector is among the most affected due to its direct dependence on natural and climatic factors. In this context, reports from the Intergovernmental Panel on Climate Change (IPCC, 2022) indicate that semi-arid and Mediterranean regions are particularly vulnerable to climate change effects, especially regarding the decline of water resources and reduced agricultural productivity, which directly threatens food security.

Economic literature suggests that a one-degree Celsius increase in temperature may lead to a significant reduction in agricultural productivity, particularly in developing countries that heavily rely on rain-fed agriculture and face limited infrastructure capable of adapting to climate shocks (Dell, Jones & Olken, 2012). Agricultural economics studies also highlight that the climate productivity relationship is neither simple nor linear; rather, it is influenced by complex interactions involving technological, institutional, and regulatory factors that affect the sector's adaptive capacity (Burke & Emerick, 2016).

Conversely, technological transformations have emerged as key strategic tools to enhance the resilience of the agricultural sector against climate change, through improving input-use efficiency, developing crop varieties more resistant to heat and drought, and adopting modern irrigation and precision farming techniques. In this regard, the Food and Agriculture Organization (FAO, 2013) emphasizes that adopting modern agricultural technologies can partially mitigate the negative effects of climate change by improving production efficiency and rationalizing the use of natural resources. However, the effectiveness of these technological transformations remains contingent upon their integration with sustainable agricultural policies that balance climate adaptation requirements with improved production performance.

Regarding the Algerian context, the agricultural sector represents a fundamental pillar in supporting economic diversification and achieving food security. Nevertheless, it exhibits high sensitivity to climate shocks due to Algeria's semi-arid climate and its relative dependence on limited water resources. National data indicate an increased frequency of heatwaves over the past two decades, accompanied by significant fluctuations in rainfall, raising critical questions about the capacity of technological transformations implemented within the sector to offset the adverse climate impacts.

Despite the growing international literature on the effects of climate change on agricultural activity, empirical studies in the Algerian context remain relatively limited, particularly those examining the interaction between climatic and technological variables within a dynamic analytical framework that combines short- and long-term perspectives. Against this backdrop, this study aims to analyze the impact of climate changes (temperature, water resources, etc.) and technological transformations (fertilizers, irrigation, etc.) on the productivity performance of Algeria's agricultural sector, using the autoregressive distributed lag (ARDL) model, which allows testing for equilibrium relationships in both the short and long run and exploring the dynamics of adjustment toward long-term equilibrium.

Despite the growing body of literature examining the effects of climate change and technological factors on agricultural performance, several gaps remain. Previous studies have often focused on either climatic variables or technological inputs separately, while limited attention has been given to their combined effects within a unified analytical framework. Furthermore, empirical evidence for Algeria remains relatively scarce, particularly regarding the long-run and short-run dynamics linking climatic conditions, water resources, fertilizer use, irrigation, and agricultural productivity. In addition, existing studies have produced mixed findings concerning the effectiveness of irrigation and other production inputs in improving agricultural performance under semi-arid conditions. This study contributes to the literature by providing an integrated ARDL-based analysis of climatic, technological, and structural determinants of agricultural value added in Algeria over the period 1999–2023. By jointly examining these factors within a single framework, the study offers new evidence on the mechanisms through which climate-related and technological changes influence agricultural performance in the Algerian context.

1.1 Research Problem

The agricultural sector in Algeria has undergone rapid transformations amid increasing climate change and technological advancements in production methods, making its performance closely linked to a combination of environmental, economic, and structural factors. Given the strategic importance of the agricultural sector in achieving food security and supporting economic development, there is a need to analyze the impact of climate and technological changes on agricultural production using empirical approaches that allow the examination of these relationships in both the short and long term.

This study seeks to answer the following question: How do climate and technological changes, in both the short and long run, affect the productivity performance of Algeria's agricultural sector, and to what extent is the sector capable of adapting to climate shocks within a dynamic equilibrium framework?

1.2 Research Hypotheses

Based on the theoretical and empirical literature on agricultural production, climate economics, and agricultural technology, this study is founded on the general assumption that the productive performance of the agricultural sector in Algeria is influenced by a set of climatic, technological, and structural factors. Accordingly, the following hypotheses are formulated:

Null Hypothesis 1 ($H0_1$): Temperature does not exert a statistically significant effect on agricultural value added in Algeria.

Alternative Hypothesis 1 ($H1_1$): Temperature negatively and significantly affects agricultural value added in Algeria.

Null Hypothesis 2 ($H0_2$): freshwater availability does not exert a statistically significant effect on agricultural value added in Algeria.

Alternative Hypothesis 2 ($H1_2$): freshwater availability positively and significantly affects agricultural value added in Algeria.

Null Hypothesis 3 ($H0_3$): fertilizer use does not exert a statistically significant effect on agricultural value added in Algeria.

Alternative Hypothesis 3 ($H1_3$): fertilizer use positively and significantly affects agricultural value added in Algeria.

Null Hypothesis 4 ($H0_4$): irrigated land does not exert a statistically significant effect on agricultural value added in Algeria.

Alternative Hypothesis 4 ($H1_4$): irrigated land positively and significantly affects agricultural value added in Algeria through improving water-use efficiency and production stability.

Null Hypothesis 5 ($H0_5$): agricultural labor does not exert a statistically significant effect on agricultural value added in Algeria.

Alternative Hypothesis 5 ($H1_5$): agricultural labor may negatively or weakly affect agricultural value added in Algeria due to low productive efficiency and the persistence of disguised unemployment within the agricultural sector.

2 CONCEPTUAL FRAMEWORK OF AGRICULTURAL ECONOMIC GROWTH

Agricultural economic growth constitutes a fundamental pillar in analyzing overall economic performance, particularly in developing economies where the agricultural sector remains a major source of employment and income. It is generally understood as a sustained increase in real agricultural output or agricultural value-added over time, accompanied by improvements in the efficiency of input utilization. However, agricultural growth is not measured merely by increased production volumes. Rather, it is viewed from a dynamic perspective that encompasses improvements in total factor productivity (TFP), advancement of agricultural technologies, more efficient reallocation of resources, and enhancement of sectoral competitiveness. According to economic development (Todaro & Smith, 2020), agricultural growth serves as a precondition for structural transformation by raising rural incomes, generating food surpluses that support urban growth, and liberating labor for more productive sectors. Furthermore, the Food and Agriculture Organization emphasizes that sustainable agricultural growth must balance production expansion with the conservation of natural resources, given agriculture's direct dependence on soil, water, and climate conditions. Accordingly, agricultural growth can be understood as a cumulative production process supported by technological, institutional, and

environmental factors, rather than merely an increase in output quantity.

Agricultural productivity performance is assessed using quantitative indicators that reflect the efficiency of input utilization and their transformation into economically valuable outputs. Among the most important indicators is agricultural value-added (AVA), which represents the difference between the total value of agricultural output and the value of intermediate inputs, thereby capturing the sector's actual contribution to GDP. AVA is considered a central indicator because it measures the net performance of the sector, reflects changes in productivity rather than merely output volumes, and allows for international comparisons. According to World Bank data, AVA is widely used as a primary measure of real agricultural growth, excluding distortions from nominal price fluctuations. Its use in empirical models enhances the precision of productivity measurement, as it represents net output that can be economically interpreted within an extended production function. Another essential indicator is the marginal productivity of inputs, which refers to the change in output resulting from a one-unit increase in a particular input while holding other factors constant. This concept is fundamental in production theory because it enables the evaluation of the efficiency of each production input individually. In the agricultural context, marginal productivity reflects the efficiency of agricultural labor, the effectiveness of fertilizer usage, the productivity of irrigation systems, and the sensitivity of output to climatic variations. The empirical literature emphasizes that using a logarithmic specification of the production function allows estimated coefficients to be interpreted directly as elasticities, facilitating economic analysis and rendering the results more actionable for policymakers. As noted by Econometrics by Example (Gujarati, 2015), logarithmic transformation reduces issues of heteroscedasticity, improves the linearity of relationships, and allows coefficients to be interpreted as productivity elasticities. This approach provides a deeper economic dimension compared to traditional linear specifications, enabling more insightful and policy-relevant analysis.

The agricultural sector is a key structural component of the Algerian economy, not only in terms of its contribution to GDP but also regarding its social, nutritional, and environmental dimensions. Despite the dominance of the hydrocarbon sector in foreign revenues, agriculture remains a pivotal element for achieving long-term economic stability, particularly amid fluctuations in oil prices. From a developmental perspective, agriculture serves as a lever to achieve multiple objectives beyond food production, including social stability, job creation, and strengthening national economic security. The sector plays a fundamental role in ensuring food security by providing essential products locally and reducing dependence on volatile international markets, especially in the face of external shocks, whether economic, climatic, or geopolitical. According to the Food and Agriculture Organization (2022), food security rests on four main dimensions: availability, access, utilization, and stability. In the Algerian context, food availability is directly linked to the performance of the domestic agricultural sector, while low productivity increases reliance on imports, making food security sensitive to exchange rate fluctuations and global market volatility. Consequently, enhancing agricultural growth is not merely a sectoral choice but a strategic necessity for strengthening food sovereignty and reducing economic vulnerability to external shocks.

Given the rentier nature of the Algerian economy, agriculture also represents a realistic pathway to expand the productive base and reduce reliance on hydrocarbons. Development literature, including economic development (Todaro & Smith, 2020), emphasizes that economic diversification is essential for achieving sustainable and balanced growth, particularly in economies dependent on a single natural resource. World Bank reports on Algeria highlight that diversifying the production structure contributes to reducing growth volatility linked to oil prices, increasing employment opportunities in rural areas, and expanding the tax base beyond the energy sector. Accordingly, developing the agricultural sector should be viewed as part of a broader strategy for structural economic rebalancing rather than as a stand-alone sectoral policy.

In addition, the agricultural sector is closely linked to sustainable development due to its direct dependence on natural resources, especially soil and water. Poor management of these resources can lead to long-term environmental degradation, negatively affecting future production capacity. The Brundtland report defines sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This concept applies directly to agriculture, where productivity growth requires balancing production intensification, soil conservation, efficient water use, and adaptation to climate change. In the Algerian context, the importance of sustainability is amplified by limited water resources and the semi-arid climate, making sustainability a prerequisite for the long-term continuation of agricultural growth.

3 CLIMATE CHANGE AND AGRICULTURAL DEVELOPMENT

Climate change refers to long-term shifts in average temperatures, precipitation patterns, and extreme weather events, driven either by natural factors or by human activities, particularly greenhouse gas emissions. According to the Intergovernmental Panel on Climate Change (2021), climate change constitutes one of the most significant contemporary global challenges due to its multidimensional economic, environmental, and social consequences. The agricultural sector is among the most sensitive sectors to climatic changes because of its direct dependence on climatic conditions and natural resources. The Intergovernmental panel on climate change further emphasizes that rising temperatures and increasing rainfall variability will directly affect agricultural productivity and agricultural production, especially in semi-arid regions such as north africa, thereby intensifying pressure on water and soil resources. In this context, climate change is no longer viewed solely as an environmental issue but also as a structural determinant influencing agricultural development, food security, and long-term economic sustainability.

Climate change affects agricultural production through multiple direct and indirect channels, primarily temperature fluctuations, water availability, and soil dynamics. Rising temperatures accelerate crop growth cycles, increase heat stress on plants, and reduce yields once optimal physiological thresholds are exceeded. According to the work of David Lobell et al. (2011), a one-degree Celsius increase in average temperature can generate a significant decline in the productivity of major agricultural crops. Higher temperatures also increase evapotranspiration rates, reducing soil moisture and intensifying the need for supplemental irrigation. Water scarcity constitutes another major channel through which climate change affects agricultural production, particularly in semi-arid countries such as Algeria, where agriculture depends heavily on limited water resources. Food and Agriculture Organization (2020) reports that irregular rainfall patterns and prolonged drought episodes reduce irrigation efficiency and constrain cultivated agricultural areas. In addition, increased evaporation rates contribute to further soil moisture loss, negatively affecting crop resilience and productivity. The World Bank (2021) highlights that dry and vulnerable regions will experience compounded pressure on water resources as climate change intensifies, thereby threatening agricultural sustainability and increasing production instability over time.

From a theoretical perspective, climatic variables are incorporated into agricultural production models as exogenous determinants influencing total factor productivity. The climate-agriculture supply framework assumes that agricultural output is not determined solely by conventional production inputs such as labor, land, and capital, but is also strongly influenced by climatic conditions, including temperature and precipitation. The extended production function can therefore be represented as follows:

$$Y = f(K, L, T, C)$$

where C denotes climatic variables such as temperature and rainfall. Modern econometric literature emphasizes that incorporating climate indicators into production models improves the explanatory power of agricultural output fluctuations and provides a more realistic interpretation of productivity dynamics. According to Melissa Dell, Benjamin Jones, and Benjamin Olken (2012), climatic factors significantly explain variations in economic and agricultural performance, particularly in developing countries

that are highly dependent on climate-sensitive sectors.

Climate shocks such as droughts, floods, and heatwaves are generally treated as exogenous variables because they occur independently of producers' economic decisions while exerting substantial effects on agricultural production. Contemporary econometric approaches, particularly dynamic models such as the ARDL framework, are frequently employed to distinguish between the short-run and long-run impacts of climatic shocks on agricultural value added. Recent empirical literature indicates that the adverse effects of heat shocks are especially pronounced in countries characterized by traditional agricultural structures, limited irrigation systems, and weak adaptive capacities. In this regard, Marshall Burke, Solomon Hsiang, and Edward Miguel (2015) argue that rising temperatures can substantially reduce agricultural performance and overall economic productivity in vulnerable developing economies. Consequently, understanding the interaction between climatic factors and agricultural production has become essential for designing effective adaptation policies aimed at strengthening agricultural resilience and ensuring sustainable agricultural development.

4 AGRICULTURAL TECHNOLOGY AND PRODUCTIVITY DEVELOPMENT

Agricultural technology refers to the collection of technical and organizational innovations designed to improve the efficiency and performance of agricultural production systems. It includes both modern production inputs, such as fertilizers and improved seeds, and advanced farming methods, including mechanization and modern irrigation systems. In agricultural economics, technology is considered a central determinant of total factor productivity (TFP) because it enhances the efficiency with which labor, land, and capital are transformed into agricultural output. According to Yujiro Hayami and Vernon Ruttan (1985), technological progress in agriculture constitutes the primary source of long-term productivity growth, particularly in developing countries characterized by limited arable land and increasing demographic pressures. Likewise, World Bank reports (2020) emphasize that the adoption of modern agricultural technologies contributes to higher yields, improved production efficiency, and reduced wastage of productive resources. Consequently, technological advancement is widely recognized as a strategic mechanism for achieving sustainable agricultural growth and strengthening food security.

Modern agricultural inputs play a crucial role in enhancing agricultural productivity by improving the efficiency of resource utilization and increasing output per unit of land. Chemical fertilizers (FERT) are among the most important technological inputs because they improve soil fertility and replenish nutrients depleted through continuous cultivation. Empirical literature indicates that the rational use of fertilizers is strongly associated with higher crop yields, especially in intensive farming systems where nutrient depletion is more pronounced. The Food and Agriculture Organization (2019) demonstrates that increased fertilizer use in developing countries has directly contributed to agricultural growth and food security, while also emphasizing the need to address environmental concerns linked to excessive fertilizer application. Similarly, Xiaohui Zhang et al. (2015) reports a strong positive relationship between fertilizer use and crop productivity, although this relationship may exhibit nonlinear characteristics depending on production conditions and environmental constraints. These findings suggest that fertilizer efficiency depends not only on the quantity used but also on the effectiveness of input management and allocation.

Modern irrigation systems (IRR), such as drip and sprinkler irrigation technologies, are also considered among the most significant innovations for improving agricultural value added, particularly in arid and semi-arid environments where water scarcity represents a structural constraint. These irrigation systems increase water-use efficiency by minimizing water losses and ensuring more precise water distribution across cultivated land. As a result, they contribute to higher productivity per hectare and greater production stability under adverse climatic conditions. According to the Organisation for Economic Co-Operation and Development (2021), investment in modern irrigation infrastructure enhances agricultural resilience and mitigates fluctuations in agricultural output caused by

drought shocks and irregular rainfall patterns. In countries such as Algeria, where agriculture depends heavily on limited water resources, the expansion of modern irrigation systems is considered essential for sustaining long-term agricultural productivity and improving resource efficiency.

Technical efficiency constitutes another fundamental concept in the analysis of agricultural value added. Productive efficiency refers to the ability of the agricultural sector to obtain the maximum possible output from a given combination of production inputs. Economic theory distinguishes between technical efficiency and allocative efficiency, where technical efficiency measures the extent to which production approaches the optimal output frontier. According to Michael Farrell (1957), technical efficiency reflects the capacity of producers to minimize waste in resource utilization while maximizing production outcomes. In the agricultural context, higher technical efficiency implies more effective management of productive resources, greater adoption of technological innovations, and improved organization of farming activities.

Input intensity also plays an important role in shaping agricultural productivity performance. Input intensity refers to the degree of dependence on productive resources such as fertilizers, irrigation systems, and mechanization per unit of cultivated land. Higher input intensity is generally associated with increased agricultural yields because it enhances the productive capacity of farmland. However, excessive reliance on intensive inputs may also generate environmental consequences, including soil degradation and water depletion, if resource use is not managed sustainably. Empirical studies indicate that incorporating technological input variables into logarithmic production functions enables estimated coefficients to be interpreted directly as production elasticities, thereby facilitating the analysis of the relative contribution of each input to agricultural output. As highlighted by Tim Coelli et al. (2005), this econometric specification provides deeper insight into production dynamics and improves the evaluation of the technological determinants of agricultural productivity growth.

5 AGRICULTURAL LABOR MARKET AND PRODUCTION STRUCTURE

Agricultural labor constitutes a fundamental component of the agricultural production process, representing the labor input that interacts with land, capital, and technology to generate agricultural value-added. Within the framework of classical production theory, labor is considered one of the principal productive factors influencing the level of agricultural output and the efficiency of resource utilization. The agricultural production function can therefore be represented as follows:

$$Y = f(K, L, T)$$

where L denotes agricultural labor. According to Theodore Schultz (1964), agriculture in developing countries depends heavily on human labor, and improving the skills and capabilities of agricultural workers represents a crucial mechanism for increasing productivity and enhancing rural incomes. Similarly, Douglas Gollin (2010) argues that the contribution of agricultural labor to economic growth depends not only on the quantity of labor employed but also on labor efficiency and the availability of complementary technologies that improve production performance. Consequently, agricultural labor should be viewed not merely as a quantitative input, but as a strategic productive resource whose effectiveness is closely linked to technological progress, education, and institutional development.

Hidden or disguised unemployment represents one of the major structural characteristics of the agricultural sector in many developing economies. This phenomenon occurs when the number of workers employed in agriculture exceeds the actual labor requirements needed to maintain existing production levels, resulting in very low or even negligible marginal productivity of labor. In such situations, the withdrawal of a portion of the agricultural workforce may occur without causing any significant decline in total agricultural output. The dual-sector model developed by Arthur Lewis (1954) explains that surplus labor in traditional agriculture can be gradually transferred to the industrial sector without negatively affecting agricultural production during the early stages of economic development. According to this theoretical perspective, structural transformation begins with the reallocation of excess labor from

low-productivity agricultural activities toward more productive industrial and service sectors. Recent empirical studies further suggest that persistent hidden unemployment weakens productivity in the agricultural sector, reduces labor productivity, and limits agriculture's contribution to long-term economic growth. This implies that improving labor allocation and increasing labor productivity are essential conditions for enhancing agricultural competitiveness and promoting sustainable rural development.

Structural transformation in the agricultural economy refers to the gradual movement of labor and economic resources from low-productivity agricultural activities toward higher-productivity sectors such as industry and services. This process constitutes one of the defining characteristics of economic development because it reflects changes in the structure of production, employment, and income generation within the economy. According to Simon Kuznets (1973), a declining share of agricultural employment in the total labor force represents a major indicator of economic modernization and structural change. As economies develop, productivity improvements in agriculture reduce the sector's labor requirements, enabling workers to transition toward more productive non-agricultural sectors. However, successful structural transformation requires sustained improvements in agricultural productivity to ensure that food production remains stable despite the declining agricultural labor share. In this regard, Peter Timmer (2009) emphasizes that increasing agricultural productivity is a prerequisite for achieving balanced structural transformation without generating food insecurity or widening rural poverty. Therefore, agricultural development and structural transformation should be viewed as complementary processes in which productivity growth within agriculture facilitates broader economic diversification and long-term development sustainability.

6 EMPIRICAL STUDY

6.1 General Overview of the Empirical Study

This empirical study aims to analyze and measure the impact of climate and technological changes on the productivity performance of Algeria's agricultural sector over the period 1999–2023, amid accelerating climate change, increasing pressures on water resources, and efforts to modernize the agricultural production system.

The agricultural sector in Algeria represents a fundamental pillar for achieving food security and diversifying the economic base beyond hydrocarbons. However, it remains highly sensitive to climatic shocks, particularly fluctuations in rainfall, rising temperatures, and limited water resources. Public policies have sought to enhance productivity by expanding irrigated areas, promoting the use of modern inputs such as fertilizers, and optimizing the allocation of agricultural labor.

The study is based on the central hypothesis that agricultural value added is determined not only by traditional factors (labor and inputs) but is also significantly influenced by climatic and structural transformations affecting the Algerian economy. Understanding the nature of these relationships, in both the short and long term, is crucial for formulating more efficient and sustainable agricultural policies.

To achieve this objective, the study employs an empirical approach based on the autoregressive distributed Lag (ARDL) model, given its suitability for small time series samples and its ability to test long-term equilibrium relationships among the variables, as well as to extract short-term dynamics through the error correction model (ECM).

Annual data covering 1999–2023 are used. Agricultural value added is measured by the sector's value-added at constant prices, climatic changes are represented by average rainfall and temperature, while technological and structural changes are proxied by the share of irrigated land, fertilizer usage, agricultural labor, and the annual freshwater withdrawal for agriculture.

6.2 Variables and Data Sources

6.2.1 Dependent Variable

Agricultural value-added (AVA**):** the study uses agricultural value-added at constant USD prices as an indicator of productivity performance, as it reflects the sector's contribution to real GDP, excluding inflationary effects. The natural

logarithmic transformation (lnAVA) is applied for the following reasons:

- To reduce heteroscedasticity;
- To interpret coefficients as long-term elasticities;
- To improve time series properties.

6.2.2 Independent Variables

The independent variables are divided into two groups: climatic variables and technological/structural variables.

Climatic Variables:

- Average temperature (TEM**P):** Annual average temperature is used as a proxy for thermal climate changes that may affect crop performance, particularly under increasing heat waves. No logarithmic transformation is applied.
- Annual freshwater withdrawal for agriculture (WAT**):** Measures the volume of water used in agricultural activities (m^3 per capita per year), reflecting pressure on water resources, a critical factor in irrigated agriculture. The logarithmic transformation (lnWAT) is applied for elasticity analysis.

Technological and Structural Variables:

- Irrigated Land (IRR): Represents the percentage of agricultural land that is irrigated, serving as a direct indicator of agricultural infrastructure modernization and the shift toward intensive farming. Logarithmic transformation (lnIRR) is applied.
- Fertilizer usage (FERT): Measured in kilograms per hectare of agricultural land (kg/ha), reflecting the level of production intensification and technological advancement. The logarithmic transformation (lnFERT) is applied to estimate productivity elasticities.
- Agricultural labor (LAB): Measured as the percentage of labor employed in agriculture relative to total employment, reflecting the sector's structural dimension. A higher value may indicate traditional farming practices or labor-intensive agriculture. No logarithmic transformation is applied due to its relative nature.

To improve the statistical properties of the data and allow coefficient interpretation in elasticity terms, logarithmic transformations were applied to variables measured in absolute quantities, namely agricultural value added (AVA), water resources (WAT), irrigated land (IRR), and fertilizer use (FERT). Logarithmic transformation helps reduce potential heteroscedasticity, smooth fluctuations, and facilitates the interpretation of estimated coefficients as elasticities.

In contrast, average temperature (TEMP) and agricultural labor (LAB) were retained at their original levels. Temperature is measured in degrees Celsius and may take values for which a logarithmic transformation would provide limited economic interpretation. Likewise, agricultural labor is expressed as a percentage share of total employment rather than as an absolute quantity. Maintaining these variables at levels preserves their direct economic interpretation and ensures consistency with their measurement scales.

6.3 Justification for the Study Period (1999–2023)

This period was selected because it provides homogeneous data for all variables and reflects:

- The post-agricultural reform era.
- Expansion of agricultural support programs.
- Rising impact of climate change.
- Economic shocks (2014 and 2020).

6.4 Data Sources

- World Bank, World Development Indicators (WDI)
- World Bank Group, Climate Change Knowledge Portal
- Food and Agriculture Organization (FAO – FAOSTAT)
- AQUASTAT database (FAO)

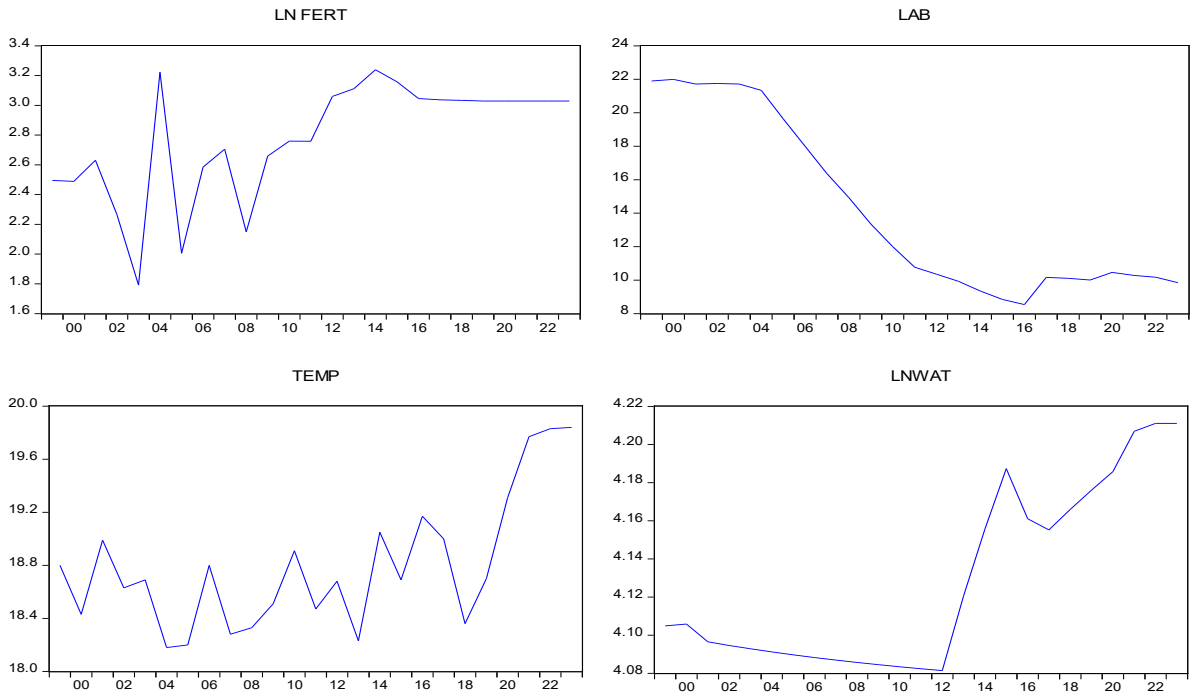
6.5 Descriptive Analysis of Study Variables

The next step involves a descriptive statistical analysis of the variables under study, providing insights into their distribution, trends, and potential correlations, which will inform the subsequent econometric modeling.

Table 1. *Evolution of Determinants of Agricultural Value-Added in Algeria (1999–2023)*

Year	lnAVA	lnWAT	lnIRR	LAB	lnFERT	TEMP
1999	22.71	4.10	2.81	21.90	2.49	18.80
2000	22.66	4.11	2.82	22.00	2.49	18.43
2001	22.78	4.10	2.82	21.72	2.63	18.99
2002	22.79	4.09	2.82	21.75	2.27	18.63
2003	22.90	4.09	2.82	21.72	1.79	18.69
2004	22.94	4.09	2.85	21.34	3.22	18.18
2005	22.97	4.09	2.85	19.65	2.01	18.20
2006	23.05	4.09	2.85	18.00	2.58	18.80
2007	23.07	4.09	2.85	16.37	2.71	18.28
2008	23.04	4.09	2.85	14.93	2.15	18.33
2009	23.25	4.08	2.85	13.34	2.66	18.51
2010	23.31	4.08	2.85	12.00	2.76	18.91
2011	23.40	4.08	2.86	10.77	2.76	18.47
2012	23.49	4.08	2.86	10.35	3.06	18.68
2013	23.61	4.12	2.86	9.93	3.11	18.23
2014	23.64	4.16	2.86	9.35	3.24	19.05
2015	23.71	4.19	2.86	8.85	3.16	18.69
2016	23.72	4.16	2.85	8.54	3.05	19.17
2017	23.68	4.16	2.85	10.16	3.04	19.00
2018	23.71	4.17	2.85	10.11	3.03	18.36
2019	23.74	4.18	2.85	10.01	3.03	18.70
2020	23.77	4.19	2.85	10.47	3.03	19.31
2021	23.74	4.21	2.85	10.28	3.03	19.77
2022	23.80	4.21	2.85	10.17	3.03	19.83
2023	23.83	4.21	2.85	9.85	3.03	19.84

Source: World Bank



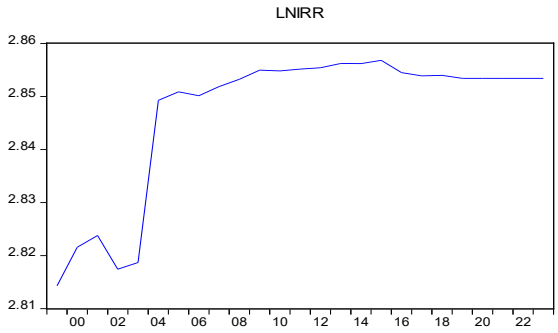


***Figure 2**. Evolution of Determinants of Agricultural Value-Added in Algeria (1999–2023)*

Source: Authors' own elaboration based on EViews outputs

The descriptive statistical analysis of the study variables over the period 1999–2023 reveals important quantitative characteristics reflecting the evolution of Algeria's agricultural sector. The mean of the natural logarithm of agricultural value-added (lnAVA) was approximately 23.29, with a median of 23.40, a standard deviation of about 0.38, and a range from a minimum of 22.66 to a maximum of 23.83. These results indicate a relatively stable upward trend with low dispersion, reflecting gradual and balanced growth over time.

Annual freshwater withdrawals for agriculture (lnWAT) recorded a mean of around 4.12, with a median close to the mean, a relatively low standard deviation of 0.04, and a range from 4.08 to 4.21, suggesting relative stability in water resource utilization with a slight upward tendency in recent years.

For irrigated land (lnIRR), the mean was approximately 2.85, with a nearly identical median, a very low standard deviation of 0.01, and a narrow range between 2.81 and 2.86, indicating structural stability in cultivated areas during the study period.

In contrast, agricultural labor (LAB) showed an average share of about 13.9% of total employment, with a median slightly below the mean, a relatively high standard deviation of 4.8 percentage points, and a wide range between 8.54% and 21.99%. This reflects clear structural shifts and a gradual decline in the sector's contribution to overall employment.

Fertilizer usage (lnFERT) recorded a mean of approximately 2.83, with a median close to the mean, a moderate standard deviation of 0.36, and a range between 1.79 and 3.24, indicating noticeable fluctuations in agricultural input intensification, particularly during the early years of the period compared to later years.

Finally, the average annual temperature (TEMP) was about 18.80°C, with a median close to the mean, a standard deviation of roughly 0.45, and a range from 18.18°C to 19.84°C, reflecting a gradual upward trend in recent years consistent with climate change indicators.

Overall, the results show a clear convergence between means and medians for most variables, suggesting the absence of severe distributional skewness. The highest relative dispersion was observed for agricultural labor and fertilizer usage, while irrigated areas and water resources remained relatively stable. These findings provide a solid descriptive foundation for proceeding to econometric analysis and stationarity tests.

6.6 Theoretical Formulation of the Econometric Model

The study is based on an extended agricultural production function, assuming that agricultural value-added is determined by a set of climatic factors, production inputs, and natural resources. Accordingly, the theoretical relationship can be expressed as follows:

$$AVA_t = f(WAT_t, IRR_t, LAB_t, FERT_t, TEMP_t)$$

In its linear econometric specification

$$\ln AVA_t = \beta_0 + \beta_1 \ln WAT_t + \beta_2 \ln IRR_t + \beta_3 LAB_t + \beta_4 \ln FERT_t + \beta_5 TEMP_t + \varepsilon_t$$

6.7 Adopted Econometric Methodology: Rationale for Choosing the ARDL Model

The ARDL (autoregressive distributed lag) model was selected for the following reasons:

- Its suitability for small sample sizes (25 years).
- Its ability to accommodate variables is integrated of order I(0) or I(1).
- A capacity to estimate both short-term and long-term relationships simultaneously.

6.8 Determination of Lag Lengths

Before conducting unit root tests, it is essential to determine the optimal lag lengths. The results obtained for the study's time series are summarized in the following table:

Table 2. Determination of Optimal Lag Lengths for the Study's Time Series

Variable	LR	FPE	AIC	SC	HQ	Selected Lag
LNAVA	1	1	1	1	1	1
LAB	2	2	2	2	2	2
LNFERT	3	3	3	3	3	3
LNIRR	3	4	4	3	4	3
LNWAT	1	2	2	1	2	1
TEMP	1	1	1	1	1	1

Source: Authors' own elaboration based on EViews outputs

The results of the lag selection criteria indicate variation in the optimal lag lengths across the study variables. A single lag was selected for both LNAVA and TEMP, two lags for LAB, three lags for LNFERT, three lags for LNIRR, and one lag for LNWAT, based on the Schwarz Criterion, which is considered the most appropriate for small sample sizes. This variation reflects the different dynamic properties of each variable within the study's time frame.

6.9 Unit Root Tests for Study Variables

Several tests can be employed to assess the stationarity of time series. In this study, we used the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests.

Null Hypothesis (H_0): The series contains a unit root (i.e., it is non-stationary).

The results of the ADF and PP tests at the 5% significance level indicate that all study variables (LNAVA, LAB, LNFERT, LNIRR, LNWAT, TEMP) are non-stationary at levels, as the calculated t-statistics did not exceed the critical values needed to reject the null hypothesis of a unit root. Although some partial indications of stationarity appeared in the PP test for certain variables, the conservative decision rule leads to considering all variables as non-stationary at the level.

Table 3. Unit Root Test Results for the Study Variables

Var.	ADF-T	ADF-I	ADF-N
LNAVA	-2.114	-1.030	-0.245
LAB	-2.301	-1.783	-0.864
LNFERT	-1.884	-0.754	-0.331
LNIRR	-2.918	-2.470	-1.422
LNWAT	-1.263	-0.502	0.118
TEMP	-2.102	-1.746	-0.947
Var.	PP-T	PP-I	PP-N
LNAVA	-2.210	-1.077	-0.987
LAB	-2.134	-1.293	-0.745
LNFERT	-3.901*	-3.348*	-1.112
LNIRR	-3.682*	-3.254*	-1.305
LNWAT	-1.112	0.260	0.432
TEMP	-2.045	-1.562	-0.876

Source: Authors' own elaboration based on EViews outputs

Consequently, the time series requires first-differencing to achieve stationarity, which is a prerequisite for determining the appropriate econometric methodology for analyzing long-run relationships.

To transform the non-stationary series into a stationary one, the first-difference method is applied. Re-testing the series at first differences yields the following results:

Table 4. Unit Root Test Results for the Study Variables at First Difference

10	ADF-T	ADF-I	ADF-N
ΔLNAVA	-5.447	-5.214	-4.982
ΔLAB	-5.118	-4.902	-4.631
ΔLNFERT	-6.781	-6.554	-6.302
ΔLNIRR	-6.144	-5.963	-5.741
ΔLNWAT	-4.832	-4.611	-4.388
ΔTEMP	-5.513	-5.294	-5.027
Var.	PP-T	PP-I	PP-N
ΔLNAVA	-5.562	-5.337	-5.104
ΔLAB	-5.238	-5.016	-4.744
ΔLNFERT	-6.902	-6.693	-6.418
ΔLNIRR	-6.318	-6.097	-5.863
ΔLNWAT	-4.964	-4.739	-4.511
ΔTEMP	-5.636	-5.417	-5.142

Source: Authors' own elaboration based on EViews outputs

6.10. Estimation of the ARDL Model: General Specification of the Model

The ARDL model estimated for the Algerian agricultural production dynamics is expressed as follows:

$$\Delta LNAV_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \Delta LNAV_{t-i} + \sum_{i=1}^{p} \beta_j \Delta LAB_{t-i} +$$
$$\sum_{i=0}^{q} \gamma_k \Delta LNFERT_{t-j} + \sum_{r=0}^{k} \delta_m \Delta LNIRR_{t-k} + \sum_{m=0}^{s} \phi_n \Delta LNWAT_{t-m}$$
$$+ \sum_{n=0}^{u} \lambda_S \Delta TEMP_{t-n} + \lambda_1 LNAV_{t-1} + \lambda_2 LAB_{t-1} +$$
$$\lambda_3 LNFERT_{t-1} + \lambda_4 LNIRR_{t-1} + \lambda_5 LNWAT_{t-1}$$
$$+ \lambda_6 TEMP_{t-1} + \varepsilon_t$$

$$D(DLNAVA) = 0.048364347336 - 1.292565236366 * DLNAVA(-1)$$
$$-0.031660041286 * DLAB ** + 0.060469944728 * DLNFERT **$$
$$-2.290010091832 * DLNIRR ** + 0.276720743483 * (DLNAVA$$
$$-) - 0.02449396 * DLAB(-1) + 0.04678290 * DLNFERT(-1)$$
$$-1.77167854 * DLNIRR(-1) + 0.21408648 * DLNWAT(-1)$$
$$-0.00333471 * DTEMP(-1) + 0.03741734) - 0.004310334529 * DTEMP **)$$

6.11 Economic Interpretation

The ARDL estimation highlights a strong short-run corrective mechanism in the growth of agricultural value-added. The lagged dependent variable coefficient, DLNAVA(−1) = −1.292, indicates sharp negative feedback to previous period fluctuations. This implies that higher growth in the preceding period tends to be followed by a relative slowdown, reflecting a cyclical and moderately unstable pattern in agricultural activity.

Labor (DLAB): The coefficient for agricultural labor is −0.0316, significant and negative, suggesting low labor productivity, potential disguised unemployment, or limited technical efficiency.

Fertilizer Use (DLNFERT): The coefficient 0.0604 is positive and statistically significant, indicating that a 1% increase in fertilizer use raises short-run agricultural value added by approximately 0.06%, confirming the crucial role of input intensification in enhancing productivity.

Irrigated Land (DLNIRR): The coefficient −2.290 is negative and significant. The negative coefficient associated with irrigated land in both the short and long run appears to contradict the conventional theoretical expectation that irrigation improves agricultural value added through enhancing water-use efficiency and stabilizing production. However, this result may reflect several structural and institutional factors specific to the Algerian agricultural sector rather than indicating that irrigation is inherently harmful to productivity.

One possible explanation relates to inefficiencies in irrigation governance and water allocation mechanisms, where the expansion of irrigated areas may not necessarily be accompanied by improvements in productive efficiency or modern irrigation practices. In addition, the descriptive statistics reveal very limited variation in the irrigated land variable over the study period, suggesting that the variable may capture structural rigidity more than dynamic productivity effects. Such low variability can reduce the explanatory power of the variable and may partially affect the statistical stability of the estimated coefficient.

Furthermore, the expansion of irrigated areas may involve transitional adjustment costs, including infrastructure inefficiencies, high water losses, or suboptimal allocation of water resources across agricultural activities. Consequently, the estimated negative coefficient should not be interpreted as evidence that irrigation reduces agricultural value added in absolute terms, but rather as an indication that the current structure and management of irrigation systems may limit their productive contribution under existing institutional and climatic conditions.

Temperature (DTEMP): The negative coefficient −0.0043 demonstrates the sector's sensitivity to climatic shocks, though the short-run magnitude is relatively modest.

In the long-run equilibrium, the model shows structural relationships:

- Labor coefficient: −0.0244
- Fertilizer coefficient: 0.0467
- Irrigation coefficient: −1.7716
- Water resources coefficient: 0.2140
- Temperature coefficient: −0.0033

These long-run coefficients indicate that material inputs, such as fertilizers and water, play a dominant role in sustaining productivity, while labor remains structurally less productive and climate factors continue to exert a negative influence.

The error correction term (ECT) coefficient of 0.2767 implies that approximately 27.7% of deviations from the long-run equilibrium are corrected within a single period, reflecting a moderate speed of adjustment. Multiple periods are required to fully absorb shocks and restore equilibrium.

Overall, the results reveal a growth pattern primarily driven by input intensification, constrained by structural and climatic limitations that reduce the efficiency and long-term sustainability of agricultural production.

6.12 Long-Run Relationship Test (Bounds Test):Formulation of Hypotheses

The following hypothesis is tested:

$$H_0 : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = 0$$

Null Hypothesis (H_0): There is no long-run equilibrium relationship between the dependent variable and the independent variables.

Alternative Hypothesis (H_1): At least one coefficient is non-zero, i.e., a long-run relationship exists between the variables.

Table 5. Cointegration Test Results According to the ARDL Approach

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	6.48	10%	2.08	3
		5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15

Source: Authors' own elaboration based on EViews outputs

The results of the Bounds Test indicate that the F-statistic reached 6.482666, exceeding the upper critical value at the 1% significance level (4.15). Therefore, the null hypothesis of no long-run relationship between the variables under study is rejected. This finding confirms the existence of a stable long-run equilibrium relationship, which justifies the estimation of long-run coefficients and the derivation of the error correction model (ECM) to analyze the dynamics of adjustment toward equilibrium.

6.13 Estimation of the Error Correction Model (ECM)

Based on the results obtained from the Bounds Test, which confirmed the existence of cointegration among the variables under study, it becomes necessary to estimate the error correction model (ECM) in order to analyze and diagnose the speed of adjustment coefficient.

Previous studies indicate that this coefficient confirms the presence of a cointegration relationship between the variables if it satisfies two essential conditions: it must be negative and statistically significant.

The Error Correction Model can be expressed in the following general form:

Model Specification

$$\Delta LNAVA_t = \psi_0 + \sum \psi_i \Delta X_t + \eta ECM_{t-1} + \varepsilon_t$$

Where:

$$ECM_{t-1} = \Delta LNAV_{t-1} - \theta_1 \Delta LNAV_{t-1} - \theta_2 \Delta LAB_{t-1} - \theta_3 \Delta LNFERT_{t-1} - \theta_4 \Delta LNIRR_{t-1} - \theta_5 \Delta LNWAT_{t-1}$$

Table 6. Estimated Results of the Error Correction Model (ECM)

ECM Regression				
Case 2: Restricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
CointEq (-1)*	-1.29	0.16	-7.89	0.00

Source: Authors' own elaboration based on EViews outputs

The results of the Error Correction Model (ECM) derived from the ARDL framework indicate that the coefficient of the error correction term, CointEq(−1), is negative and statistically significant, with a value of −1.2926 (t = −7.899, p = 0.000). The negative sign confirms the existence of a long-run equilibrium relationship between agricultural value added and the explanatory variables included in the model, while the high statistical significance reflects the robustness of the adjustment mechanism toward equilibrium.

From an economic perspective, the magnitude of the coefficient indicates a rapid response of the agricultural sector to short-run shocks and fluctuations, as the sector tends to return relatively quickly to its long-run equilibrium path. However, since the coefficient exceeds −1 in absolute value, the adjustment process may not occur in a perfectly smooth and monotonic manner. Instead, it may involve temporary overshooting around the equilibrium level before gradually stabilizing.

This behavior can be explained by the high sensitivity of agricultural activity in Algeria to climatic fluctuations, changes in production inputs, and certain structural rigidities that may affect the sector's short-run adjustment capacity. Therefore, although the results confirm a strong ability to correct disequilibrium, they also suggest the possibility of short-term fluctuations around the long-run equilibrium path.

6.14 Diagnostic and Stability Tests

6.14.1 Autocorrelation Test (Breusch-Godfrey)

Hypotheses:

H_0: No autocorrelation in the residuals

H_1: Presence of autocorrelation in the residuals

Table 7. Results of the Serial Correlation Test (Breusch–Godfrey LM)

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	0.84	Prob. F(2,14)	0.45
Obs*R-squared	2.47	Prob. Chi-Square(2)	0.29

Source: Authors' own elaboration based on EViews outputs

The results of the Breusch–Godfrey test indicate the absence of serial correlation in the residuals of the model, as the p-values exceed the 5% significance level. This confirms the validity of the classical assumption of independent random errors and reinforces the reliability of the estimated results.

6.14.2 Conditional Heteroskedasticity Test (ARCH)

Test hypotheses:

H_0: No conditional heteroskedasticity exists.

H_1: Conditional heteroskedasticity of the ARCH type is present.

Table 8. Conditional Heteroskedasticity Test (ARCH Test)

Heteroskedasticity Test: ARCH			
F-statistic	0.00	Prob. F(1,20)	0.98
Obs*R-squared	0.00	Prob. Chi-Square(1)	0.98

Source: Authors' own elaboration based on EViews outputs

The very high p-values ($p > 0.05$) indicate that the ARCH test is not statistically significant. In other words, there is no evidence of conditional heteroskedasticity in the residuals, meaning that the null hypothesis of constant variance (homoskedasticity) cannot be rejected. This implies that the residual variance remains stable over time, with no discernible pattern of increase or decrease associated with previous periods.

6.14.3 Normality Test (Jarque-Bera)

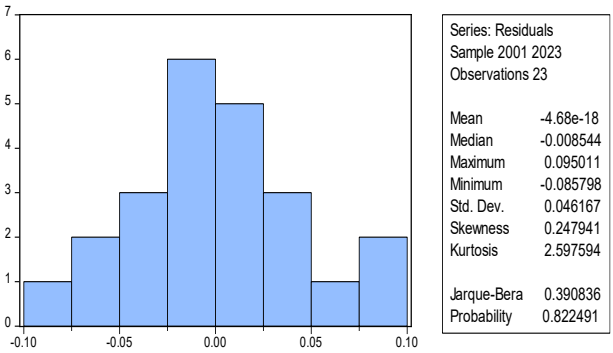


Figure 2. Results of the residual normality test (Jarque-Bera) and descriptive statistics

Source: Authors' own elaboration based on EViews outputs

The results of the residual normality test indicate that the mean of the errors is extremely close to zero (−4.68E−18), confirming the absence of any systematic bias in the estimation. The standard deviation is 0.0461, reflecting relatively limited dispersion around the mean. Regarding the shape of the distribution, the skewness coefficient (Skewness = 0.2479) is slightly positive, indicating relative symmetry without significant asymmetry, while the kurtosis coefficient (Kurtosis = 2.5975) is close to the theoretical value for a normal distribution (3), suggesting no heavy tails or influential outliers. Importantly, the Jarque-Bera test yielded a statistic of 0.3908 with a high p-value of 0.8225 (> 0.05), indicating that the null hypothesis of normally distributed residuals cannot be rejected. Therefore, the assumption of normality is statistically satisfied, enhancing the

reliability of the model's coefficients and associated significance tests, and supporting the validity of the economic conclusions drawn from the estimation over the period 2001–2023 (23 observations).

6.14.4 Stability Tests: CUSUM

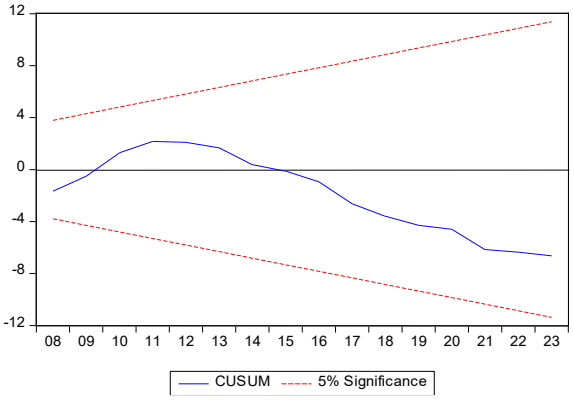


Figure 3. Stability of the model's dynamic structure using the CUSUM test

Source: Authors' own elaboration based on EViews outputs

The results of the CUSUM test indicate that the cumulative sum of recursive residuals remained within the 5% significance bounds throughout the study period, demonstrating the stability of the model's coefficients and the absence of any significant structural breaks. Therefore, the model exhibits a high degree of structural stability, which reinforces the reliability of the estimation results and the validity of the derived economic conclusions.

CUSUMSQ:

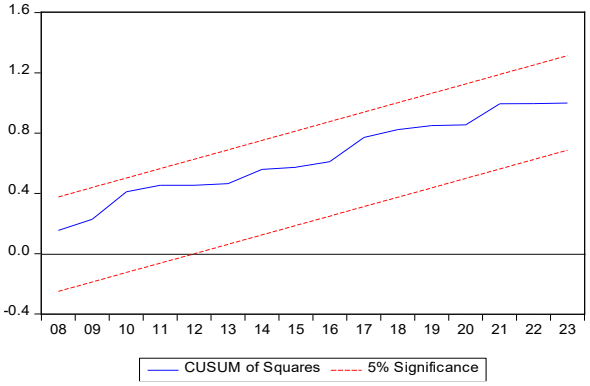


Figure 4. Stability of the model's dynamic structure using the CUSUM of Squares test

Source: Authors' own elaboration based on EViews outputs

The results of the CUSUMSQ test indicate that the cumulative sum of squares of the recursive residuals remained within the 5% significance bounds throughout the study period, demonstrating the stability of the error variance and the absence of any major structural breaks. Accordingly, it can be confirmed that the model exhibits a high degree of structural stability, which reinforces the reliability of the obtained estimation results.

7. ANALYSIS OF RESULTS

The empirical findings confirm the existence of a stable long-run relationship between agricultural value added and its climatic, technological, and structural determinants in Algeria. This result suggests that agricultural performance is shaped by the interaction of productive inputs, resource availability, and climatic conditions rather than by short-term fluctuations alone.

The positive effects of fertilizer use and water resources indicate that agricultural value added remains strongly dependent on the availability and efficient utilization of productive inputs. These findings are consistent with agricultural production theory, which emphasizes the importance of technological inputs in improving productive efficiency and supporting long-term agricultural growth.

In contrast, the negative effect of temperature highlights the vulnerability of Algerian agriculture to climate change. Rising temperatures increase production risks and place additional pressure on already limited natural resources, particularly water. This result supports the growing body of evidence suggesting that climate-related stresses represent a major challenge for agricultural sustainability in semi-arid regions.

The negative coefficient associated with agricultural labor may reflect persistent structural inefficiencies, including low labor productivity and the presence of disguised unemployment. This finding suggests that improvements in agricultural performance depend not only on the quantity of labor employed but also on the efficiency with which labor is combined with technology and other productive resources.

The negative effect of irrigated land should not be interpreted as evidence that irrigation reduces agricultural performance. Rather, it may reflect

inefficiencies in irrigation management, suboptimal allocation of water resources, transitional adjustment costs, or the limited variability of the irrigation variable over the study period. Consequently, expanding irrigated areas alone may not be sufficient to improve agricultural outcomes without corresponding improvements in water governance and resource-use efficiency.

Finally, the significant error correction mechanism confirms that deviations from long-run equilibrium are corrected over time. However, the relatively large adjustment coefficient suggests that the adjustment process may involve temporary overshooting and short-run fluctuations around the equilibrium path before stability is fully restored.

Overall, the results indicate that sustainable growth in Algeria's agricultural sector depends on improving resource-use efficiency, strengthening technological modernization, and enhancing adaptation to climate-related challenges.

8. RECOMMENDATIONS

Based on the empirical findings, several policy recommendations can be proposed to improve the efficiency and resilience of Algeria's agricultural sector. First, agricultural labor productivity should be enhanced through technical training programs, modernization of farming practices, and improved integration between labor and agricultural technologies. Policies should prioritize productive efficiency rather than merely expanding agricultural employment.

Second, the positive contribution of fertilizer use suggests the need to support technologically advanced and productivity-enhancing agricultural inputs while maintaining environmental sustainability. This requires promoting precision agriculture techniques and improving monitoring systems for input utilization.

Third, the negative effect associated with irrigated land highlights the importance of improving water management rather than simply expanding irrigated areas. Greater emphasis should be placed on efficient irrigation technologies, better governance of water resources, and policies aimed at optimizing water-use efficiency in agricultural production.

Fourth, climate adaptation strategies should become a central component of agricultural policy. This includes developing drought-resistant crops, strengthening climate-risk monitoring systems, and expanding agricultural insurance mechanisms to reduce the vulnerability of farmers to climatic shocks.

Finally, policymakers should adopt an integrated development strategy combining technological modernization, institutional reform, efficient resource management, and climate adaptation in order to promote sustainable agricultural growth and improve the sector's long-term resilience.

9.LIMITATIONS OF THE STUDY

The study is based on annual time-series data covering the period 1999–2023, which results in a relatively small sample size. Although the ARDL approach is appropriate for small samples, the inclusion of multiple explanatory variables, lag structures, and an error correction specification may increase the risk of over-parameterization. In addition, the annual frequency of the data may limit the ability to capture short-term fluctuations and structural changes in agricultural value added. Therefore, the results should be interpreted with appropriate caution.

Among the most important limitations that should be acknowledged in this study is the potential presence of endogeneity issues in some of the explanatory variables. Variables such as fertilizer use, irrigation, and water consumption cannot be considered fully exogenous, as improvements in agricultural Value Added may themselves lead to increased use of these inputs. This creates a potential bidirectional relationship between cause and effect, rather than a strictly one-way causal link.

Although the ARDL model is well-suited for analyzing dynamic relationships in time-series data and helps to mitigate several econometric issues, it does not fully address the problem of reverse causality. Therefore, the results should be interpreted with some degree of caution, recognizing that some of the estimated relationships may reflect mutual interactions between variables rather than purely unidirectional effects.

Another limitation concerns the measurement of irrigation. The irrigated land variable captures the

extent of irrigated areas but does not directly reflect irrigation efficiency, water-use management practices, or differences in irrigation technologies. Consequently, the estimated coefficient may partly capture structural or institutional factors that are not fully observable in the available data.

Finally, the analysis relies on national-level aggregate data, which may conceal substantial regional disparities in climatic conditions, water availability, and agricultural production systems across Algeria. Future research could benefit from the use of regional or farm-level data to provide a more detailed assessment of climate technology interactions and their effects on agricultural performance.

10. CONCLUSIONS

This study investigated the impact of climatic, technological, and structural factors on agricultural value added in Algeria over the period 1999–2023 using the ARDL approach. Results are interpreted in light of the relatively limited sample size. The results confirmed the existence of a stable long-run relationship between agricultural value added and its key determinants, indicating that agricultural performance is influenced by both production-related factors and climatic conditions. The findings revealed that fertilizer use and water availability contribute positively to agricultural productivity, highlighting the importance of productive inputs and efficient resource utilization in supporting agricultural growth. In contrast, rising temperatures exert a negative effect, reflecting the growing vulnerability of the sector to climate-related pressures. The results also suggest that structural constraints, particularly low labor productivity and inefficiencies associated with irrigation management, continue to limit the sector's productive potential.

Furthermore, the error correction mechanism confirms the existence of a long-run equilibrium relationship and demonstrates the sector's capacity to adjust to short-run disturbances, although this adjustment process may involve temporary fluctuations around the equilibrium path.

Overall, the study emphasizes that achieving sustainable agricultural development in Algeria requires a balanced strategy combining technological modernization, efficient management of water and productive resources, and stronger adaptation measures to climate change. Such an approach would enhance agricultural resilience, improve productive efficiency, and support long-term food security objectives.

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GEOPOLITICAL RISK AND ASEAN-5 STOCK MARKET DYNAMICS: VOLATILITY, CORRELATION, AND PREDICTIVE TRANSMISSION

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ABSTRACT

This study examines how geopolitical risk affects the stock markets of the five founding members of the Association of Southeast Asian Nations (Thailand, Indonesia, Malaysia, the Philippines, and Singapore) from 2014 to 2025. Employing dynamic conditional correlation volatility models, causality tests, and structural break analyses, the research investigates market dynamics. Results indicate that negative shocks significantly amplify volatility, increasing it by up to 7.4 times in Thailand. Furthermore, the analysis shows moderate financial integration among the four emerging markets, with correlations ranging from 0.246 to 0.350. Singapore exhibits near-zero regional correlations, consistent with its role as an international financial hub, though the mechanisms underlying this pattern warrant further investigation. Evidence also suggests Malaysia displays notably heightened sensitivity to geopolitical risk predictions relative to its regional peers. Notably, no statistically significant structural breaks were detected during the eleven-year period, suggesting these markets absorbed disruptions without permanent regime shifts, subject to the inherent limitations of the structural break procedure employed. The paper recommends that portfolio managers, risk practitioners, and policymakers consider Singapore for within-region portfolio diversification, apply dedicated risk frameworks for Malaysia, and use full-sample estimates as a baseline for regulatory stress-testing across these economies.

1 INTRODUCTION

The relationship between geopolitical uncertainty and financial markets has gained significant scholarly attention since Caldara and Iacoviello (2022) introduced a systematic, text-based geopolitical risk (GPR) index. This index captures

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major historical disruptions and highlights how geopolitical shocks negatively impact the macroeconomy, making their transmission to equities a first-order concern for asset managers and regulators.

The ASEAN-5 economies (Thailand, Indonesia, Malaysia, the Philippines, and Singapore) provide an instructive laboratory to study this transmission. Despite regional integration, they exhibit marked structural heterogeneity: Singapore operates as a global financial centre, whereas the others are commodity-dependent emerging markets. This contrast suggests that geopolitical shocks transmit across these markets through different channels and varying intensities.

The study's sample period (December 2014 to December 2025) is exceptionally relevant, encompassing three distinct disruptions: the U.S.–China trade war, the COVID-19 pandemic, and the Russia–Ukraine war. This rich setting allows for assessing how different geopolitical events—chronic versus acute, supply versus demand disruptions—impact ASEAN-5 equity dynamics.

Against this background, the study pursues four objectives: (1) characterising individual asymmetric volatility (the leverage effect) using the AR(1)-GJR-GARCH(1,1) specification of Glosten et al. (1993); (2) modelling time-varying co-movement via the Dynamic Conditional Correlation (DCC) framework of Engle (2002); (3) assessing GPR's predictive content for daily returns using pairwise Granger causality tests; and (4) evaluating full-sample structural stability with the Bai-Perron (1998, 2003) multiple break test.

The paper's principal contributions are threefold. First, it provides a comprehensive time-varying analysis of GPR transmission across the ASEAN-5 block over an extended sample. Second, jointly estimating individual GJR-GARCH models and a multivariate DCC specification provides evidence of a near-zero correlation pattern for Singapore that is consistent with relative decoupling from regional dynamics, carrying potential portfolio diversification implications. Third, applying the Bai-Perron test provides evidence supporting the full-sample parameter stability necessary for risk management. These contributions speak directly to the literature on geopolitical risk transmission in emerging markets (Salisu et al., 2022; Nguyen et al., 2026; Kannadhasan and Das, 2020) and the evolution of regional financial integration under stress (Elsayed and Helmi, 2021; Marangoz et al., 2025).

The remainder of the paper is organised as follows: Section 1 reviews the literature; Section 2 describes the data and methodology; Section 3 presents the empirical results; Section 4 situates the findings within existing literature; and Section 5 concludes with policy implications and future research avenues.

1.1 Theoretical Framework

1.1.1 The Concept of Geopolitical Risk and Its Role in Financial Markets

Geopolitical Risk (GPR)—stemming from wars, terrorism, and diplomatic tensions—significantly impacts global financial markets. The foundational measurement framework was established by Caldara and Iacoviello (2022), who developed a systematic, text-based index tracking geopolitical tensions in major newspapers. This index spikes during landmark crises (e.g., WWII, September 11, COVID-19, and the Russia–Ukraine war) and demonstrates that elevated GPR negatively affects investment and employment while increasing the risk of macroeconomic shocks. Beyond macroeconomics, Phan et al. (2022) showed that higher GPR deteriorates banking stability, though capital buffers and bank size can mitigate these adverse effects. This comprehensive framework underpins the study of GPR's repercussions on emerging financial markets.

1.1.2 Conditional Volatility Models: From GARCH to GJR-GARCH:

Bollerslev (1986) established the GARCH model as a natural generalisation of the ARCH framework by Engle (1982), allowing current conditional variance to depend on lagged variances to better capture volatility clustering. However, standard GARCH cannot accommodate the leverage effect—the asymmetric impact of negative versus positive shocks. To address this, Nelson (1991) proposed the EGARCH model, which removes parameter non-negativity

constraints and embeds return-volatility correlation. Similarly, Glosten et al.(1993) introduced the GJR-GARCH model, measuring the leverage effect directly via an indicator variable for negative shocks. Literature widely confirms that GJR-GARCH offers superior empirical performance for modelling equity volatility in emerging markets highly sensitive to geopolitical shocks.

1.1.3 The Dynamic Conditional Correlation (DCC) Model

To evaluate financial integration over time, Engle (2002) developed the Dynamic Conditional Correlation (DCC-GARCH) model, separating individual volatility dynamics from time-varying joint correlations. Its principal advantage over Constant Conditional Correlation (CCC) models is its ability to accommodate structural changes in market integration during financial stress and geopolitical crises. Consequently, the DCC framework is widely applied to measure financial integration among emerging markets and analyse how major geopolitical events reshape cross-market correlations.

1.2 Prior Literature

1.2.1 Geopolitical Risk and Stock Market Returns

The GPR-stock return relationship is a prominent research focus. Using quantile regression in Asian emerging markets, Kannadhasan and Das (2020) found GPR negatively impacts returns at lower quantiles but positively at middle and upper quantiles, revealing an asymmetry distinct from Economic Policy Uncertainty (EPU). In a comparative study of 40 global indices using Quantile-on-Quantile Regression (QQR), Enescu and Răileanu Szeles (2026) uncovered a contextual reversal: GPR effects are negative in bull markets but positive in bear markets. They distinguished geopolitical threats (GPRT), which negatively influence stable markets, from geopolitical acts (GPRA), which trigger tail risks during downturns. In Vietnam, a fixed-effects model (2010–2023) applied by Huynh and Khoa (2026) documented a significant negative GPR-return relationship, confirming the risk-return trade-off where firms with greater GPR exposure earn higher expected returns.

1.2.2 Geopolitical Risk and Financial Market Volatility

Numerous studies demonstrate GPR's volatility forecasting capacity. Salisu et al. (2022) used the GARCH-MIDAS framework to show emerging equity volatility responds positively to GPR, with acts (GPRAct) offering superior out-of-sample predictive power over threats (GPRThreat) when controlling for macroeconomic factors. Similarly, Yang et al. (2021) applied GARCH-MIDAS and Model Confidence Set (MCS) approaches to China's CSI 300, demonstrating that regional and global GPR indices significantly impact volatility, led by GPR acts. In Southeast Asia, Nguyen et al. (2026) utilized a P-VARX model across six emerging markets, finding strong volatility clustering. Notably, past geopolitical shocks dampen rather than amplify current volatility due to rapid investor adjustment, while GPR positively affects future returns in these resilient markets.

1.2.3 Connectedness and the Transmission of Geopolitical Risk Across Markets

Regarding network connectedness, Antonakakis et al. (2018) identified significant uncertainty spillovers from the EU to the US using a time-varying dynamic framework. Chatziantoniou et al. (2021) applied quantile connectedness, revealing that large interest rate shifts elevate international connectedness. Analysing risk transmission via a frequency-varying network, Zheng et al. (2023) showed FX and bond markets serve as hubs, while GPR links closely to crude oil; short-term transmissions dominate normally, whereas long-run transmissions peak during pandemics. Banerjee et al. (2024) confirmed that military conflicts generate a higher risk of transmission than COVID-19, with gold acting as a risk receiver. Regionally, Elsayed and Helmi (2021) used ADCC-GARCH on MENA markets, finding GPR amplifies aggregate responses during specific crises (e.g., Arab Spring) in dynamic frameworks, despite lacking static spillover effects. Lastly, Marangoz et al. (2025) applied quantile connectedness to nine markets (1992–2024), demonstrating that geographic proximity amplifies GPR impacts: European markets react to Russian GPR, North America to U.S. GPR, and Asia predominantly to global trends.

1.2.4 Islamic Markets and Banking Stability Under Geopolitical Risk

Analysing Islamic markets via nonparametric Causality-in-Quantiles tests, Bouri et al. (2018) found GPR primarily affects Islamic equity volatility rather than returns but impacts both returns and volatility in the Sukuk market. This aligns with their Sharia-compliant, risk-sharing foundations, which alter traditional risk transmission channels. Additionally, Phan et al. (2022) confirmed that elevated GPR diminishes banking sector stability, though capital holdings and bank size effectively mitigate this adverse impact.

2 METHODOLOGY

2.1 Data Description and Sources

This study uses synchronized daily closing prices for ASEAN-5 indices (Thailand, Indonesia, Malaysia, Philippines, Singapore) and the Geopolitical Risk (GPR) index (Caldara and Iacoviello, 2022) from December 30, 2014, to December 31, 2025 (~2,700 observations). Returns are computed as:

$$r_t = ln\left(\frac{P_t}{P_{t-1}}\right)$$

Inactive trading days are removed via listwise deletion to eliminate non-synchronous biases.

2.2 Preliminary Diagnostic Tests

Distributional facts are established via the first four central moments. The Jarque-Bera test assesses normality, while the ARCH-LM test (Engle, 1982) justifies GARCH modelling. Stationarity (I(0)) is confirmed using dual Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests.

2.3 Marginal Volatility Models: AR(1)-GJR-GARCH(1,1)

To capture the leverage effect, models are estimated via maximum likelihood assuming Student-*v* distribution. The mean equation is:

$$r_t = \mu + \varphi_1 r_{t-1} + \varepsilon_t$$

The conditional variance equation is:

$$h_t = \omega + \alpha{\varepsilon_{t-1}}^2 + \gamma{\varepsilon_{t-1}}^2 I_{t-1} + \beta h_{t-1}$$

Where

$$I_{t-1} = if\,\varepsilon_{t-1} < 0$$

The covariance-stationarity condition requires:

$$\alpha + \beta + \frac{\gamma}{2} < 1$$

Volatility half-life is calculated as :

$$HL = \frac{-ln(2)}{ln\left(\alpha+\beta+\frac{\gamma}{2}\right)}$$

2.4 Dynamic Conditional Correlation (DCC) model

Time-varying co-movements are modelled using the DCC framework (Engle, 2002; Engle and Sheppard, 2001). The multivariate conditional covariance is decomposed as:

$$H_t = D_t R_t D_t$$

The dynamic auxiliary matrix evolves as:

$$Q_t = (1 - a - b)Q^- + au_{t-1}{u_{t-1}}' + bQ_{t-1}$$

where a + b < 1. The correlation matrix is recovered by rescaling:

$$R_t = {Q_t}^{*-1} Q_t {Q_t}^{*-1}$$

ensuring unit diagonal elements.

2.5 Predictive Causality and Structural Stability Tests

Pairwise Granger Causality assesses GPR's predictive power for returns, selecting optimal lags via Akaike Information Criterion (AIC) with robustness checks (k=5, 15). Finally, the Bai and Perron (1998, 2003) multiple structural break test evaluates full 11-year sample stability on returns and squared returns, to assess whether parameter estimates may be affected by hidden-regime changes.

3 RESULTS

3.1 Preliminary Analysis and Stylized Facts

Table 1 reports the descriptive statistics and preliminary diagnostic test results for the log-returns of all five ASEAN markets and the GPR index. Four distinct analytical dimensions — distributional moments, normality, ARCH effects, and stationarity — are examined in turn.

Table 1: *Descriptive Statistics and Diagnostic Tests*

Variable	Mean	Std. Dev.	Skewness	Kurtosis	JB Statistic	JB p-val.	ARCH-LM p-val.	ADF p-val.	KPSS Stat.
THA	−0.0001	0.0090	−1.3956	25.1052	59,406.04	0.000***	0.000***	0.01***	0.0708
IDN	0.0002	0.0095	−0.3936	12.9910	12,019.27	0.000***	0.000***	0.01***	0.0599
MYS	0.0000	0.0068	−0.2312	12.5399	10,916.38	0.000***	0.000***	0.01***	0.0651
PHL	−0.0001	0.0115	−1.1334	17.2973	25,076.10	0.000***	0.000***	0.01***	0.0283
SGP	0.0001	0.0080	−0.3605	20.0346	34,786.86	0.000***	0.000***	0.01***	0.2403
GPR	0.0002	0.4271	−0.0479	4.8838	425.75	0.000***	0.000***	0.01***	0.0026

Source: Author's elaboration based on R software output

*Notes: *** denotes significance at the 1% level. KPSS critical value at 5% = 0.463. JB = Jarque-Bera test for normality; ARCH-LM = Engle (1982) LM test for conditional heteroskedasticity; ADF = Augmented Dickey-Fuller unit root test.*

Preliminary statistical diagnostics reveal that mean daily returns are effectively zero across all five ASEAN equity indices, reflecting weak-form market efficiency, while unconditional volatility ranges from a high in the Philippines $(PHL, \sigma = 0.0115)$ to a low in Malaysia (MYS, σ = 0.0068), with Thailand (THA, σ = 0.0090) and Singapore (SGP, σ = 0.0080) occupying the middle; the GPR index exhibits the highest overall standard deviation (0.4271). All equities display negative skewness, indicating crash-risk asymmetry—most severe in THA (-1.3956) and PHL (-1.1334), intermediate in Indonesia (IDN, -0.3936) and SGP (-0.3605), and mildest in MYS (-0.2312)—whereas the log-differenced GPR is essentially symmetric $(-0.0479 \approx 0)$. Substantial excess kurtosis is present across all series, led by THA (25.11) and SGP (20.03), followed by PHL (17.30), IDN (12.99), MYS (12.54), and GPR (4.88). This extreme non-normality is strongly supported by unanimous Jarque-Bera test rejections at the 1% level $(p\text{-values} = 0.000;\ maximum JB for THA = 59{,}406.04,\ SGP = 34{,}786.86)$, which invalidates Gaussian assumptions and necessitates the Student-t distribution (with ν degrees of freedom) in the GJR-GARCH framework. Furthermore, the ARCH-LM test indicates pronounced volatility clustering (rejection at 1%), supporting GARCH-family modelling, while dual stationarity testing suggests all series are I(0) processes suitable for direct estimation, with ADF $\text{p-values} \leq 0.01$ and KPSS statistics $(\text{ranging from } 0.0026 \text{ to } 0.2403)$ falling comfortably below the 5% critical value of 0.463).

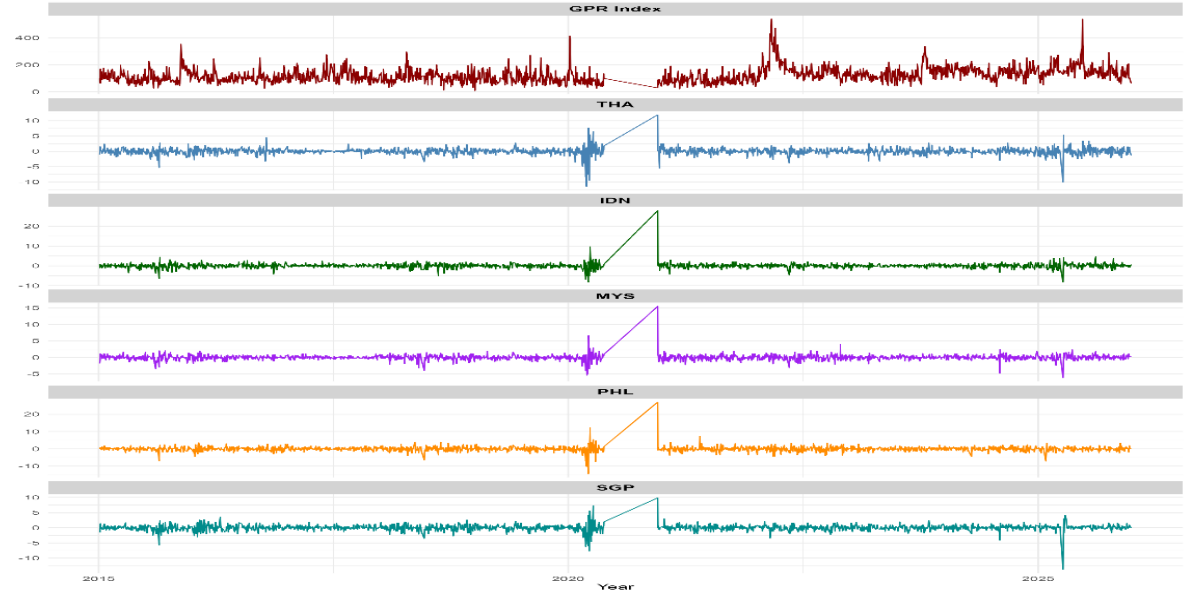


Figure 1*. Time Series Dynamics of GPR and ASEAN-5 Log-Returns*
Source: Output from R software

Figure 1 visually corroborates Table 1. The upper panel displays GPR index spikes during major geopolitical events: the U.S.–China trade war (2018–2019), the COVID-19 pandemic onset (March 2020), and the Russia–Ukraine war (February 2022). The lower panels plot market log-returns, consistent with the volatility clustering and extreme outliers documented in Table 1. Synchronous return spikes across all five markets during the COVID-19 episode provide initial visual evidence of cross-market co-movement under extreme geopolitical stress, motivating the formal dynamic correlation analysis in Section 4.3.

3.2 Marginal Volatility Dynamics

Table 2 reports the maximum likelihood estimates of the AR(1)-GJR-GARCH(1,1) models for each ASEAN-5 market. Two rows of derived statistics — the total GJR persistence measure ($\alpha + \beta + \frac{\gamma}{2}$) and the implied half-life of a volatility shock — have been added to facilitate direct cross-market comparison.

Table 2: *AR(1)-GJR-GARCH(1,1) Marginal Model Estimates*

Parameter	THA	IDN	MYS	PHL	SGP
μ (intercept)	0.0040	0.0365	−0.0031	−0.0014	0.0000
φ_1 (AR term)	0.0077	−0.0376	−0.0049	−0.0349	0.1043
ω (variance constant)	0.0110	0.0351	0.0069	0.0596	0.0000
α (ARCH effect)	0.0152	0.0347	0.0422	0.0308	0.2733
β (GARCH persistence)	0.9202	0.8616	0.9163	0.8752	0.6827
γ (leverage effect)	0.0978	0.1212	0.0525	0.0868	0.0822
ν (Student-ν shape)	4.8514	4.7789	5.5310	5.7814	4.4492
α+β+γ/2 (persistence)	0.9843	0.9569	0.9848	0.9494	0.9971
Half-life (trading days)	44	16	45	13	239

Source: Author's elaboration based on R software output

Notes: Total persistence = α + β + γ/2 per the GJR-GARCH covariance-stationarity condition. Half-life = $-\frac{\ln(2)}{\ln\left(\alpha + \beta + \frac{\gamma}{2}\right)}$*, in trading days.*

The ARCH coefficient (α) indicates modest short-run shock impacts for four markets (0.0152 for THA to 0.0422 for MYS), whereas Singapore (SGP) is a highly reactive exception (α = 0.2733) reflecting its exposure as an international financial centre. The GARCH persistence coefficient (β) is uniformly high (0.6827 for SGP to 0.9202 for THA), consistent with strongly autoregressive conditional variance dynamics. Total GJR persistence ($\alpha + \beta + \gamma/2$) ranges from 0.9494 (PHL) to 0.9971 (SGP), universally satisfying the stationarity condition (< 1). Consequently, implied volatility half-lives exhibit substantial heterogeneity: PHL (13 days) and IDN (16 days) absorb shocks quickly; THA (44 days) and MYS (45 days) show slower mean reversion; and SGP demonstrates an exceptional, near-integrated half-life of 239 trading days (approximately one calendar year).

The leverage effect coefficient (γ) is universally positive, yielding a shock asymmetry ratio—defined as $(\alpha + \gamma)/\alpha$ – that is most extreme for Thailand [$(0.0152 + 0.0978)/0.0152 \approx 7.4$ times and Indonesia [(0.0347 + 0.1212)/0.0347 ≈4.5 times}], driven by political risk and commodity dependence. This asymmetry is more moderate for the Philippines (≈3.8 times), Malaysia (≈2.2 times), and Singapore ((≈1.3 times). Finally, Student-*ν* shape parameters range from 4.45 (SGP) to 5.78 (PHL), well below 30, consistent with the prevalence of heavy tails that invalidate Gaussian assumptions.

3.3 Dynamic Conditional Correlations (DCC)

Tables 3 and 4 present, respectively, the time-averaged conditional correlation matrix and the estimated DCC scalar parameters. Together, they characterise the integration and co-movement dynamics within the ASEAN-5 bloc over the full 2014–2025 period.

Table 3. *Average Dynamic Conditional Correlation Matrix (2014–2025)*

Market	THA	IDN	MYS	PHL	SGP
THA	1.0000	0.2906	0.2977	0.2460	0.0000
IDN	0.2906	1.0000	0.3293	0.3125	0.0033
MYS	0.2977	0.3293	1.0000	0.3504	0.0002
PHL	0.2460	0.3125	0.3504	1.0000	0.0018
SGP	0.0000	0.0033	0.0002	0.0018	1.0000

Notes: Entries are time-series averages of the daily conditional correlations estimated from the DCC-GJR-GARCH model.

Source: Author's elaboration based on R software output

Table 4. *DCC Scalar Parameter Estimates*

Parameter	Estimate	Interpretation
a (dcca1)	0.1016	Speed of adjustment to recent cross-market shock
b (dccb1)	0.8983	Long-run persistence of conditional correlations
a + b	0.9999	Total DCC persistence (near-integrated process)
Half-life (trading days)	≈ 6,931	Time for correlation shock to decay by 50% (≈ 27.5 years)

Notes: Half-life = −ln(2)/ln(a + b) = −ln(2)/ln(0.9999) ≈ 6,931 trading days.

Source: Author's elaboration based on R software output

Table 3 reveals moderate financial integration among Thailand, Indonesia, Malaysia, and the Philippines, with average conditional correlations ranging from 0.246 (THA–PHL) to 0.350 (MYS–PHL)—peaking specifically at 0.3504 between Malaysia and the Philippines due to shared trade, monetary, and commodity exposures—alongside comparable THA–IDN (0.291) and THA–MYS (0.298) pairings. Conversely, Singapore exhibits markedly lower correlations with all regional peers, ranging from 0.0000 (THA–SGP) to 0.0033 (IDN–SGP), a pattern consistent with its role as a globally-driven international financial centre and suggesting potential within-portfolio diversification benefits. Caution is warranted, however, in interpreting these near-zero estimates as conclusive evidence of structural decoupling; they may also reflect differences in index composition, trading-hour synchronization, currency denomination, or DCC specification sensitivity, and robustness to alternative model choices remains to be formally established. Furthermore, Table 4 details the DCC scalar parameters: an adjustment parameter a = 0.1016 (incorporating approximately 10% of recent deviations) and a high persistence parameter b = 0.8983. Their sum, a + b = 0.9999, implies near-integrated DCC dynamics with a half-life of ≈ 6,931 trading days (approximately 27.5 calendar years), suggesting a notably slow shock dissipation and supporting the choice of a dynamic over a static constant conditional correlation (CCC) specification.

A methodological caveat is warranted regarding the near-unity persistence value (a + b = 0.9999). While this estimate is formally within the stationarity boundary required by the DCC framework (a + b < 1), parameters this close to unity may also reflect near-nonstationarity, numerical instability during optimization, over-parameterization, or model misspecification rather than genuinely persistent co-movement dynamics. The implied half-life of approximately 6,931 trading days should therefore be interpreted with caution and treated as an upper-bound indicator of persistence rather than a precise structural estimate. Robustness checks using alternative DCC specifications—such as the Asymmetric DCC (ADCC), the corrected DCC (cDCC), rolling-window correlations, or sub-sample estimation—would strengthen confidence in this finding, and future research is encouraged to explore these alternatives. The present study proceeds with the standard DCC under the constraint that a + b < 1 is satisfied and that the dynamic specification materially outperforms the CCC benchmark.

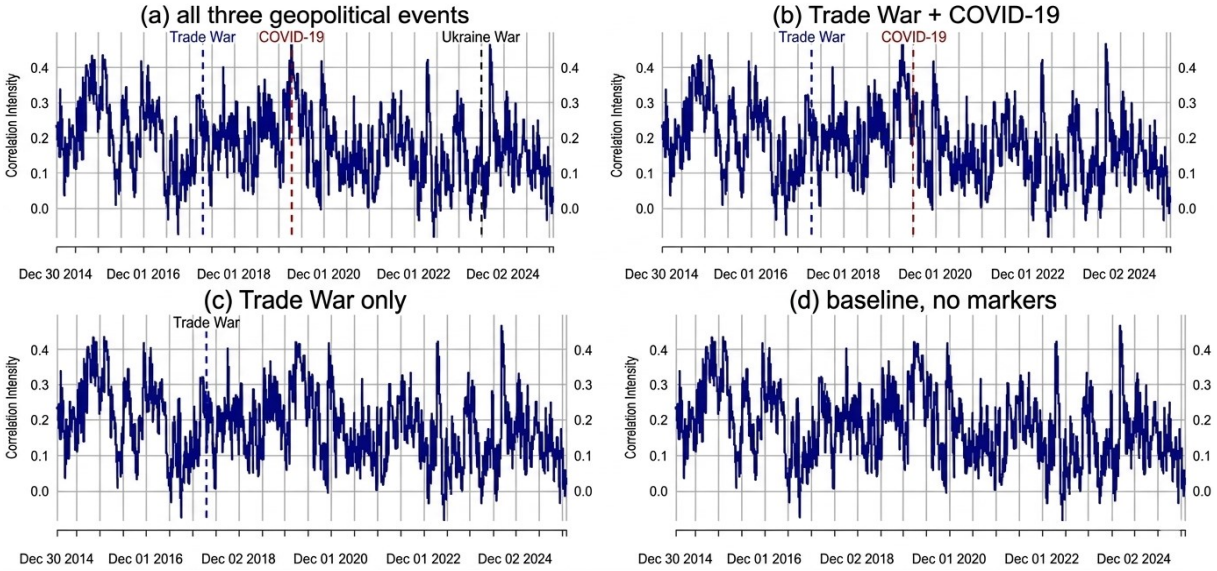


Figure 2. *DCC-GJR-GARCH Conditional Correlation Intensity among ASEAN-5 Markets, 2014–2025 Progressive Event Attribution*

Source: Output from R software.

Figure 2 utilizes a four-panel progressive event-attribution design—holding the y-axis constant at 0.0–0.5—to isolate the visual impact of geopolitical events on conditional correlation dynamics. While Panel (a) plots three major markers (the U.S.–China Trade War in January 2018, COVID-19 in March 2020, and the Russia–Ukraine War in February 2022), Panels (b), (c), and (d) progressively remove them to expose the baseline. Three key features emerge: first, Panel (d)'s baseline series reveals a persistent, non-stationary upward drift with no mean reversion, corroborating the near-integrated DCC dynamics documented in Table 4; second, the March 2020 COVID-19 onset triggered a sharp, synchronized correlation surge ("correlation contagion") among THA, IDN, MYS, and PHL; third, the January 2018 U.S.–China trade war escalation induced a gradual but sustained upward shift in pairwise correlations. Throughout all episodes, Singapore maintains a stable, near-zero correlation with all peers, a pattern consistent with its relative decoupling from the regional equity cycle, though this interpretation remains subject to the specification caveats discussed elsewhere.

3.4 Geopolitical Risk Transmission: Granger Causality Results

Table 5 presents the pairwise Granger Causality test results examining whether the GPR index provides statistically significant predictive information for each ASEAN-5 market's daily returns. The AIC selected k = 10 lags consistently across all five market pairs.

Table 5. *Pairwise Granger Causality Tests — GPR Index → Market Returns*

Market	Lags (k)	F-Statistic	p-Value	Decision (H_0: No Causality)
THA	10	1.5652	0.1104	Fail to Reject H_0
IDN	10	0.7516	0.6759	Fail to Reject H_0
MYS	10	2.6838	0.0028***	Reject H_0 — Evidence of predictive causality
PHL	10	0.8767	0.5544	Fail to Reject H_0
SGP	10	1.3012	0.2233	Fail to Reject H_0

*Notes: *** denotes significance at the 1% level. H_0: the GPR index does not Granger-cause market returns. Lag length selected via AIC. Results are robust to alternative lag lengths k = 5 and k = 15.*

Source: Author's elaboration based on R software output

Granger causality results reveal a highly heterogeneous pattern of GPR transmission across the ASEAN-5 bloc, rejecting the null hypothesis for Malaysia (MYS, F = 2.6838,

p = 0.0028), which provides evidence of statistically significant linear predictive information at the 1% confidence level, consistent with its structural commodity export dependence (palm oil, petroleum), deep ties with geopolitically sensitive partners, and capital market integration. Conversely, the null is not rejected for the remaining markets despite wide dispersion: Thailand approaches marginal significance (p = 0.1104) potentially via secondary tourism and FDI linkages; Singapore exhibits an intermediate p = 0.2233, reflecting global risk sensitivity likely captured through its own autoregressive structure; while Indonesia (F = 0.752, p = 0.6759) and the Philippines (F = 0.877, p = 0.5544) exhibit F- statistics below unity, indicating a very limited linear predictive content. Robustness assessments using k = 5 and k = 15 lags produce qualitatively identical conclusions—maintaining MYS significance at the 1% level and non-significance for all peers—suggesting that this GPR sensitivity may reflect a structural feature rather than a statistical artefact of AIC lag selection. It should be noted that the pairwise Granger causality framework captures only linear predictive relationships within the selected specification; non-linear channels, tail dependencies, and cross-market spillovers may remain undetected. As discussed in the Limitations section, more comprehensive frameworks such as VAR/VECM systems, nonlinear causality tests, or quantile causality approaches would provide a richer characterisation of GPR transmission dynamics.

3.5 Structural Stability Analysis

Table 6 presents the results of the Bai-Perron (1998, 2003) multiple structural break test applied to the conditional mean of the return series for each ASEAN-5 market over the full 2014–2025 sample.

Table 6. *Bai-Perron Multiple Structural Break Test Results*

Market	Breaks Detected	Break Dates	Result
THA	0	N/A	No structural breaks detected
IDN	0	N/A	No structural breaks detected
MYS	0	N/A	No structural breaks detected
PHL	0	N/A	No structural breaks detected
SGP	0	N/A	No structural breaks detected

Notes: Bai-Perron (1998, 2003) test applied to daily log-returns (conditional mean). Supplementary application to squared returns yields identical findings.

Source: Author's elaboration based on R software output.

The Bai-Perron test detects no statistically significant structural breaks in the conditional mean returns across all five ASEAN-5 markets over the complete 2014–2025 sample period. This suggests that the severe global disruptors under study—namely the U.S.–China trade war (2018–2019), the COVID-19 pandemic (2020), and the Russia–Ukraine conflict (2022)—were not accompanied by permanent shifts in the mean-generating process, with any disruptions appearing to be transient in nature, as also reflected in the volatility clustering and temporary correlation surges documented in Sections 4.2 and 4.3. The supplementary application of the Bai-Perron procedure to squared returns yields the same null result for the conditional variance. Jointly, these findings are consistent with full-sample structural stability of both the first and second conditional moments of ASEAN-5 returns, lending support to the validity of the DCC-GJR-GARCH parameter estimates reported in Tables 2 and 4.

Several important caveats should be considered when interpreting this null result. First, the statistical power of the Bai-Perron procedure to detect a given break depends on its magnitude, persistence, and location within the sample; transient but economically significant volatility episodes may not generate the sustained mean-shift required for the test to reject. Second, the use of daily-frequency returns may cause short-lived regime disruptions to be smoothed within the rolling window, rendering them statistically

indistinguishable from noise. Third, the distinction between permanent structural change—as measured here—and temporary but prolonged volatility spikes is methodologically important; the absence of detected breaks in the conditional mean does not preclude the possibility of more subtle changes in higher-order dynamics or in tail behaviour that lie beyond the scope of the Bai-Perron framework. These considerations underscore that the stability result, while reassuring, should be treated as suggestive rather than conclusive, and further validation via complementary approaches (e.g., recursive estimation, rolling-window parameters, or Markov-switching specifications) would be valuable.

4 DISCUSSION

4.1 Structural Volatility and the Asymmetric Effect of Adverse Shocks

The AR(1)-GJR-GARCH(1,1) models provide evidence consistent with the leverage effect (Glosten et al., 1993). Significant positive γ coefficients demonstrate that negative shocks amplify volatility more than positive ones, with an asymmetry ratio ranging from 1.3× in Singapore to 7.4× in Thailand. This aligns with Salisu et al. (2022) regarding emerging markets' vulnerability to elevated GPR. Singapore acts as an exception with a high ARCH coefficient (α = 0.2733) and a 239-trading-day half-life. This reflects its globally integrated nature, constituting a pivotal node in global risk transmission with longer-lived consolidation mechanisms (Banerjee et al., 2024; Zheng et al., 2023; Yang et al., 2021).

4.2 Conditional Correlation Dynamics and Regional Financial Integration

DCC-GJR-GARCH analysis indicates moderate integration among Thailand, Indonesia, Malaysia, and the Philippines (mean correlations 0.246–0.350). The highly persistent dynamics (a + b = 0.9999, half-life ≈ 27.5 years) are consistent with gradual long-run convergence (Engle, 2002), though this near-unity estimate should be interpreted cautiously as discussed in Section 4.3. The COVID-19 pandemic appears to have induced a sharp “correlation contagion” episode (Zheng et al., 2023; Banerjee et al., 2024), whereas the U.S.–China trade war had a more gradual impact, aligning with Elsayed and Helmi’s (2021) distinction between acute and protracted shocks. Singapore exhibits near-zero correlations with all regional peers, a pattern consistent with its response to global rather than regional dynamics, though further robustness analysis would be required to fully establish the structural nature of this divergence (Marangoz et al., 2025; Kannadhasan & Das, 2020).

4.3 Geopolitical Risk Transmission: Malaysia Versus Its Peers

Malaysia is the only market among the five for which the GPR index provides statistically significant linear predictive content for returns within the pairwise Granger framework (F = 2.684, p = 0.0028). This is consistent with the quantile-based differentiation of Enescu and Răileanu Szeles (2026) over uniform sensitivity (Huynh and Khoa, 2026; Kannadhasan and Das, 2020). Malaysia’s apparent vulnerability may stem from its commodity exports (crude and palm oil) and trade links, channeling GPR signals directly to the real economy (Caldara and Iacoviello, 2022; Zheng et al., 2023). This mirrors causality differences across markets, particularly the deep exposure of commodity-dependent economies (Bouri et al., 2018; Elsayed and Helmi, 2021). Singapore’s lack of Granger causality may reflect rapid, complex shock absorption due to global integration (Banerjee et al., 2024). Thailand’s borderline sensitivity (p = 0.1104) may reflect secondary transmission through tourism and FDI channels.

4.4 Structural Stability and Model Validity

The Bai-Perron test reveals no statistically significant structural breaks in conditional mean or variance across the five markets, despite major geopolitical shocks during the 2018–2022 period. This is consistent with the markets’ capacity for rapid absorption of geopolitical disruptions without permanent structural displacement (Nguyen et al., 2026; Antonakakis et al., 2018), though, as noted in Section 4.4, the inherent power limitations of the procedure and the daily-frequency smoothing of short-lived regimes warrant cautious interpretation. Subject to these caveats, the results suggest that the parameter estimates for

the complete 2014–2025 period is unlikely to be materially distorted by hidden regime changes, supporting the view that while dynamic correlations respond to political events, the underlying model structure broadly captures the relevant relationships (Elsayed and Helmi, 2021).

4.5 Study Limitations

Several methodological limitations qualify the findings of this study and should be borne in mind when interpreting results or extending the analysis.

First, the study relies on a single composite GPR index (Caldara & Iacoviello, 2022), which, while widely used, aggregates qualitatively distinct categories of geopolitical stress. Decomposing the index into its component sub-indices (geopolitical threats versus geopolitical acts) may reveal heterogeneous transmission patterns that are masked in the aggregate. Second, the DCC specification, while flexible, imposes parametric assumptions on the correlation dynamics and as discussed in Section 4.3, produces a near-unit persistence estimate that may reflect numerical boundary issues rather than true economic dynamics. Alternative multivariate volatility specifications, including ADCC, cDCC, or factor-GARCH models, would provide robustness to this concern. Third, the pairwise Granger causality framework captures only linear predictive relationships; non-linear dependencies, tail spillovers, and frequency-domain dynamics are not accommodated. Richer frameworks such as quantile causality, nonlinear causality tests, spillover indices (Diebold and Yilmaz, 2012), or TVP-VAR models would offer a more complete characterisation of GPR transmission across the ASEAN-5 bloc. Fourth, the analysis is subject to sample dependence: the 2014–2025 window encompasses specific geopolitical regimes, and results may not generalise to other time periods or market configurations. Fifth, the linearity assumption embedded in the AR(1) mean equation may cause the models to understate the impact of non-linear dynamics during extreme events. Sixth, potential omitted variables—such as commodity price cycles, domestic monetary policy shocks, and currency movements—could act as confounders. Finally, while the standard DCC-GARCH framework is well-suited for linear co-movement, it may not fully capture nonlinear contagion effects or sudden correlation jumps of the kind observed during crisis episodes. These limitations define productive avenues for future research.

5 CONCLUSIONS

This study examined the multidimensional impact of geopolitical risk (GPR) on the ASEAN-5 stock markets (Thailand, Indonesia, Malaysia, the Philippines, Singapore) from December 2014 to December 2025. Encompassing the U.S.–China trade war, the COVID-19 pandemic, and the Russia–Ukraine war, the analysis utilized AR(1)-GJR-GARCH(1,1), DCC-GJR-GARCH, pairwise Granger causality, and the Bai-Perron structural break procedure, yielding four empirical conclusions.

The Leverage Effect Across ASEAN-5 Markets The results indicate that the leverage effect is present across all five ASEAN-5 markets, with negative return shocks amplifying conditional volatility from 1.3× (Singapore) to 7.4× (Thailand). Given that standard symmetric models tend to understate downside risk, asymmetric specifications such as GJR-GARCH appear to be better suited for Value-at-Risk estimation, portfolio optimization, and regulatory stress-testing in this context.

Regional Financial Integration vs. Apparent Structural Divergence: DCC analysis reveals a notable contrast in integration patterns. The four emerging-market members exhibit moderate, persistent integration (average conditional correlations of 0.246–0.350; half-life ≈ 27.5 years, subject to the near-unity persistence caveats discussed above). Conversely, Singapore exhibits near-zero time-averaged correlations with all regional peers, a pattern consistent with its global financial centre identity and its responsiveness to international rather than regional dynamics. This characteristic suggests potential diversification benefits for within-region portfolios, though the near-zero correlation estimates should be interpreted with caution given the possible role of index composition differences, currency effects, and model specification sensitivity in generating this result.-Malaysia's Distinctive GPR Sensitivity Among the five markets examined, the Granger causality tests provide statistically significant evidence of linear predictive transmission from the GPR index to Malaysian returns only (F = 2.684,

p = 0.0028 at k = 10 lags; results are robust to alternative lag lengths k = 5 and k = 15). This finding is consistent with Malaysia's commodity-export structure (palm oil, petroleum) and its trade links with geopolitically sensitive partners. The absence of linear predictability in the remaining markets does not imply immunity to geopolitical risk; rather, Singapore may absorb shocks rapidly via efficient price discovery, while the others may involve non-linear or lagged transmission channels not captured by the pairwise Granger framework.

Regime-Preserving Resilience the Bai-Perron analysis detects no statistically significant structural break in the conditional mean or variance across the eleven-year sample despite three major disruptions. The results suggest the markets exhibited transient volatility and correlation surges without permanent regime alterations, lending support to the use of full-sample GJR-GARCH and DCC parameter estimates for long-horizon risk projections, subject to the power and specification caveats noted in the Limitations subsection.

Practical Implications:

- Portfolio Managers: May consider a combined ASEAN-5 allocation for within-region diversification, bearing in mind that correlation surges during crises (such as COVID-19) appear to be transient.
- Risk Officers & Regulators: Are advised to consider asymmetric GARCH-family models as baselines for stress tests and to monitor the GPR index as a potential leading risk indicator for Malaysia.
- Policymakers: Can cite the absence of detected structural breaks as indicative evidence of macroeconomic resilience to help attract long-term institutional investors, bearing in mind the limitations of the structural break test discussed above.

Avenues for Future Research Future extensions should include: (1) applying nonlinear or quantile-based causality tests to examine tail distributions, aligning with Kannadhasan and Das (2020) and Enescu and Răileanu Szeles (2026); (2) utilizing higher-dimensional DCC or factor-GARCH models incorporating non-ASEAN benchmarks (U.S., China, EU) to isolate true regional integration; and (3) decomposing the GPR index into threats versus acts, following Caldara and Iacoviello (2022) and Salisu et al. (2022), to precisely identify Malaysia's transmission mechanisms.

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RESPONSE TO WOJDA ON EVICTIONISM, PRO-LIFE, AND PRO-CHOICE

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ABSTRACT

Professor Wojda is not exactly a fan of my evictionist theory. He accurately explicates it but does nothing to obliterate it. Instead, he maintains that my own understanding of the pro-life and pro-choice theories that I mean evictionism to supplant is faulty. He also opines that my use of metaphors is problematic. I am exceedingly grateful to him for helping me publicize this perspective of mine. As he notes, I have been at it since 1977. I regret that I have not made virtually any headway at all in having this policy implemented, let alone widely discussed. With his important efforts, hopefully this state of affairs will soon end. I learned a great deal from Professor Wojda's paper and am grateful to him for it. My thought, hope, is that this correspondence on this complex matter will enable both of us, together, to shed more light on it than would otherwise be the case.

1 INTRODUCTION

Wojda (2025) starts off his in many ways splendid essay with a reprise of metaphors. He gives numerous examples thereof.

He is kind enough to mention that I "(Block 1977), gives us a few more [metaphors]: the woman as 'landlord,' embryonic/fetal life as 'intruders,' 'squatters,' even 'trespassers' (though, oddly enough, never 'renters'), and of course, the act of abortion as itself an 'eviction.'"[1]

This distinguished scholar suggests, as a presumably friendly amendment, that while I am at it, I should also employ "landlord" as a metaphor. I cannot see my way clear to adopting this nomenclature regarding the pregnant woman. For while the landlord agrees to allow a tenant to occupy her premises, the latter never does any such thing. Wojda also finds it "oddly enough" that I never equate the fetus with "renter." But the same considerations apply here. A renter, whether of a car, or a lawnmower or a residence

[1] All of my mentions of Wojda are to this one article of his (2025). Unless otherwise mentioned, I do not include his footnotes.

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or anything else of the kind, has *agreed* to use the property in question for a fixed duration. Nothing of the kind can apply to the pre-born child. No agreement whatsoever takes place in this context.

Moreover, I object to this general thrust of his. I am not at all using terms such as "homeowner," "trespasser," "owner of her body," as mere metaphors. I mean them quite literally. Here are a few examples of metaphors:

- Life is a rollercoaster.
- She has a heart of gold.
- The classroom was a zoo.
- He is a walking encyclopedia.
- I could eat a horse
- She is an open book
- He wears his heart on his sleeve
- You're building castles in the air
- I was a million miles away
- Splitting hairs

What do all these have in common? They are metaphors. They are wild exaggerations! Not a single one of them is literally or even conceivably true. Hearts are in bodies, not on sleeves. If yours was literally on your sleeve, or made of gold, you'd be dead. Being a million miles away is just plain silly; our highways simply do not stretch that far, nor can our airplanes traverse such distances. We can surely and easily distinguish between life and a rollercoaster.

In very sharp contrast by my use of words like "intruder," "squatter," 'trespasser" to describe the unwanted fetus is meant precisely, exactly, literally. I am not saying that the pre-born infant is "like" these descriptions. I mean them to apply quite literally. It would be akin to describe this very young human being as weighing in at 6 ounces, or of a height of 3 inches. Wojda seriously misunderstands my eviction in this regard since he avers, they are merely metaphors.

Even more egregious is his claim that the act of abortion is a metaphor for eviction. Nothing could be further from the truth. Not only do I not regard abortion as like, or similar, or resembling, abortion, as would be true for a metaphor, I see them, if anything, as almost polar opposites. In my view, abortion is a two-stage phenomenon. It consists of two separate and distinct aspects: first, evicting the fetus from the womb and then, second, the outright murder of the very young baby.

This is not a good opening on Wojda's part for a criticism of evictionism. It he does not so much as know exactly what it is, it is difficult to see how his criticism of it can be valid.

Our author's next critique of my view is this: "… evictionism has all the appearances of an effort to rescue, not human life, but libertarianism from perishing on the messy shoals of human experience." This is motive mongering, and somewhat improper in scholarly exegeses. The academic community should not at all care what my purposes or intentions are in promoting evictionism. The only and sole issue should be, is this thesis, correct, truthful, accurate, justified?

But since he raises this issue, allow me to unburden myself about my goals. Yes, certainly, one of them is indeed to "rescue human life." Despite the fact that there are some individuals whose actions I strongly disapprove of[2] I am still very much a strong supporter of our species. All my best friends are members of this category, plus my wife, children, grandchildren and other relatives.

Do I also want to promote libertarianism in this endeavor? This is certainly true. It is the last best hope for the flourishing, even the preservation, of the human race. Further, evictionism is entirely based upon libertarian theory, particularly its non-aggression principle[3] and private property rights. I do not wish to return the "favor" and enquire into Wojda' motivation in trying to besmirch the only correct solution to the abortion controversy.

Here is Wojda's next swing at the baseball: "While it wouldn't be the first theory to be so vanquished, given its presuppositions, libertarianism seems particularly ill-suited to address, much less resolve contemporary debates about abortion…. as a form of human relationship, pregnancy is *sui generis.* Gestation is a factual situation for which

[2] Hitler, Stalin, and Mao come to mind in this context

[3] For a critique of the NAP see Huemer (2019). For a defense Block (2013)

our ordinary moral and legal categories of fully independent beings are ill-suited."

I beg to differ. I respectfully disagree with the characterization of pregnancy as sui generis. This is not the first time in the history of the world in which there was a dispute between two people over conflicting property rights. I don't know about "our ordinary moral and legal categories," but I do know a bit about the John Lockean type theories of property rights, ownership of the first homesteader, upon which libertarianism is predicated.[4] I know enough to categorically reject this notion of legal uniqueness regarding the abortion issue.

Our author continues his intellectual onslaught: "In other words, as helpful as the image of ourselves as owners of our bodies may be in some instances (e.g., resisting arbitrary governance, whether public or private), when it comes to pregnancy and childbirth, the libertarian picture is seriously flawed. In sum, if evictionism is the best that libertarians can offer on the disputed question of abortion, then, like many other theories before it, it may be time to admit defeat and move on." Is the libertarian picture seriously flawed? We shall soon see about them apples.

2 WOJDA'S CHARACTERIZATION OF EVICTIONISM

In this section of his paper, my critic brilliantly expostulates on the theory of evictionism. And not only that. He almost perfectly articulates my critiques of both the pro-life and the pro-choice, from the evictionist point of view. He offers such an insightful, succinct and even brilliant summary that I am inspired by him to even the more support evictionism. My thought at this point is How can he then reject this airtight solution to the abortion controversy?

I have only two very minor additional reactions to this tour de force of his. First, I am grateful to Wojda for pointing out the facts about the date of viability for a fetus outside of the womb. However, these numbers are continually changing, as medical technology continues to improve. It seems simpler to stick to the old trimester system than to continually update the week of viability. Then, there is sheer laziness on my part, with regard to a factual situation that does not at all impinge upon the debate

Second, regarding two swimmers clutching on to a piece of wood that can only save one of them from drowning. My view is that if one of them is the owner of this piece of flotsam, or reaches it first and then homesteads it, the nod goes to him. If there is a tie in race to grab it, then only a coin flip will suffice. States Wojda, "Oddly, we are supposed to imagine ourselves as sea-captains with the power to shove one person off the wood, but not ourselves also struggling to survive. Sea captains? Not a bit of it. Rather, we are viewing this in the role of political philosophers, hopefully, libertarians.

3 A CRITIQUE

We now arrive, supposedly, at the crux of this scholar's critique of evictionism. I say supposedly, because in this very long section of this paper, not only does this author not lay a glove on evictionism, he does not even try to do so. This is very strangest critique of evictionism I have ever seen, and I have seen many.[5] What does he do, here, instead of criticizing my position? He claims that my understanding of the other two contending theories, pro-life and pro-choice, is wanting.

For example, he states: "On a superficial level, evictionism seems an appealing alternative to both the pro-life and the pro-choice positions, but only in the versions of those two positions that Block offers. Upon closer inspection, it is not clear that his description of both the pro-life and pro-choice positions hasn't given us straw men, in this

[4] Block, 1990, 2002A, 2002B; Block and Edelstein, 2012; Block and Nelson, 2015; Block and Yeatts, 1999-2000; Block vs Epstein, 2005; Bylund, 2005, 2012; Gordon, 2019A, 2019B; Grotius, 1625; Hoppe, 1993, 2011; Kinsella, 2003, 2006A, 2006B, 2007, 2009A, 2009B, 2009C; Locke, 1948; McMaken, 2016; Paul, 1987; Pufendorf, 1673; Rothbard, 1969, 1973, 32; Rozeff, 2005; Watner, 1982

[5] Akers, 2012A, 2012B; Davies, 2012; Feser, 2004; Goodwin, 2014; Parr, 2011, 2014; Mosquito, 2014, 2015; Rothbard, 1978; Sadowsky, 1978; Shaffer, 2012; Rothbard, 1978; Vance, 2008, 2012; Wisniewski, 2010A, 2010B, 2011, 2013. Here are some of my responses to the foregoing: Block, 2010A, 2010B, 2011A, 2011B, 2011C, 2014; 2017, 2025A, 2025B, 2025C, 2025D, 2025E

case two extreme versions, neither of which would be acknowledged as fair representations of those positions by the many of those who profess to hold them."

But I am not at all interested in whether evictionism is "an appealing alternative to both the pro-life and the pro-choice positions," and to be told it is not because of my erroneous understanding of the other two. I was hoping for, expecting, rather to be informed regarding the errors of evictionism. This was not at all forthcoming. I felt like saying, hey, I'm over here, come get me, stop ignoring me.

Instead, Wojda waxed eloquent about all sorts of non-evictionists.[6] For example, Paglia mentioned no fewer than 11 times, Wolf (also 11), Camosy (13). Let us stipulate, arguendo, that what I know of pro-life and pro-choice could not fight its way out of the proverbial wet paper bag. This, still, in no way obviates the virtues of evictionism, which I thought was the entire point of his essay. My error. I was tempted to claim that the title of his paper, "Evictionism, Pro-Life and Pro-Choice: A Response," verged on fraud. But, in the event, I couldn't bring myself to make this charge. For he did indeed "respond" to evictionism, with a sterling summary, and certainly mentioned, all too often, my supposed misunderstanding of the latter two options. So, even though there was not a word of criticism of the former, when you are ready willing and able to respond and don't get any, all sorts of whining rise to the fore.

What, then, are my misperceptions of pro-choice?

It would appear that my error consists of the fact that I do not fully appreciate that "Not all those who describe themselves as such deny that abortion is the taking of a human life." I plead guilty to this "oversight" of mine. I do not, indeed, focus on such folk who mislabel themselves. Rather my target is limited to those pro-choicers who do take this position. Why do I do this?

This is because I wish to intellectually obliterate the pure pro-choice position which maintains that the fetus has no more rights than an appendix. I fully realize that there are some pro-choice compromisers, fair weather friends of this viewpoint, who do not go all the way to the pro-choice doctrine; who compromise with it, and yet claim to support this perspective.

If my misconstrual of pro-choice is serious, I am far more guilty when it comes to pro-life, he avers: "But if the shortcomings of evictionism's account of the pro-choice position are significant, they pale in comparison with its description of the pro-life position, which it must be stated border on parody."

Where did I go wrong here? Wojda instructs me: "Are there pro-life voices that take the moral worth of embryonic and fetal human life to be absolute? That hold the sanctity of fetal life to be such that it overrides all other goods and imposes on us—on pregnant women and medical professionals—a perfect duty to respect it regardless of the cost? To be sure, there are. Are these voices the pro-life majority? Hardly."

I confess. I admit it. I do not give a fig for majority vote. I do not care much if there were not a single solitary supposed pro-lifer who held the pure version of this philosophy. That and no other is my target, and I make no apology for sharply criticizing this view, rather than one of its unimportant compromises. If pro-lifers wish to compromise with their own supposed position, and take on some aspects of evictionism, I welcome them for coming at least partially to their senses. But this will not deflect me in the slightest from critically addressing what I regard as a deeply flawed position.

States Wojda: And "… it is nothing short of astounding that Block's argument gives hardly any attention to this [Catholic] tradition or any religious tradition, for that matter." All I can say in response is that I welcome folks who represent this perspective to give some "attention" to evictionism. Also, in a critique, it is usual to reprimand writers for what they actually say, not for what they fail to say. I could with equal justice upbraid Wojda for not mentioning at all, totally ignoring, what Locke and other libertarian

[6] Not that there are all that many after all, I must admit. But then at one time in our history there were precious few who maintained that the earth was round or that it revolved around the sun. Still, he could have spared at least a few words about this doctrine, not my supposed failure to understand its two competitors.

homesteading theorists had to say about the just generation of property rights.

While we are on the subject of irrelevancies I have ignored, what are we to make this statement which my critic approvingly quotes? "The first commandment of real feminism … is: when in doubt, listen to women. What she hears is the same struggle many experiences when faced with similar, agonizing choices of whether to choose self over another." Does this sort of thing really belong in a scholarly journal? How would read if we reversed matters and put men, or whites, or blacks, instead, in the catbird seat? Not too well. Let me just say that I welcome all critics of evictionism, feminists, Catholics, all others, to consider changing their views and embracing the one and only correct theory, evictionism.

Wojda is pleased to characterize my targets as "the simplified descriptions of the pro-life and pro-choice positions." I hereby call upon Occam's Razor as a refutation of this jibe.

My rendition of pro-life and pro-choice are, admittedly, extreme versions of both. Yes, many people hold positions not 100% in accord with how I have depicted each.

Consider the debate between pacifists and non-pacifists. Some people holding the former position might make an exception in one or two cases. Ditto for warmongers. They, too, do not wish to fight everyone without exception. Suppose there was an intermediate position between the two. Would it behoove the analysist to focus on the extreme positions in each case, or on the compromisers? Of course, the former is correct. Ditto for the debate between communists and free enterprisers. Clarity alone requires commentators to consider the extremes in each case.

This is true even if there were not a single solitary person on the planet who subscribed to either position fully. This is part and parcel of the ceteris paribus tradition. The human mind is limited. We cannot consider every single gradation between pacifism and its opposite, between socialism and capitalism, nor, either, between pro-life or pro-choice. My difficulty with Wojda's critique is that he is in effect muddying up the waters. It is extremely difficult to make any progress in coming to grips with the abortion controversy with only three clear-cut alternatives: pure pro-life, pure pro-choice and evictionism.[7] Instead, he wants to introduce numerous gradations, which only make it more difficult to analyze.

Consider an example of ceteris paribus type of thinking from the realm of economics. I want to maintain that in equilibrium, a minimum wage law will necessarily unemploy all workers with a discounted marginal revenue product below the level stipulated by this legal enactment. One problem with this absolutely true statement is that we are never, ever, in a state of full equilibrium. Another is that we can never attain ceteris paribus conditions either. Something is always changing in the real world: new discoveries, new innovations, new markets, changes in the prices and quantities of substitutes and compliments. If we are to make any sense whatsoever of the claim mentioned above, given our limited human intellectual capacities, we must sweep all this aside at least in our mind's eye, and function, only, based on a pure situation.

This is exactly what I have long been doing with evictionism, that Wojda so definitively rejects. He brings in Camille Paglia, Charles Camosy, Naomi Wolf, Matthew Desmond, religious considerations, etc. This to be sure, is interesting. It enhances our deliberations. But it complicates them. It takes our eye off the proverbial ball: is evictionism correct or is it not? What are the assets and debits of pure pro-choice and pure pro-life? I appreciate my debating partner's interest in making our efforts more realistic by bringing it into contact with the extant literature he unearths. But I cannot think it a valid criticism of my "simplistic" approach.

Next, this eminent philosopher brings into the analysis the concepts of "killing versus allowing to die," "*aiming* at death" and "material performance."

Indubitably, mens rea is important. No, scratch that. It is crucial in the determination of criminal behavior. However, it simply must be accompanied by something illegal to be even

[7] I add the word "pure" here since I appear to be the only advocated of this position, and I treat is in a manner pure as the driven snow, with no compromises whatsoever.

relevant to the law. According to that old aphorism, if mere thoughts counted, we would all be in jail. Thus, contrary to Wojda, there is nothing per se legally wrong with "aiming at death." A pregnant woman who terminates a pregnancy before the fetus reaches viability knows full well that the fetus will die. She might well regret this eventuality, but it cannot be denied that she is also "aiming at death." She is both killing and allowing to die, and neither should be a legal problem since she is justified in undertaking both.

The next point raised by my interlocutor is this statement of my debating partner's: "Block himself recognizes this in his admission that, prior to viability, any removal (eviction) of the fetal human being from its domicile will result in its death. If such removal is justified, as Block argues it is at any stage of the pregnancy, then it can only be under the description of ceasing to aid, as he takes killing to be always wrong.

But I do not at all "take … killing to be always wrong." Surely, for most people, killing an attacker in self-defense is not always wrong.8 However, for the libertarian, morally wrong is of little interest. The key concern of this philosophical viewpoint is not all of morality, but only a small bit of it: what is just law. So, would killing always be illegal? Certainly not, in the case of self-defense. But this is precisely the justification in the case of evictionism. The pregnant woman is defending her property, her person, against the incursion of an unwanted fetus, literally a trespasser or squatter.

I also find wanting this statement of this scholar who considers:

"… the different ways in which one might evict an embryonic/fetal human being from the womb. The most common surgical method of abortion in the first trimester is suction dilation and evacuation. It would be difficult, if not impossible, to describe such a procedure as a ceasing to aid the embryonic/fetal human being. But is such a procedure always to be described as aiming at death, i.e., always a morally unjustifiable taking of a human life. To this question the Catholic tradition, drawing most famously on Aquinas' argument in the Summa Theologiae (II-II.64.7) about the permissibility of killing in self-defense, has relied on the distinction between direct versus indirect killing. While all direct killing (aiming at death) is prohibited, indirect killing can be justified as a last resort or for proportionate reasons."

My difficulty with this analysis is that, at least on the assumption that the very early fetus can feel no pain, and, also, cannot possibly live outside of the womb, that these practices are entirely justified. This is so based on the right of the owner of any property, most certainly including property in her very person, to evict even an innocent intruder, even though it eventuates in his death. Either we support private property rights, or we do not support private property rights, in general. And to be specific, either we support private property rights in ourselves, or we do not support private property rights in persons, including women. This issue raises fundamental questions about the foundations of civilization

4 CONCLUSION

Wojda offered not only an accurate rendition of evictionism, but also a highly sympathetic one. I expected that he would either congratulate me on this, become an enthusiastic supporter of this vision, or, at the very least, criticize it. He did neither. Instead, he spent more of his time and effort criticizing my understanding of the two alternatives to it, pro-choice and pro-life, as being too simplistic. Perhaps in a future article he will explain why he does or does not embrace evictionism.

Let me end on this note. According to my learned friend: "It's worth noting here that, despite Block's contention that 'evictionism' is 'less known' than either the pro-life or pro-choice positions, a version of his argument, i.e., abortion as 'ceasing to aid' rather than 'killing,' has been well-known for many years. It's fundamental to Thomson's famous analogy, of course…."

I beg to differ. The cite for Thomson's famous essay is this: Thomson, Judith Jarvis. 1971. "A Defense of Abortion." Philosophy and Public Affairs 1(1), 47–66. That is, she defends abortion; I strongly reject Thomson's defense of abortion. To see the sharp difference between me and Thomson, one that seems to have escaped Wojda's attention, see Block (2018).

[8] The only exceptions would be extreme pacifists

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REJOINDER TO HOPPE ON REACTIONARY LIBERTARIANISM

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ABSTRACT

Professor Hans-Hermann Hoppe gave a public speech that is filled with errors, misrepresentations, and fallacies. He takes on several main subjects: monarchism, Israel, the Frankfurt School, Donald Trump, Volodymyr Zelenskyy, and Javier Milei. This author views all three through the eyeglasses of libertarianism and misunderstands them all. Is he an anti-Semite? He makes many statements that can be construed as such. Read what he has to say and decide for yourself. It cannot be denied Hoppe is regarded by some as a world class libertarian theoretician. His work in democracy and monarchism; in defense of private property rights; his contribution to argumentation ethics; his arguments in behalf of anarcho-capitalism, are usually presented to sustain this stance. Those who support him do so on the grounds of his views on Austrian economics in general, and praxeology in particular. However, when many of this author's premises are analyzed, they do not pass rigorous tests. The subjects treated in the present work are an example of this phenomenon.

REJOINDER TO HOPPE ON REACTIONARY LIBERTARIANISM

Hans-Hermann Hoppe gave a lecture titled "Considerations and Reflections of a Veteran Reactionary Libertarian" at the annual libertarian conference held by the Mises Institute (LewRockwell.com, 2025). Besides his clearly visible anti-Semitic inclinations scattered throughout the lecture, the veteran libertarian

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made numerous historical blunders that simply cannot go unaddressed or unrebuffed. This rebuttal argues that Hoppe's stance is pseudo-historic and pseudo-scientific, built upon selectively chosen examples and ideological biases rather than on a comprehensive and nuanced understanding of history. Through meticulous historical evidence and analysis, we demonstrate that his generalizations are oversimplified, unsupported, and inevitably collapse under scrutiny.

From the very first moments of the lecturer's performance, any thinking individual should have felt sufficiently puzzled to raise a few obvious questions. Yet, curiously enough, neither the esteemed professors in attendance nor their otherwise eager graduate students, not to mention the undergraduate students, bothered interrupting this spectacle with queries, neither during nor at its conclusion. Apparently, the lecturer's overwhelming aura of authority ensured his narrative remained entirely unchallenged.

Yes, we acknowledge this speaker's prominent role in shaping anarcho-capitalism, but let's be perfectly clear: This prominence does not grant him carte blanche to mangle historical interpretations. He's certainly no historian, and his simplistic method of categorizing historical events firmly proves this point. His lecture might well have quietly slipped into oblivion—noticed by no one beyond the fifty or so present—but the good folks at the Mises Institute, in their infinite wisdom, decided the world deserved to witness this "masterpiece" on YouTube.

Since apparently nobody present dared to ask Hoppe critical questions, we'll bravely shoulder this responsibility ourselves. Who exactly are "we"? Just three Jews representing three different generations, born in three countries—the USA, the Soviet Union, and Argentina—all supporting Israel. Surely, some observers might quickly leap to the conclusion that this critique is yet another nefarious global Jewish conspiracy aimed squarely at poor German/Turkish Hoppe.

Let's remind ourselves, however: Genuine scientific research rests upon three fundamental foundations—observation, logic and classification. Hoppe, in his infinite creativity, proposes classifying wars as either "Monarchical" or "Democratic." Hoppe's analysis contrasts monarchical wars, which he describes as limited, pragmatic, and easily resolved, with democratic wars, which he portrays as ideological, involving entire populations, and concluding with vindictive peace treaties. He claims this distinction reflects fundamental differences in governance: Monarchs, reliant on their own resources, wage restrained conflicts, while democracies, driven by public sentiment, pursue total wars with punitive outcomes.

Hoppe cited the Napoleonic Wars and the Vienna Congress of 1815, claiming that these wars were resolved fairly by "gentlemen," even sparing Napoleon's life. In contrast, he argued that democratic wars result in vindictive peace treaties, such as those following the American Civil War and World Wars I and II. This distinction, rooted deeply in his usual and not original critique of democracy, frames monarchies as inherently restrained and democracies as prone to excess.

But what evidence, what historical records did he draw upon to concoct such a tidy schema? To answer that, one doesn't need a Ph.D.; a decent grasp of middle-school history would suffice.

Monarchical Wars: Not Always Limited or Pragmatic

Hoppe's portrayal of monarchical wars as limited, pragmatic, and easily resolved does not withstand historical scrutiny. Many monarchical conflicts were deeply ideological, extended over decades or centuries, involved broad societal participation, and concluded with punitive treaties—precisely the features he attributes exclusively to democratic wars.

The Thirty Years' War (1618–1648) is a prime example of a monarchical war driven by ideology rather than mere territorial pragmatism (Britannica Editors, 2026, February 16). Originating as a religious conflict between Catholic and Protestant states within the Holy Roman Empire, it escalated into a European-wide struggle involving monarchies such as France, Spain, Sweden, and Austria. The ideological stakes of control over religious authority and the soul of Christendom fueled its intensity. Monarchs like Ferdinand II of Austria and Gustavus Adolphus of Sweden framed the war as a divine mission, rallying support through appeals to faith.

Far from being limited, the war's devastation was staggering. Germany's population plummeted from approximately 21 million to 13 million, with some regions losing up to 50% of their inhabitants due to combat, famine, and disease (Heinz, et. al., 2023). Entire towns were razed, and economic collapse followed, with trade routes disrupted and agricultural production greatly halted. This was not a restrained territorial dispute but a protracted ideological clash, lasting three decades and directly contradicting Hoppe's claim that monarchical wars end quickly due to resource constraints. The war's scope and destructiveness rival the "total wars" he associates with democracies, exposing the pseudo-historic nature of his generalization.

The Hundred Years' War (1337–1453) between England and France further undermines Hoppe's thesis (Britannica Editors, 2026, February 13). Spanning an exhaustive 116 years, this conflict arose from dynastic claims but rapidly evolved into a broader ideological struggle fueled by burgeoning national identities. Monarchs sustained this prolonged war through innovative financing methods, including heavy taxation, international loans from Italian bankers, and the systematic plundering of occupied territories. Brutal battles such as Crécy (1346) and Agincourt (1415), coupled with prolonged sieges like Orléans (1428–1429), resulted in devastating casualties, widespread suffering, and significant economic ruin.

Hoppe argues rather simplistically that monarchical wars are short because monarchs bear the financial burdens personally. Yet, English and French kings adeptly circumvented such constraints by mobilizing resources across their realms, cleverly rallying nobles and commoners alike through appeals to patriotism and divine right. The war's unprecedented duration and brutality, marked by village destruction, famine, and mass displacement, flatly contradict Hoppe's romanticized notion of limited monarchical conflicts. The ideological undertones of national honor and legitimacy further erode his supposed clear-cut division between monarchical pragmatism and democratic ideological fervor.

Hoppe's assertion that monarchs, unlike democracies, do not rely on mass public support for warfare collapses entirely when confronted with the Crusades (1095–1291). Initiated by Pope Urban II and led by monarchs such as Richard the Lionheart of England and Louis IX of France, these campaigns were unmistakably ideological, and framed explicitly as holy wars to reclaim Jerusalem from Muslim rule. The relentless religious propaganda promising salvation and indulgences galvanized not only knights but also peasants, clergy, and even children, tragically exemplified by the ill-fated Children's Crusade of 1212 (Williams, 2023).

The Crusades spanned two centuries, absorbing vast resources and mobilizing entire societies through feudal levies and ecclesiastical taxation. Such extensive societal mobilization mirrors precisely the mass engagement Hoppe attributes almost exclusively to democratic wars. The deep ideological fervor rooted in religious zeal drove sustained participation, undermining his claim that monarchical wars lacked ideological intensity or widespread public involvement.

These examples clearly illustrate that monarchical wars often bore ideological motivations, were prolonged and often involve large-scale societal mobilization. Hoppe's daydreamed and overly simplistic views systematically ignore this overwhelming historical evidence, rendering his stance undeniably pseudo-historic.

Furthermore, Hoppe's glowing portrayal of monarchical peace treaties as inherently reasonable conveniently overlooks historical evidence that directly contradicts his idealized narrative. Numerous monarchical treaties, far from being generous acts of noble magnanimity, were explicitly punitive, strategically designed to weaken and punish defeated monarchies.

For instance, the Treaty of Westphalia (1648), ending the Thirty Years' War, starkly contradicts Hoppe's rosy depiction (Britannica Editors, 2026, January 23). While it indeed laid foundations for modern state sovereignty, the treaty imposed significant penalties on defeated powers. The Holy Roman Empire lost substantial cohesion, France acquired Alsace, and Sweden gained territories like Pomerania—all explicitly designed to weaken Habsburg dominance.

The Treaty of Utrecht (1713), which concluded the War of the Spanish Succession, serves as a good example too (Downey & Maypole, 2023). Rather

than providing a magnanimous resolution, it harshly stripped Spain of strategically vital territories, including Gibraltar and Minorca to Britain, and the Spanish Netherlands to Austria; thus, crippling Spain's power and greatly diminishing its international influence. This treaty was less about restoring peaceful relations and more about victoriously redrawing Europe's political map to benefit the winning monarchies, revealing a clear intention to dominate rather than reconcile.

Similarly, the Treaty of Paris (1763), which ended the Seven Years' War, was exceptionally severe towards France (Boundless World History, n.d.). The treaty imposed heavy territorial losses, forcing France to relinquish vast colonial holdings, including Canada and territories in India, significantly weakening its global influence and imperial ambitions. This wasn't an example of restrained monarchical fairness but rather a calculated and ruthless power play by victorious monarchies, aiming explicitly to punish and contain French power.

Even the Treaty of Aix-la-Chapelle (1748), concluding the War of the Austrian Succession, was punitive, compelling Prussia to cede crucial territories to curb its rising influence and ambitions Britannica Editors, 2025, October 11). Such harsh settlements clearly illustrate that monarchical treaties often mirrored the very punitive traits Hoppe exclusively attributes to democratic agreements, further demolishing his oversimplified binary classification.

Thus, historical evidence abundantly demonstrates that monarchical treaties, far from always being reasonable and restrained, frequently embodied calculated strategies of dominance, punishment, and power redistribution. This starkly contradicts Hoppe's simplistic portrayal and further highlights the intellectual bankruptcy and historical inaccuracies at the core of his thesis.

Democratic Wars: Not Uniquely Ideological or Vindictive

Actually, the notion of 'democratic war' should be placed in quotation marks, as such a classification is absurd on two points.

1. As Natan Sharansky (yes, another Jew) argued in his book *The Case for Democracy: The Power of Freedom to Overcome Tyranny and Terror* (2004), liberal democracies are less likely to go to war with one another. Truly democratic wars are a historical rarity.
2. Most wars classified by Hoppe as democratic were, in fact, initiated by various authoritarian and totalitarian regimes. The fact that a democratic coalition won should not make the war itself 'democratic.'

Nevertheless, we will use his nomenclature for clarity.

Hoppe argues that democratic wars inherently embody ideological fervor, mobilize entire populations, and inevitably end with vindictive peace treaties. However, a nuanced historical analysis reveals a far more complicated reality: 'Democratic wars' often encompass mixed motives, involve monarchies or totalitarian regimes, and can lead to constructive outcomes, thereby severely undermining his generalized assertions.

The American Civil War (1861–1865), one of Hoppe's own examples, perfectly demonstrates a blend of ideological and pragmatic elements. While undeniably driven in part by the ideological divide over slavery (Northern abolitionists fiercely opposed Southern defenders of slavery) the Union's primary initial objective was the preservation of territorial integrity, mirroring the territorial motivations frequently seen in monarchical conflicts. President Abraham Lincoln's Emancipation Proclamation (1863) served strategic purposes, undermining Confederate power by freeing slaves within rebel territories, thus bolstering Union morale and international support.

Lincoln initially proposed lenient peace terms through his Ten Percent Plan (1863), seeking rapid reconciliation rather than revenge. It was only after his assassination in 1865 that harsher Reconstruction policies emerged, driven by Radical Republicans who sought political leverage and retribution against Southern elites. These context-specific shifts clearly refute Hoppe's simplistic claim that democratic wars invariably conclude vindictively.

Furthermore, Hoppe cites World War I (1914–1918) and World War II (1939–1945) as quintessential examples of democratic wars

culminating in vindictive peace agreements. Yet, both conflicts involved complex dynamics beyond simple ideological motivations. World War I saw significant participation by monarchical and imperial powers such as Nicolas II Russian Empire, Germany under Kaiser Wilhelm II, Austria-Hungary, and the Ottoman Empire, all driven by expansionist ambitions, nationalism, and militarism.

Hoppe maintains that World War I "… ended as an increasingly democratic war, especially after the Americans entered and the Russian Revolution broke out, the Tsar was executed…" But this is more than passing curiously. Russia after 1917 was "democratic" forsooth? This will come as shocking news not only to the suffering population, but also to the dictatorial communists. Lenin, as far as the historical record shows, was not ever elected to any office by the Soviet Populace, nor did he require such democratic legitimacy to implement the proletarian dictatorship envisioned in the Marxist framework.

Contrary to the mainstream point of view, we do not consider Germany the sole guilty party in WWI. By the traditions and diplomatic norms of the time, the assassination of Archduke Franz Ferdinand and his wife was used as a valid pretext for military operations. A deeper motivation behind the decision of the allied cousins in Great Britain and Russia to wage war may have been to contain the growing intellectual, industrial and technological power of the Central European states, particularly Germany, which was beginning to challenge the dominance of the colonial empires.

The harsh Treaty of Versailles (1919), which imposed severe territorial and economic sanctions on Germany, resulted not from democratic vengeance alone but from a combination of security concerns, economic interests, and complex international politics.

World War II, initiated by totalitarian regimes of Nazi Germany and the Soviet Union with their infamous partition of Poland also included monarchies such as Imperial Japan and Fascist Italy. The Allies, composed of democratic nations like the United States and Britain, alongside communist Soviet Union (since 1941) and various other mixed political formations, were driven by a blend of ideological, economic, and geopolitical motives. During this war, the scale of atrocities committed by the Germans, along with the immense death toll and suffering they inflicted, was so great that material retribution alone was deemed insufficient; only a complete purification of national conscience and values - was considered necessary.

The complexity and diversity of democratic wartime motivations and outcomes stand in stark contrast to Hoppe's simplistic dichotomy, thus revealing the pseudo-scientific basis of his claims.

Moreover, Hoppe conveniently ignores cases where democratic nations engaged in limited conflicts with clearly pragmatic resolutions, directly contradicting his oversimplified framework.

In addition, democratic conflicts have sometimes catalyzed constructive geopolitical changes, underscoring their potential for pragmatic and forward-looking outcomes. The democratic-led Marshall Plan following World War II serves as a prime illustration, providing unprecedented economic support to rebuild war-torn Europe, including defeated Germany. This practical approach not only ensured European stability but also strategically countered Soviet influence, demonstrating a level of foresight and practicality completely missing from Hoppe's caricature of democratic warfare.

Thus, when carefully analyzed in their proper historical contexts, both monarchical and democratic wars exhibit complexities and contradictions that Hoppe's overly simplistic classifications fail spectacularly to capture. His sweeping generalizations, far from scholarly, reveal more about ideological bias than any genuine understanding of history, further undermining the intellectual credibility of his entire argument.

Hans-Hermann Hoppe's overly simplistic distinction between monarchical and democratic wars stands exposed as a pseudo-historic and pseudo-scientific fabrication, one built more on his flavor of libertarian dogma than any genuine historical scholarship. Monarchical conflicts such as the Thirty Years' War, the Hundred Years' War, and the Crusades clearly illustrate that monarchies were perfectly capable of waging protracted, ideological, and devastating wars that ended in harshly punitive peace treaties.

Meanwhile, democratic (in his classification) wars such as the American Civil War and World War II reveal complexities, mixed motives, and outcomes far more nuanced and occasionally constructive than Hoppe's cartoonish portrayal admits.

Moreover, peace treaties—whether Vienna, Versailles, Utrecht, or Paris—consistently reflect geopolitical context, strategic calculations, and prevailing economic conditions rather than simplistic government typologies. Hoppe's selective interpretation of historical events conveniently ignores ample evidence that blurs the rigid categories he proposes. Ultimately, his analysis is revealed as little more than an ideologically-driven narrative, devoid of rigorous historical accuracy or intellectual integrity.

By carefully examining historical facts in their proper contexts, this rebuttal dismantles Hoppe's superficial dichotomies and affirms the intellectual bankruptcy underlying his arguments. Hoppe's argument is historically inaccurate and grossly oversimplified. It cherry-picks examples specifically to fit his narrative while blatantly ignoring the complexities of historical conflicts.

1.1 Patents

Hoppe has undoubtedly made many and important contributions to libertarian theory. However, he has slipped, and slipped badly, when he asserts "the Americans stole all the patents from German industries." Even assuming this generalization is true (which we do not for a minute do), it ignores a basic libertarian perspective on patents as such. This is not the time or place to go deeply into the case for why patents are not legitimate property titles, and, hence, cannot be stolen in the first place. Rather, they should all be rescinded.

Briefly, the case is that they consist of ideas, and ideas are not scarce limited phenomena such as houses, cars, real estate, etc. Pythagoras invents the theorem named after him. Jones, "steals" this idea from the creator. But Pythagoras still "has" this idea in his possession. In contrast, if Jones robs Pythagoras' bicycle, this mathematician no longer has it in his possession. Similarly, bicycle ownership has no end point. This mode of transportation can be handed on to children and grandchildren, ad infinitum. Patents are typically time limited, unlike any other property. Also, each and every word in every language was invented by someone. If patents were allowed for verbiage, and there was not time limitation imposed, no one could use words in speech. A position that cannot even be articulated is not a very sound position. For an in depth libertarian critique of patents, see (Boldrin & Levine, 2008; Block, 2014, 2020; De Wachter, 2013; Kinsella, 2001, 2008, 2012; Long, 1995; Menell, 2007A, 2007B; Mukherjee & Block, 2012; Navabi, 2015; Palmer, 1989). This is all libertarianism 101. Hoppe should have known better.

1. Anti-Semitism?

The word "Jew" appears no fewer than ten times in the course of Hoppe's presentation. The phrase "chosen people," once; ditto for "Judaism," for a total of twelve mentions. This, perhaps, is barely understandable in the section of his talk where he discusses Israel.[1]

But what is the point of harping on the fact that the Frankfurt School "was founded and financed by two people: a German *Jew*,[2] … and his son Felix Weil, born in Argentina." Do we really need to be informed that the latter "… inherited about $400 million in current terms from his *Jewish* mother." Is it really important that Hoppe inform his audience about "the Institute of Social Research, associated with the University of Frankfurt. All the leading figures of this institute were *Jews*, just like Felix and his father.… Even though practically all of them were *Jewish*, they didn't particularly like the Ostjuden—the Eastern European *Jews*, considered low-life *Jews*."? And what are we to make of this tidbit of knowledge: "The most famous studies they (the Frankfurt School) produced, funded by *Jewish* organizations in the U.S…" We are also informed by this author that Javier Milei is "a creation of the *Jewish* oligarchs in Argentina and has toyed with converting to *Judaism*." Nor does Hoppe fail to vouchsafe his audience that "Zelenskyy, president of Ukraine—the most corrupt country in Europe, if not the

[1] Some 20% of the Israeli population is of Arab extraction; most are presumably non-Jewish.

[2] This word is emphasized by the present authors.

world, also Jewish, promoted by *Jewish* oligarchs..."

There are many critics of Zelenskyy. There must be precious few of them who have focused on the fact that he is Jewish. Did this Hoppe claim that the President of the Ukraine compelled the students of this country to study the Talmud? No. Maybe he asserted that this politician is trying to shove the Torah down the throats of the Ukrainian citizenry? We must answer in the negative. Possibly, Hoppe accused Zelenskyy of making matzo, or the bagel or maybe challah compulsory at every meal enjoyed by members of that nation. No, he did not. It would appear that this German/Turkish scholar upbraids Zelenskyy on the basis of none of these charges. Rather, he castigates him, merely, for being of the Hebrew ethnicity. That is not kosher.

Hoppe has suggested that a small group of wealthy, malevolent Jews, leaders of the Frankfurt School are responsible for the "wokism" plaguing Western civilization. However, this author falls into the same trap as did the German Nazis. When the Nazis began determining who could be included in the "pure Aryan race," they initially argued that even a single drop of Jewish blood rendered a person a non-Aryan. But this led to a devastating realization: If one drop of Jewish blood was stronger than five liters of German blood, their ideology was undermined; it faced a logical contradiction. Confronted with this conclusion, the Nazis eventually relaxed the requirements for Aryan acceptance, allowing some few individuals with Jewish heritage to be included.

According to Hoppe, a cohort of Jews from the Frankfurt School wielded intellectual power greater than that of all other Western intellectuals and populations combined. If Jews possessed such a superpower, Hoppe should recognize that his intellectual crusade is doomed to fail.

The truth of the matter is that Jews have been involved in many intellectual movements, including those that opposed socialism in all its manifestations. Hoppe himself tied his life to two such prominent figures with libertarian philosophical worldviews who became his teachers: Ludwig von Mises and Murray Rothbard. He does not explain why these thinkers failed to shape Western civilization into a libertarian world order. We hope Hoppe will eventually realize that Jewishness is neither the source of all evil nor the key to all good in the world.

Hoppe (2001, p. 218) writes as follows: "There can be no tolerance toward democrats and communists in a libertarian social order. They will have to be physically separated and expelled from society… the advocates of alternative, non-family and kin-centered lifestyles such as for instance, individual hedonism, parasitism, nature environment worship, homosexuality, or communism – will have to be physically removed from society too, if one is to maintain a libertarian order."

The wonder of it is that he did not include Jews as a demographic which should be banished from society.[3] An astute reader will note the absence of one group from this list, a type of person reviled by most who can boast of at least a modicum of civilized values: Nazis. One can only wonder at this lacunae. Is this eminent libertarian author trying to tell us something, here, perhaps unconsciously? One can only wonder.

Why, then, is Hoppe continually harping on people associated with this religion? He does so in contexts where this affiliation is simply irrelevant. Several hypotheses immediately present themselves. One, he is suffering for Jewish Derangement Syndrome. He in effect has Jews on the brain. All too much of his intellectual armamentarium is focused on this one group of people.

Two, he is an out and out anti-Semite. However, it is difficult to entertain this explanation, given that two of his own mentors, Ludwig von Mises and Murray N. Rothbard were both Jews. As well, for some forty years he was a good friend of one of

[3] Can we interpret this more sympathetically to be asserting that these "undesirables" would only be excluded from a condominium that Hoppe and his ilk would occupy? No. He clearly and unambiguously mentions "society," not anything else. Particularly egregious on Hoppe's part is his mention of homosexuals in this context. Ralph Raico, Ron Hamowy and Justin Raimondo were all gay, and all made important contributions to our libertarian philosophy. Has Hoppe not even a smidgen of respect for this fact? Evidently not.

the authors of the present essay and even was his co-author several times (Hoppe & Block, 2002; Hoppe, Hulsmann & Block, 1998).

Difficult, but far from impossible. What is the other side of this argument? It is that Hoppe would not be the only anti-Semite to make exception for some favorite Jews. For example, Hitler, himself, no Jew-lover, he, also did so (CNN, 2012). So, given that making exceptions for some Jews certainly didn't absolve Hitler from being an anti-Semite, it cannot per se absolve anyone else either, including Hoppe.

2. Egalitarianism

Then there is the fact that Hoppe is continually railing against great wealth, not stolen, but earned honestly in the market place. He here reveals himself as some sort of egalitarian.[4] For example, he sniggers at Zelenskyy as a "huckster, running around collecting money to ruin his country…" But "huckster" is merely a denigration of "entrepreneur." It is similar to using the "N" word for blacks, or the "K" word for Jews or the "B" or "C" word for females. Here is yet another instance; he sneers at Frankfurt School creator "Hermann Weil, who immigrated to Argentina and became the *wealthiest*[5] grain dealer in the world…" And again: He "built a building for them, paid the people employed there quite well—these people were enormously *wealthy*—and established a network of countless socialist friends all over Europe." He complains that "those influential at this (Frankfurt) institute came from very *wealthy* families: Horkheimer, Herbert Marcuse, Erich Fromm,[6] all had *wealthy* businessmen as parents." And again, a deprecation of "Max Horkheimer, became very influential—a theoretician from a *wealthy* family." We are not yet finished, not by a long shot. Hoppe continues this diatribe in favor of egalitarianism: "Felix (Weil) studied in Germany and became very rich." Here is some more along these lines: "Marx came from a well-off family, but his financier Engels was the son of a very rich industrialist." Nor is Hoppe yet finished with his diatribe. He complains of the Frankfurt scholars that "They were very smart about their finances… They lived a luxurious life." Is there supposed to be something per se wrong with that? Not from a libertarian perspective, one would have thought.

A rich socialist might be ipso facto hypocrite. Not because he is rich, but because he is a socialist! Unless there is something inherently vicious in being rich (in conjunction to being Jewish, we add), which is apparently what Hoppe has in mind.

To summarize this point: It is more than passing curious that Hoppe would be so bitterly opposed to the mere amassing of wealth and luxurious living. This is hardly compatible with the libertarianism he elsewhere so eloquently and effectively espouses. What could possibly explain this phenomenon? Jewish Derangement Syndrome? Israeli Derangement Syndrome? What leads him to so seriously misconstrue libertarian theory? We leave the answer to this question to those better able to answer it than we Jewish authors.

3. Mr. Javier Milei

According to "historian" Hoppe: "Mr. Milei … is on record saying he was largely inspired by Murray Rothbard and myself." Now, it is one thing for a historian to get his facts wrong with regard to events that took place not years ago, not decades ago, not centuries ago. This is forgivable, understandable, comprehensible, given that time waits for no man. The further back one goes into the past, the more difficult, other things equal, it is to ascertain the truth.

However, here we catch our "historian" making an error laden claim with regard to the very recent past. It is also more than a bit self-serving on his part. President of Argentina Javier Milei mentions only Rothbard and Hoppe as mentors? Not true not true at all. As a matter not of historical fact, but that of practically the present day, this free-market politician credits those two alright, but, in addition, the following: Walter Block, Jesús Huerta de Soto, Philip Bagus (Block, 2023; Freedman, 2024).

Says Hoppe of Milei: "I felt, given that he cited me as one of his inspirations, I was perfectly entitled

[4] Perhaps the Frankfurt School, he tells us that his earliest mentors were members, has had a greater effect on his thinking than he realizes or will admit.

[5] Emphasis by present authors

[6] These are the bad guys, get it. They are of *wealth*.

to criticize him.[7] I didn't deny he had to make compromises—some accused me afterward, 'Don't you realize he can't do everything immediately? There's a parliament and all that.' Of course, I was aware you have to make compromises, but they shouldn't be contrary to your ultimate goals."

But this is more than passing curious. Hoppe's native language is not English, so perhaps he does not realize the meaning of the word "compromise." If it is a true compromise, of course it must necessarily be "contrary to your ultimate goals." If it were not so, then it would not be a compromise at all. Rather, it would be the attainment of your favored option. For example, A wants to sell a shirt to B for $100, but the latter is willing to pay, only, $50. A compromise would be anywhere between $51 and $99. But every number with no exceptions that lies in between these latter two dollar amounts is contrary to the "ultimate goal" of both parties. In a compromise, neither party gets what he aims at.

Hoppe is incensed that Milei has not rid Argentina of its central bank. The former claims that the latter, therefore, cannot be a libertarian. But no members of the Chicago School, such as Milton Friedman and George Stigler, wanted to "End the Fed" as did Ron Paul. True, Friedman and Stigler are not anarcho-capitalists. But they are certainly libertarians! Ditto for James Buchanan and Gordon Tullock of the Public Choice School of thought. In castigating Milei for the continued presence of the Argentinian central bank, Hoppe is in effect claiming not that this man is not a libertarian but has not yet fully implemented anarcho-capitalism. Javier is a magnificent libertarian, but he is not a magician. He has no magic want. All he has on his side is magnificent grit, intelligence, purpose, and a libertarian vision.

While we are handing out compliments, we must also further congratulate Hoppe: He is excellent in terms of reading people out of the libertarian movement. One of the present authors is a case in point (Hoppe, 2024), and for a rebuttal see (Block & Futerman, 2024). Mr. Milei is a gift to supporters of our philosophy. He names his dogs after libertarian greats. He talks about the right anarcho-capitalist talk. Is he 100% on board with every jot and title of laissez faire capitalism? No one is, no one can be, since the leading lights often disagree with one another on these matters. Thus, no one can qualify in this regard. Does Hoppe welcome him to our movement? No. He begrudgingly approves of some of his steps but reserves most of his comments for denigrating him. Is this any way to build a movement? Our author seems more interested in restricting entry to it than promoting libertarianism.

Hoppe castigates Milei for not repudiating Argentinian debt, a la Rothbard. He fails to appreciate that this is a very radical step. We know of no survey of libertarians on this matter, but our back of the envelope assessment it that, oh, 5% of our movement would approve. This is a bridge too far for virtually all libertarians. It constitutes a wildly unfair litmus test to apply to the president of this great South American country.

Our author quotes Milei as stating: "'I'd rather cut off my arm than raise taxes'—then he raised several taxes and still runs around with two arms." True, enough. However, this libertarian hero lowered many other taxes, and thus deserves the full use of his arms, Hoppe to the contrary notwithstanding.

Argentina before Milei, was on the brink of hyperinflation, replete with absurd regulations, with numerous deficits, unemployment, etc. In other words, Argentina was on the brink of economic collapse before Milei took up the office of presidency. As of the present writing, only a few short months later, the economy of this country is greatly improved (Bourne & Falcone, 2025; Brattström, 2024; Buenos Aires Times, 2025; Hall, 2025; Ma, 2025; Ventura, 2025).

The real problem for Hoppe in this regard is that Milei is a friend of Israel and the Jews. He could privatize everything to the last road, river, central bank and government building in Argentina and Hoppe would still find grave fault with him on libertarian grounds.

Hoppe reserves his most serious criticism of Javier Milei for the foreign policy of the latter. He

[7] What? It would be impermissible for people Javier does not cite as mentors to criticize him?

asks: "What's the Austro–libertarian position on foreign policy? We're neutral—we stay out of foreign countries' business, don't engage in entanglements, we're a peace party, we don't want war, we're non-interventionists."

First of all, and Hoppe really should know better, there is no such thing as an Austrian economic point of view on foreign policy. Praxeological economics is entirely a positive science, while foreign policy is totally a normative discipline. Never the twain should ever meet.

What of libertarianism? Secondly, this philosophy most certainly is not a "peace party." Hoppe's understanding of this perspective, of which he is one of the undoubted leaders, is seriously flawed in this regard. We libertarians want justice, not peace. If unduly attacked, we are not necessarily pacifists, as per this author. We fight back. We engage in defensive wars. Mr. Libertarian, Murray N. Rothbard, favored what he regarded as just wars.[8] We most certainly do "want war" when pounced upon by evil enemies. What is the alternative? Surrender?[9] Is that what Hoppe recommends, and as a supposed libertarian requirement? For shame.

As for "entanglements" there is no incompatibility with the freedom philosophy for two small countries entering into an alliance against a predatory nation. For example, suppose Lichtenstein and Monaco made a treaty with one another such that in case of an invasion of either one of them, the other would support its partner. Is this antithetical with libertarianism? Not at all.

Hoppe's articulation of neutrality is rooted in the dogma that prioritizes non-interventionism as a safeguard against state-driven aggression. In his lecture, he explicitly states, "We stay out of foreign countries' business. We do not do any entanglements with other countries… we are non-interventionists". This stance aligns with the non-aggression principle of libertarianism, NAP, which prohibits the initiation of force and, by extension, precludes involvement in conflicts beyond one's immediate sphere of voluntary association. For Hoppe, this neutrality is not merely a pragmatic choice but a principled rejection of imperialism and centralized state power, which he views as inherently tied to war and coercion.

Theoretically, the NAP provides a clear binary: aggression is impermissible, and non-aggression is obligatory. In bilateral relations—say, between two agents or countries—this principle appears straightforward. However, as Gindler (forthcoming) argues, the NAP's simplicity falters in multi-agent scenarios, where the presence of a third party introduces ambiguity.

A rigid mathematical logic was employed to demonstrate that when a third party witnesses a violation of the NAP (e.g., one agent aggressing against another), the principle yields a "NULL" result—neither mandating intervention nor enforcing neutrality. This NULL state is not synonymous with neutrality but reflects an inherent ambiguity that permits varied interpretations and actions. Hoppe's insistence on neutrality as the default stance thus rests on an unexamined assumption, one that the NAP itself does not unequivocally support.

In order to eliminate ambiguity, it is necessary to add an explicit clause addressing multi-agent interactions to the definition of the NAP. For example, the following axiom has been proposed: *Everyone has the right—but not the obligation—to assist anyone, provided there is explicit or implicit consent from the victim to do so.*

But as long as ambiguity remains, one can adopt different interpretations as to how the NAP applies in multi-agent situations. Hoppe defaults to a position of neutrality, yet he immediately violates this stance of his when analyzing real-life scenarios.

In addressing Israel's conflict with Hamas, Hoppe abandons any pretense of neutrality, offering a scathing critique of Israeli Prime Minister Benjamin Netanyahu. His characterization is not a neutral observation but a morally charged judgment, implying a clear stance against Israel. Hoppe's statements violate the very rule of

[8] He maintained that the thirteen colonies were justified in engaging in a revolutionary war of secession against England, and that the South was warranted in fighting the North for its right to secede.

[9] Pacifism of the sort here recommended by Hoppe is compatible with libertarianism, but by no means required by this philosophy.

neutrality he outlines—"we stay out of foreign countries' business"—by actively engaging with and condemning Israel's actions.

This deviation is particularly striking given the complexity of the Israel-Hamas conflict. Israel's military operations, often framed as responses to Hamas's rocket attacks and terrorist activities, involve a web of historical, political, and ethical considerations that defy simplistic categorization as "genocide." Hoppe's failure to acknowledge this complexity, coupled with his emotive rhetoric, suggests not a dispassionate application of the NAP but rather selective moral outrage. If neutrality were truly his guiding principle, he would refrain from such pronouncements, leaving the conflict to its participants.

Hoppe's treatment of the Russo-Ukrainian War further illustrates this logical inconsistency of his. He expresses sympathy for Russia, framing its 2022 invasion as a "provoked war" resulting from NATO's eastward expansion and American interference. He justifies this position by arguing that Russia perceived a threat from NATO's proximity, a concern he deems legitimate by analogy: "What would Americans have done if the Chinese had stationed troops in Mexico or Canada?" Conversely, he vilifies Ukrainian President Volodymyr Zelenskyy, calling him "a huckster … a clown installed by Jewish oligarchs," and accuses him of "ruining his own country" by conscripting citizens into a "meat grinder."

This stance is thus far from neutral. Hoppe not only takes sides—favoring Russia over Ukraine—but also invests emotionally in the narrative, wishing for America's "defeat" in the conflict. By opinionating about Zelenskyy's leadership and Russia's motives, Hoppe again breaches his own rule of non-engagement, revealing that his neutrality is conditional rather than absolute. This selective alignment with Russia, juxtaposed against his condemnation of Ukraine, mirrors the ambiguity in the NAP's third-party application, where the absence of a clear directive enables ideological bias to dictate action.

Does Hoppe want to keep the libertarian movement to himself? To not allow the entry of brilliantly promising until recently outsiders such as Milei? Maybe banish them from libertarian "society?" That is no way to build a movement. Milei is the freshest breath of fresh air to adorn our libertarian movement in not years but decades. Hoppe offers him but the back of his hand. Not the present authors, not us. We appreciate a gift from the gods.

4. Donald Trump

Hoppe waxes eloquent about Milei befriending Trump. He castigates him for so doing on the ground that "Trump's not a libertarian; he's a protectionist and war-maker, sending money to Israel, bombing the Houthis, Syrians, involved in Ukraine up to this day."

This is highly problematic. Yes, it cannot be denied that Trump loves tariffs and implementing them is incompatible with libertarianism. However, he has already fired thousands of bureaucrats. If he replaces the income tax with tariffs, and perhaps a revenue neutral VAT or sales tax, it really becomes difficult to get up a full head of libertarian steam against him on this matter of tariffs (Block, 2025C).

A "war-maker?" Trump is a man after the heart of the pacifist Hoppe. The president of the United States worked out the Abraham Accords, trying to make peace in the volatile Middle East. He is now heavily involved in trying to end the war between Russia and Ukraine. What planet is Hoppe writing about? It is certainly not the third rock from the Sun.

As to the Houthies, they are making it all but impossible for commerce to be conducted on international waters. Is Hoppe opposed, also, to ridding the planet of the analogous Barbary Pirates? Does his pacifism have no limits? Our objection, of course, is not to his sudden turn toward this doctrine. It is his equation with it and libertarianism. He is free to adopt any policy he wishes. However, we wish he were not in a position to drag down the libertarian philosophy with him. This is the very same charge he makes against Milei.

5. Ukraine and Zelenskyy

Hoppe has claimed that Ukraine is the most corrupt nation in the world. Given that the country is currently led by a "Jewish" president, this seems to be, in his view, an aggravating factor—though he does not state this explicitly. Yet even in this assertion, Hoppe misleads his audience. According to Transparency International's

Corruption Perceptions Index (2024), the most corrupt country in the world is not Ukraine, but South Sudan, which ranks last at 180th. Ukraine, by contrast, holds a mid-tier position at 105th and has shown steady improvement in recent years. It even places above Turkey (107th), the very country Hoppe has chosen as his place of residence. Russia, ranks significantly lower at 154th, placing it indeed among the most corrupt countries globally.

When we shift from corruption to broader indicators of political and civil liberties, Freedom House offers a reliable and widely recognized assessment (Freedom House, n.d.). Their March 2025 report evaluates 208 countries and territories, each assigning a score from 0 to 100—where 0 represents the least free and 100 the most free. According to this framework, Gaza receives a score of 2, Russia 12, and Turkey 33. All three are classified as “Not Free.” Ukraine, by comparison, scores 51 and is designated as “Partly Free,” while Israel, with a score of 73, is categorized as “Free.”

As a matter of concern, it is rather striking that a self-professed libertarian—someone who champions unrestricted economic and personal freedoms—would choose to reside in a state as authoritarian as Turkey while criticizing far freer societies such as Ukraine, Argentina, Israel, and the United States.

Hoppe’s recent commentary, including the lecture in question, suggests a curious inversion of values. One is reminded here of Marx’s materialist proposition that "being determines consciousness" (Marx (1859 [1977]). In Hoppe’s case, this may well be a fitting lens through which to interpret his evolving worldview.

Hoppe has made a provocative claim, accusing Ukrainian President Volodymyr Zelenskyy of being a puppet of what he calls the "Ukrainian Jewish oligarchy." According to Hoppe, Zelenskyy’s rise to power was orchestrated by “Jewish oligarchs” within Ukraine who promoted his candidacy to serve their interests.

Given that there are relatively few oligarchs of Jewish descent in Ukraine, it is possible to examine the publicly available data to evaluate this assertion. To ensure a thorough analysis, this exploration will not only focus on oligarchs but also include other wealthy and influential Jewish figures in Ukraine, providing a broader picture of their potential involvement. It seems unlikely that Hoppe’s claim relies on secret sources; rather, it appears to be a product of his interpretation—or perhaps imagination—of known events and relationships.

It is true that Ukraine’s political landscape (as that of Russia) has long been shaped by the influence of oligarchs—wealthy individuals who have accumulated vast fortunes through industries such as media, energy, banking, and manufacturing. These oligarchs have often used their resources to sway political outcomes, backing candidates or parties that align with their business interests or ideological leanings. Given that there are relatively few oligarchs of Jewish descent in Ukraine, it is feasible to examine publicly available data to evaluate this assertion.

One figure worth considering is Mykhailo Brodskyy, a businessman, politician, and media owner whose career offers insight into Ukraine’s intersecting worlds of commerce and governance. Brodskyy founded *Obozrevatel.com* a widely visited online news platform that has established him as a significant player in Ukraine’s media sphere (Dumont, 2023). His political journey includes a stint in the Verkhovna Rada, Ukraine’s parliament, from 1998 to 2002, followed by his role as Chairman of the State Committee for Regulatory Policy and Entrepreneurship until its dissolution in 2014.

Beyond media and politics, Brodskyy has been involved in various business ventures, including real estate and trade, reflecting the diverse portfolio typical of Ukraine’s elite. If Brodskyy were part of an oligarchic effort to propel Zelenskyy to power, one might expect his media outlet to have championed Zelenskyy’s candidacy during the 2019 election. However, *Obozrevatel.com* maintained a neutral stance, offering no clear editorial bias toward Zelenskyy over his main rival, incumbent President Petro Poroshenko. There are no records of financial contributions, public endorsements, or behind-the-scenes alliances linking Brodskyy to Zelenskyy’s campaign. His lack of overt support suggests that he did not play a significant role in promoting Zelenskyy’s rise, casting doubt on his inclusion in Hoppe’s alleged "Ukrainian Jewish oligarchy."

Similarly, Volodymyr Groysman emerges as an unlikely supporter of Zelenskyy. Groysman's political career is deeply tied to the *Petro Poroshenko Bloc*, under which he served in the Verkhovna Rada from 2014 to 2019. Rising to become Chairman of the parliament and later Prime Minister, Groysman was a key figure in Poroshenko's administration, overseeing economic reforms and navigating Ukraine's challenges during a period of conflict with Russia. Given that Zelenskyy ran against Poroshenko in the 2019 election, positioning himself as an outsider challenging the establishment, it is implausible that Groysman, a loyal Poroshenko ally, would have backed Zelenskyy's candidacy. After Zelenskyy's inauguration, he called for the Cabinet's resignation, prompting Groysman to submit his own. Although the Verkhovna Rada rejected it, requiring Groysman to remain in office until a new government was formed, this episode underscores their political opposition rather than collaboration. While both men share Jewish heritage, this cultural connection does not translate into evidence of political support or influence (Gryvnyak, 2021). Groysman's tenure as Prime Minister and his subsequent return to private life offer no indication that he played a role in Zelenskyy's ascent, a la Hoppe.

Victor Pinchuk, the son-in-law of former President Leonid Kuchma, brings a different perspective to this analysis. As a prominent oligarch and media proprietor, Pinchuk controls several television channels, including *ICTV, Novyi Kanal,* and *STB*, which collectively wield considerable influence over public opinion. However, during the 2019 election, these outlets adopted a neutral posture, refraining from endorsing either Zelenskyy or Poroshenko. Some thought that Pinchuk likely supported the *Holos* party because their advertisements were cheaper for *Holos* than for others (Polianska, 2019).

Pinchuk's broader profile reveals a sophisticated operator: His wealth stems from steel and pipe manufacturing through his company *Interpipe,* and he has cultivated an international reputation through philanthropy, notably via the *Victor Pinchuk Foundation*, which hosts events like the *Yalta European Strategy* conference.

Post-election, however, investigative reports suggest that Pinchuk adapted to the new political reality. Individuals linked to him gained positions within Zelenskyy's *Servant of the People* party, as well as other groups like *Strength and Honor* and *Batkivshchyna*, indicating a strategic effort to maintain influence after Zelenskyy's victory. This maneuvering reflects opportunism rather than pre-election support, suggesting that Pinchuk did not promote Zelenskyy's candidacy but rather sought to benefit from his success after the fact.

In stark contrast, Vadim Rabinovich stands out as an outright adversary of Zelenskyy's. A businessman and politician, Rabinovich co-led the *Opposition Platform — For Life* party, which has consistently aligned with pro-Russian interests. In the 2019 election, he opted not to run for president, instead throwing his support behind Yuriy Boyko, who garnered 11.67% of the vote in the first round, finishing fourth. Rabinovich's media ventures, including ownership of the *NewsOne* channel (later sold), amplified his political messaging, but there is no hint of support for Zelenskyy—quite the opposite. In February 2021, Rabinovich launched impeachment proceedings against Zelenskyy after the government shut down three pro-Russian television channels, accusing him of authoritarianism. By April 2022, Ukraine's National Agency for the Prevention of Corruption branded Rabinovich a "collaborator" and "pro-Russian politician," citing his absence from Ukraine during Russia's invasion and his statements blaming the West and Ukraine for the conflict. In July 2022, Zelenskyy revoked Rabinovich's Ukrainian citizenship, alongside others, due to his possession of Israeli citizenship (Liphshiz, 2022). Rabinovich's consistent opposition, from the election through subsequent years, makes it absurd to consider him part of any effort to install Zelenskyy as a puppet, as Hoppe would have it.

The Surkis brothers, Ihor and Hryhoriy, add another layer to this inquiry. Known primarily for their dominance in Ukrainian football—Ihor as president of *Dynamo Kyiv* and Hryhoriy as a former vice president of the *Ukrainian Football Association*—their influence extends into commercial business. They co-owned *Ukrenergoconsulting*, a firm tied to energy and construction, and held stakes in media, including the TV company *TET*. In the 1990s and early 2000s, they were associated with the "Kyiv Seven," a powerful oligarchic clique. Their political

leanings have historically favored pro-Russian figures, such as Viktor Medvedchuk, rather than reformist candidates like Zelenskyy. During the 2019 election, no evidence suggests they supported or promoted Zelenskyy's campaign. Their business empire and connections, while formidable, do not align with Zelenskyy's anti-establishment platform, making their involvement in his rise improbable. In February 2022, they reportedly left Ukraine through Hungary, carrying significant sums of money (Hungary Today, 2022).

The most compelling case involves Ihor Kolomoisky and his business partner Hennadiy Boholyubov, whose ties to Zelenskyy have fueled significant speculation. Kolomoisky, a billionaire oligarch, owned the *1+1 Media Group*, which aired Zelenskyy's hit show *Servant of the People*. The series, in which Zelenskyy played a teacher-turned-president fighting corruption, aired for years before the election, boosting his public profile and embedding his image as a relatable everyman. During the 2019 campaign, *1+1's* coverage was perceived as supportive of Zelenskyy, leading to allegations that Kolomoisky backed his candidacy (Williams & Zinets, 2019).

Kolomoisky's influence stems from his ownership of *PrivatBank*—nationalized in 2016 amid fraud allegations—and other ventures in energy and aviation. Boholyubov, his long-time partner, shared in these enterprises, though his role in the election is less well documented. Despite this media exposure, Zelenskyy and Kolomoisky have both denied any puppet-like relationship. Since taking office, Zelenskyy has distanced himself from Kolomoisky through decisive actions: In September 2023, Kolomoisky was arrested on charges of fraud and money laundering and remains in custody at present (Voitovych, et.al. 2023). In February 2025, Zelenskyy imposed sanctions on both Kolomoisky and Boholyubov, accusing them of threatening national security. Boholyubov fled Ukraine using forged documents to evade prosecution tied to the *PrivatBank* case.

Some conspiracy theorists argue that Kolomoisky's arrest is a ploy to shield him from U.S. extradition, but this notion falters given Ukraine's reliance on American aid during the ongoing war, which gives the U.S. ample leverage to demand his transfer if desired. The Kolomoisky connection, while notable, appears more opportunistic than controlling.

Zelenskyy's path to the presidency is best understood through the lens of public support rather than oligarchic machination. Before politics, he was a celebrated comedian and actor, founding the *Kvartal 95* comedy troupe and starring in *Servant of the People*, which premiered in 2015 and ran through 2019. The show's premise—a principled outsider upending a corrupt system—mirrored the frustrations of many Ukrainians, amplifying Zelenskyy's appeal. In December 2018, he launched his candidacy under the *Servant of the People* party, named after the series, emphasizing anti-corruption and reform. His campaign relied heavily on social media and grassroots momentum, targeting voters—especially younger ones—tired of traditional elites. The election unfolded in two rounds: On March 31, 2019, Zelenskyy won 30% of the vote, advancing to a runoff against Poroshenko. On April 21, he secured over 73% of the vote, a landslide reflecting widespread disillusionment with the status quo. Voter turnout exceeded 60%, with Zelenskyy dominating across regions, from urban centers to rural areas, underscoring his broad appeal.

This overwhelming mandate suggests that Zelenskyy's rise was driven by a populist wave, not a coordinated oligarchic plot (Mashtaler, 2021). While figures like Kolomoisky provided platforms that enhanced his visibility, and others like Pinchuk sought influence afterward, the evidence does not support Hoppe's narrative of a "Ukrainian Jewish oligarchy" pulling strings. Brodskyy remained neutral, Groysman opposed him, Rabinovich fought him, and the Surkis brothers exhibited no involvement. Kolomoisky's role, though significant, is countered by Zelenskyy's subsequent actions against him. Neither Ukrainian nor international investigative journalists have uncovered a conspiracy aligning with Hoppe's claim. Instead, Zelenskyy's victory reflects a public craving for change, channeled through a charismatic figure who leveraged his fame and message effectively.

Hoppe's accusation, while bold, lacks the empirical foundation to hold up under scrutiny, appearing more as a speculative leap than a substantiated truth.

6. Israel

In the view of our author, Milei's "greatest friend of all is Netanyahu—a mass killer involved in genocide. For a critique of this unhinged claim see (American Jewish Committee, 2024A, 2024B; Anti-Defamation League, 2023; Block, 2024A, 2024B; Florida Holocaust Museum, 2024; Ostrovsky & Pavlovschi, 2024; Pletka & Soleimany, 2024; Pollard, 2024; Rullo, 2024). I can't understand how any libertarian would defend him, but Milei danced in the streets with him."

Full disclosure here. If ever the present authors were offered the opportunity to "dance in the streets" with Netanyahu, we would immediately bone up on our dance lessons.[10]

What is genocide? It is defined as "a crime committed with the intent to destroy a national, ethnic, racial or religious group, in whole or in part." (UN Article II of the Genocide Convention, 1951) Certainly, purposefully aiming to kill women and children would be a paradigm case of such a despicable act. Clearly, the atrocity perpetrated on Israel by Hamas on October 7, 2023, would more than qualify in this regard. These monsters purposefully murdered and kidnapped civilians, many of whom later died in captivity. Does Hoppe call out this terrorist organization for that crime against humanity? To ask this is to answer it, but we will offer an explicit response: He does no such thing.

What is the case for the claim that Israel, too, is guilty of such a war crime? Yes, some 40,000 plus Gazans have been killed since that infamous date. But whose fault is that? Clearly, it must be laid at the door of Hamas, not the IDF. This Iranian backed group places its military hardware in schools, hospitals, residential areas, and then in effect dares to the Israeli military to destroy them. What does the IDF do first? Bomb these places? No. Instead, it drops leaflets on these areas, in an attempt to preserve civilian life. The average army kills nine civilians for every enemy fighter. The IDF record? Almost a one-to-one ratio (Block, 2024C). That is to say, the Israeli military is more concerned with *not* committing genocide, and successful in this regard, than any other army. On this general question, see Block (2024A, 2024B, 2024C).

Hoppe clearly takes the side of Russia vis a vis Ukraine. But has not the former country killed many civilians of the latter? Our author, surprisingly, shockingly, condemns Israel for these unfortunate deaths, but not Russia.

Here is Hoppe on his high horse once again, playing fast and loose with the facts: "Israel can do whatever they want in the minds of Germans and Europeans because of the Holocaust 80 years ago." The actual situation is far different. Germans, along with other Europeans, have been vociferous in their condemnation of Israel's defensive war. For example, the ICC has declared Netanyahu a war criminal. It is located in Hague, Netherlands, which, the last time we looked, was located in Europe. The United Nations has been one sided in its denunciation of Israel; most European nations have supported this institution's numerous and almost unanimous votes condemning Israel.

As for Germany, the same applies. Weinthal (2024) reports that "… Germany's Foreign Minister Annalena Baerbock Blamed Israel, Not Terrorists, for Endangering Hostages Held by Hamas. According to this journalist: Michael Blume, the German Christian Democratic Union commissioner stated: "Right-wing extremists from Israel, the U.S. and Europe, and also the Netanyahu government, use the accusation of antisemitism in an inflationary way and exploit it." In the view of the Middle East Eye (2024): "… most Germans oppose continued Israel arms sales." Then there is this report (von der Burchard 2024) on the matter: "German Vice Chancellor Robert Habeck on Saturday accused Israel of breaking international law by continuing its offensive against Rafah… 'It must not do so,' Habeck said at a citizens (sic) dialogue in the German capital. 'Of course, Israel must abide by international law,' he said." Then, there is the undeniable fact that "German Chancellor Olaf Scholz warns Netanyahu against Rafah attack." (Al Jazeera English, 2024).

[10] Two of the present authors were honored that the Prime Minister of Israel wrote a forward to one of our books.

So much for Hoppe's false claim to the effect that Germany is unanimously a supporter of Israel in its present war due to guilt over past occurrences. Cannot this man get anything right, even as concerns recent history?

7. Federalism

Hoppe's next "contribution" is to support decentralization versus centralization, and in the name of our philosophy. Again, he reveals an abysmal ignorance of what he is talking about. He states:

"Another tendency: All states try to centralize—centralization means more loot. Austro-libertarians favor decentralization." He does so on the ground that the former is worse since: "You can't vote with your feet."

What error does he commit here? First of all, he again confuses the normative with the positive. Austrians qua Austrians have no view, none whatsoever, on the normative question of which is to be preferred, centralization or decentralization, federalism or anti-federalism. Praxeology is a value-free discipline that has no preferences for either of these alternatives.[11]

Secondly, the proper libertarian position is neither of these two options. When President Ronald Reagan threatened to cut off financial aid to New York City unless it ended its socialistic rent controls, the libertarian position supports centralism, not decentralism. When President Joe Biden intimidates a city for not expending DEI[12] programs, we switch gears, and become decentralists. The point is, libertarians support whichever level of government is more libertarian on any given issue. The level of centralization, federalism, is strictly speaking irrelevant. For a more in depth treatment of this Hoppean error, see (Block, 2025B) and (Block & Kinsella, 2005).

Opines Hoppe: "The U.S. expanded NATO continuously. After the Soviet Union broke apart, NATO's purpose was supposedly gone—it was to defend against a Bolshevik takeover. When that was no longer possible, Russians withdrew from East Germany, but Americans didn't—they expanded closer to Russia. Russians considered it a threat—what would Americans do if China stationed troops in Mexico or Canada? They'd start a war in weeks. Russians warned, 'Don't get too close,' especially about Ukraine."

This author reserves his venom for Israel, since it (because of its defensive actions) unintendedly killed many Gazan civilians. But Russia did kill Ukrainian civilians in the war. Yet, nary a word emanates from his lips about this latter situation. No charges of "genocide" are to be heard. One wonders at his inability to see any parallels here whatsoever.

In the view of this libertarian leader: "… one word about Israel—it rules U.S. foreign policy." After all, the only civilized country in the Middle East is the single greatest recipient of US foreign disbursements. And, under the second Trump Administration, the US is no longer forcing this country to fight its enemies with one hand tied behind its back as occurred under Biden.[13] On the other hand, American foreign aid[14] to all Arab countries put together is a multiple of that accorded to this one nation (Block, 2025A). Moreover, the US maintains good relations with bitter enemies of the Jewish State, such as Qatar. "Ruling" US foreign policy is more than a ridiculous accusation.

Let us conclude. This was a disgraceful rendition of the application of libertarian principles to a whole host of issues. Hoppe should be ashamed of himself. Just what is his problem with Jews? Some of us are mighty fine folks.

A word about the Mises Institute. They have run hundreds, maybe thousands, of essays attacking Israel. Not a single solitary one articulates the case for the other side. That is not explicit anti-Semitism. It is anti-Israeli-ism.[15] They invite Hoppe to give a speech at one of their functions. That is not anti-Semitism either, despite his past record on this matter. Who knows, people can change

[11] This repeated error of his is particularly puzzling since there are few scholars who have made a greater contribution to praxeology than Hoppe. How, then, can we explain this basic error of his, now repeated for a second time?

[12] DEI stands for "Didn't Earn It."

[13] Check that. One and three quarters hands.

[14] Apologies to Peter Bauer

[15] It is not compatible with the best traditions of scholarship, but that is entirely a different matter. And, to be sure, there is a relation between Anti-Zionism and Anti-Semitism.

their minds. However, after this blatantly anti-Semitic speech, the Mises Institute chose to publish it. They thus gave it their imprimatur. That is anti-Semitism. Did they offer anyone such as any of the present authors an opportunity to rebut this talk? That is not their way.

Anti-Semitism is not an ambiguous term, although it could be wrongly used. Not *everything* critical of Jews is Anti-Semitic but some things indeed *are*. It implies a form of hatred that essentially shares the same structure as Anti-Zionism. According to *refusenik* Natan Sharansky (yes, the same "Jew" we mentioned above), Anti-Zionism can be identified by the 3 Ds: Delegitimization, Demonization and Double Standard. Anti-Semitism follows the same path. The first implies that Jews, as such, are inherently, uniquely, flawed (especially compared to other groups). The second means that Jews ultimately are the source of all evil, hence the language used to describe them includes the worst slanders. The third is to place an obsessive focus on Jews or their actions, or their associates' actions, and applying to them a different standard than the one utilized with regard to the rest of the world. Manicheism is another feature of Anti-Semitism, as everything evil comes from Jews, while nothing good comes from them as such.

It is important to point out that Anti-Semitism does not necessarily lead-to favoring the mass murder of the Jews. Historically, they were either expelled, expropriated, treated as second class citizens, or confined in Ghettos. Apart from the (not few) instances of mass murder, rape, torture and violence against Jews for 2,000 years, Anti-Semitism has been mostly of the former kind. Eliminationist Anti-Semitism of the latter kind, of which Nazism was its lowest point, is far from being the only type of Anti-Semitism that exists. Now with this in mind read the previous paragraph again and think if Hoppe's speech fits this bill or not.

The reason why Hoppe offers no evidence for his claims is because that is how the conspiratorial, and especially the antisemitic, mindset, works. It uses a sort of *a priori* reasoning (Futerman and Block, 2023) or (in Hoppe's own terminology) extreme rationalism. The axiomatic principles of this hatred are the 3Ds mentioned above.

Hence, evidence won't do. For the Hoppean mind, absence of evidence is *not* evidence of absence, and at the same time *anything* pointed as evidence is *good* enough. It is inherently unfalsifiable.

Think about it. What qualifies as a "Jew" to Hoppe? How is Zelenskyy's "Jewishness" relevant to his other characteristics? Would not the same perfidy that Hoppe applies to Zelenskyy's Jewishness (or its associates, such as Milei) also smear Mises and Rothbard? What is the matter with "Jewishness" as such? The truth is that Hoppe is a classic Anti-Semite. To the Judeophobic Mayor of Vienna 120 years ago, Karl Lueger, was attributed the quote: "I decide who is a Jew" (Ebeling, 2005).

Undoubtedly, Hoppe still has in high regard both Mises and Rothbard *despite* their having been Jews. This is precisely why he has scarcely mentioned the fact that they were Jews throughout his work, apart from a biographical curiosity. But when giving a talk about what is wrong with the world, "Jews" are on center stage, in a speech resembling a "libertarian" adaptation of the well-known forgery *The Protocols of the Elders of Zion*. If the Mises Institute sees no problem with that, they would do well in re-reading Mises own *Omnipotent Government*, Part III, Chapter VIII. After all, it is the sign *Mises* Institute that appears behind Hoppe throughout his talk. Not Hoppe Institute.

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ARTIFICIAL INTELLIGENCE MANAGEMENT AND SMART UNIVERSITIES: ASSESSING READINESS, PROSPECTS IN ALGERIA

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ABSTRACT

This study aims to examine the readiness of Algerian universities for the adoption of Artificial Intelligence Management and to explore its relationship with the prospects of transitioning toward smart universities. A quantitative descriptive-analytical approach was adopted using a questionnaire administered to a convenience sample of 100 academic and administrative staff members from various Algerian universities. Data were analyzed using SPSS software, employing descriptive statistics. The findings indicate that the level of AI readiness in Algerian universities remains relatively low to moderate across its main dimensions, including human resources, digital infrastructure, and strategic and administrative frameworks. The results also reveal a statistically significant positive correlation between AI readiness and the prospects of smart universities. Based on these findings, the study emphasizes the need to strengthen digital infrastructure, develop human competencies, and establish clear strategic, financial, and governance frameworks. It also highlights the importance of fostering innovation and inter-university collaboration to support the effective implementation of Artificial Intelligence Management in Algerian higher education institutions.

1 INTRODUCTION

The world has witnessed a profound digital transformation in recent decades, in which data-driven systems and smart technologies, particularly artificial intelligence (AI), have become key drivers of enhanced institutional performance and improved decision-making processes. In this context, artificial intelligence is no longer merely a technical tool, but a strategic enabler that reshapes management practices and supports the development of more efficient, adaptive, and intelligent organizations.

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In the higher education sector, universities worldwide are increasingly striving to adapt to this transformation by integrating AI technologies into administrative and academic processes, improving the quality of education, and strengthening scientific research. This shift has facilitated the emergence of the "smart university" model, which relies on data, innovation, and digital ecosystems to enhance institutional effectiveness.

In the Algerian context, this transformation is of particular importance given the challenges faced by higher education institutions, including limited digital infrastructure, varying levels of human resource preparedness, and the need to further develop strategic and administrative frameworks. Despite ongoing efforts toward digitalization, the adoption of Artificial Intelligence Management in Algerian universities remains at an early stage, raising important questions regarding their actual readiness for such a transformation.

Despite the growing global body of literature on artificial intelligence in higher education, there remains a limited number of empirical studies examining AI readiness in developing countries, particularly in the Algerian context. Moreover, existing studies have rarely adopted a multidimensional framework that simultaneously integrates human, technological, and governance-related dimensions of readiness.

Accordingly, the main research problem of this study is formulated as follows: To what extent do Algerian universities possess the necessary readiness to adopt Artificial Intelligence Management, and how does this readiness relate to the prospects of developing smart universities?

Based on this main question, the study seeks to address several sub-questions aimed at analyzing the level of AI readiness in Algerian universities. These include examining the availability of digital infrastructure, assessing the preparedness of human resources, and evaluating the role of strategic and administrative frameworks in supporting the adoption of Artificial Intelligence Management within the university environment.

2 LITERATURE REVIEW

2.1 Artificial Intelligence: Concept and Definition

Khaleel and Jebrel (2024) defined artificial intelligence as the development of computer systems that can perform tasks which typically require human intelligence, including learning from experience, understanding natural language, recognizing patterns, reasoning, problem solving, and adapting to new situations. In their view, AI systems are designed to emulate human cognitive functions so that they can accomplish complex tasks autonomously or with minimal human intervention (Khaleel & Jebrel, 2024). Further, AI is defined, in economic terms, as a "prediction machine," arguing that it takes available data and uses it to generate missing information, thereby improving the quality of decisions under uncertainty (Agrawal et al., 2018). These definitions portray AI both as a broad field of computer-based intelligence and as a core capability for generating useful predictions that transform organizational processes

So, Artificial intelligence can be defined as a configurable capability of artificial systems to continuously transform raw data into context-sensitive judgments and actions, by autonomously discovering patterns, updating internal representations, and coordinating with humans or other machines, so that the overall socio-technical system behaves in an increasingly adaptive and goal-oriented way.

2.2 Artificial Intelligence Management

Management of artificial intelligence has emerged as a managerial approach that embeds AI technologies into core organizational functions to enhance knowledge creation, innovation, and decision-making. In this perspective, Raina et al. (2026) describe it as the systematic use of AI tools such as machine learning, predictive analytics, and natural language processing to redesign activities in areas like human resource management, operations, strategic leadership, and customer or service management to support sustainable business models.

Artificial intelligence-driven management is the coordinated set of managerial policies, processes, and practices through which an organization aligns data, algorithms, and human expertise to plan, deploy, and continuously supervise AI applications, with the aim of improving the effectiveness, efficiency, and responsibility of its decisions and operations.

2.3 Requirements and Capabilities of AI Management

Raina et al. (2026) argued that effective management of AI requires organizations to develop AI-specific resources that are valuable, rare, inimitable, and non-substitutable, such as high-quality data assets, advanced digital infrastructure, and strong analytics capabilities. Drawing on the resource-based view and dynamic capabilities theory, they defined AI management capabilities as the organizational processes that allow firms to sense AI opportunities, seize them through appropriate investments, and reconfigure structures and routines to integrate AI into everyday operations. (Kolbjørnsrud, 2024) added that intelligent organizations also need principles for human AI collaboration, emphasizing that requirements for AI management include building complementary human skills, transparent organizational architectures, and a learning-oriented culture so that human and digital actors can jointly solve problems and adapt over time.

2.4 Smart Organizations: Concept and Evolution

With the advancement of digital technologies, the concept of smart organizations has been further expanded. (Filos, 2005) Defined smart organizations as knowledge-driven and internetworked entities that can adapt dynamically to new organizational forms and practices enabled by the digital economy. This definition highlights the central role of information and communication technologies in enhancing organizational adaptability and learning.

More recently, Pissardini et al. (2024) emphasized that organizational intelligence should be understood as an evolutionary property that develops through the progressive integration of digital and smart technologies into organizational functions. They argued that intelligent organizations emerge as organizational functions acquire advanced, technology-enabled capabilities that support autonomous and data-driven decision-making.

Despite growing interest in intelligent organizations, the literature reveals a lack of consensus regarding a single, universally accepted definition. Early conceptualizations emphasized the role of knowledge and learning as core organizational capabilities. Wiig (2000) described intelligent organizations as those that effectively leverage knowledge to manage present challenges while anticipating future uncertainties (El Haiba et al., 2017). Building on this view, Schwaninger (2001) emphasized that intelligent organizations are characterized by high levels of performance derived from their capacity to understand environmental complexity and respond to it in a purposeful and coordinated manner. Intelligence, therefore, is not limited to information processing alone but extends to the organization's systemic ability to align structures, processes, and human competencies with environmental demands.

Building on these perspectives, intelligent organizations can be conceptualized as organizations that possess the capacity to sense environmental changes, transform data and information into actionable knowledge, and dynamically adapt their structures and processes to sustain value creation. This synthesized understanding provides a suitable foundation for examining the role of artificial intelligence management in enabling and shaping intelligent organizations.

2.5 Dimensions of Smart Organizational Capability

Smart organizational capability can be understood through several key dimensions that together capture how an organization intelligently adapts, learns, and innovates in an AI-driven environment. First, the knowledge and learning dimension (El Haiba et al., 2017; Razavi, 2013) reflects the organization's ability to continuously generate, store, share, and reuse knowledge through formal and informal mechanisms, supported by digital platforms and AI-driven analytics that transform dispersed data into actionable insights, which requires moving beyond traditional routines, encouraging critical reflection, and structuring idea management processes to ensure that high quality ideas are captured and developed. Second, the human capital and collaborative culture dimension (El Bassiti & Ajhoun, 2013) refers to the extent to which employees are empowered to initiate and develop ideas, work in cross-functional and interdisciplinary teams, and engage in open communication and trust-based relationships, where ethical conduct, shared responsibility, and psychological safety enable

constructive debate and collective problem solving that reinforce organizational intelligence. Third, the digital and technological smartness dimension (Abiodun et al., 2023; Cheng et al., 2018 ; Lopes Nunes et al., 2017) captures the strategic integration of advanced technologies such as the Internet of Things, cyber physical systems, cloud computing, big data analytics, and artificial intelligence into core processes and supply chains, enabling hyperconnectivity, real-time monitoring, predictive decision making, and the optimization of resources, quality, and responsiveness without compromising sustainability or safety. Finally, the networking and innovation dimension (El Haiba et al., 2017) denotes the organization's capacity to operate as an internetworked node within broader ecosystems, leveraging virtual collaboration, knowledge hyperlinking, and recommendation-based systems to connect internal and external actors, combine heterogeneous ideas, and continuously generate innovative products, services, and solutions that match evolving environmental demands and stakeholder expectations.

AI management increasingly acts as a strategic engine for building smart organizations by orchestrating how data, technologies, people, and processes are aligned to create intelligent, adaptive systems. Effective AI management first enables data-driven learning by establishing governance structures, architectures, and analytical capabilities that transform large, heterogeneous data streams into organizational knowledge, thereby reinforcing the knowledge and learning dimension of smart organizations through systematic data acquisition, advanced analytics, and feedback loops embedded in daily operations (Abiodun et al., 2023; Kolbjørnsrud, 2024; Sposato & Dittmar, 2025). Second, AI management shapes human AI collaboration by defining roles, responsibilities, and interaction patterns in which algorithms augment, rather than replace, human judgment, supporting agile teams with decision support systems, intelligent recommendation engines, and adaptive workflows that enhance collaboration, creativity, and responsiveness (Kolbjørnsrud, 2024; Jarvenpaa & Välikangas, 2025). Third, by integrating AI into core Industry 4.0 technologies such as IoT, cyber physical systems, and smart factories AI management drives digital smartness across value chains, enabling real time monitoring, predictive maintenance, autonomous coordination, and end to end optimization that materially improve productivity, sustainability, and customer experience (Abiodun et al., 2023; Cheng et al., 2018; Lopes Nunes et al., 2017). Finally, AI management provides a strategic and ethical compass for AI deployment, ensuring that algorithmic systems are aligned with organizational values, regulatory frameworks, and human-centric principles, which is essential for building trust, safeguarding fairness, transparency, and sustaining the long-term legitimacy of smart organizations in a rapidly evolving socio-technical environment (Nübler, 2023; Sarlak, 2010).

2.6 Smart Universities

The concept of Smart University appeared because of the digital transformation in higher education. It refers to the universities that apply advanced technologies such as the Internet of Things (IoT), AI, cloud computing, big data, and smart systems in their academic and administrative processes to enhance efficiency and fulfil strategic goals. Smart universities are built on digital infrastructure and intelligent technologies to offer flexible learning environments, support data-driven decision making, and improve the quality of educational and administrative services via interconnected and automated systems (Mbombo & Cavus, 2021).

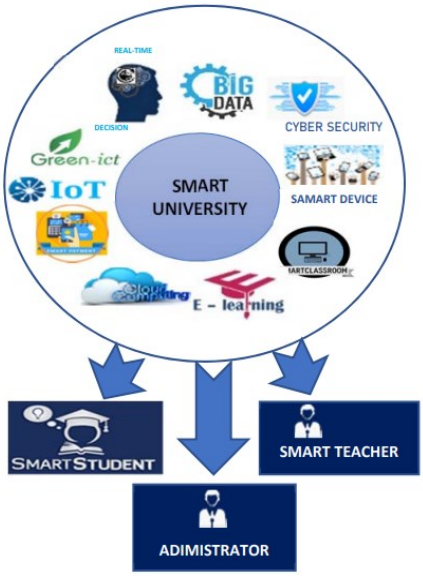


Figure 1. *Main components of the Smart University*
Source: (Mbombo & Cavus, 2021)

3 EMPIRICAL LITERATURE RELATED TO THE STUDY

3.1 Previous Studies

Kassa and Worku (2025) conducted a quantitative study examining the impact of artificial intelligence on organizational performance in service firms. Using survey data from managers and employees, the study tested structural relationships between AI use, process efficiency, and innovation outcomes. The findings indicate that AI adoption significantly improves service quality, response speed, and cost efficiency, particularly when supported by employee training, clear ethical guidelines, and strong top management support. The study highlights that artificial intelligence management should be understood as a strategic capability that aligns technological investments with human skills and organizational processes.

Hyiamang and Liu (2025) adopted a multiple case study design involving organizations from the manufacturing, finance, and healthcare sectors to explore how AI strategies are formulated and implemented at the top management level. The results show that organizations with explicit AI strategies covering data infrastructure, governance, talent, and partnerships are more successful in scaling AI initiatives and generating measurable business value compared to those with fragmented approaches. The study concludes that AI management at the executive level requires cross-functional coordination and continuous monitoring of both performance outcomes and socio-ethical risks.

Abiodun et al. (2023) develop a conceptual and empirical model to explain how Industry 4.0 technologies drive “smartness” for organizational performance, using survey data from manufacturing companies combined with qualitative evidence. The study identifies dimensions of smart organizations, such as digital connectivity, real time data transparency, process optimization, and sustainable operations, and demonstrates that these dimensions mediate the relationship between Industry 4.0 adoption and performance indicators like productivity, quality, and flexibility. The authors argue that becoming a smart organization requires aligning technology, people, and processes rather than focusing on isolated tools.

Holmström and Hällgren (2022) conceptually examined AI management by emphasizing the mutual shaping between artificial intelligence systems and organizational contexts. Through conceptual analysis and illustrative cases, the authors propose a typology of AI use based on the co-constitution of technology and organizational arrangements. They further highlight three key principles for effective AI management: defining the purpose of AI use, determining appropriate levels of transparency and algorithmic control, and recognizing the contextual nature of AI outcomes. The study positions AI management as an ongoing socio-technical process involving organizational practices, power relations, and contextual dynamics.

Adamik and Sikora-Fernandez (2021) investigated smart organizations as drivers of competitiveness and sustainable development in the industry 4.0 context. Using a conceptual framework supported by empirical illustrations, the study shows that smart organizations characterized by networking, knowledge intensity, innovation, and adaptability contribute to regional and national development through enhanced competitiveness and resilience. The authors conclude that building smart organizations requires coordinated efforts at both the organizational level (strategies, structures, and capabilities) and the institutional level (supportive policies and ecosystems).

Lopes Nunes et al. (2017) examined smart digital organizations with a focus on smart products and lifecycle integration. Based on case studies from high-tech manufacturing, the study demonstrates that embedding sensors and connectivity in products enables continuous feedback loops that enhance predictive capabilities, customization, and adaptive design. The findings show that smart organizations extend their informational boundaries beyond internal systems to include product in use data, thereby strengthening organizational learning and innovation capacity.

Collectively, these perspectives highlight that Artificial Intelligence Management is not merely a technical function but a strategic organizational capability that shapes decision-making and institutional transformation. Moreover, the studies consistently demonstrate that successful AI implementation depends on the alignment between technological infrastructure, human

capabilities, and strategic governance frameworks.

3.2 Research Gap and Added Value

Despite the growing literature on Artificial Intelligence Management and smart organizations, most studies have focused on organizational performance and strategic applications in business and industrial contexts, as evidenced by Kassa and Worku (2025) and Hyiamang and Liu (2025), as well as socio-technical perspectives highlighted by Holmström and Hällgren (2022). Other studies, such as Abiodun et al. (2023), Adamik and Sikora-Fernandez (2021), and Lopes Nunes et al. (2017), have primarily examined smart organizations within industrial environments.

However, limited attention has been given to higher education institutions, particularly in developing countries. Moreover, existing studies have not sufficiently explored Artificial Intelligence readiness as a multidimensional construct, nor its relationship with prospects from the perspective of university stakeholders.

Accordingly, this study addresses this gap by examining the readiness of Algerian universities using a multidimensional framework and analyzing its link with the prospects of smart universities. It contributes to the literature by providing empirical evidence from a developing country context and extending AI Management research into higher education.

3.3 Research Hypotheses

H1: First main hypothesis: Algerian universities do not demonstrate sufficient readiness to implement artificial intelligence management.

The main hypothesis is divided into the following sub-hypotheses.

H1a: The necessary digital tools for implementing artificial intelligence management are not sufficiently available.

H1b: The necessary human resources for implementing artificial intelligence management are not sufficiently available

H1c: A supportive strategic and administrative framework for implementing artificial intelligence management is not sufficiently available.

H2: Second main hypothesis: There is no statistically significant positive relationship between university readiness and future AI adoption prospects.

4 RESEARCH METHODOLOGY

4.1 Sample

The study population consists of academic and administrative staff in Algerian universities. A total of 100 valid questionnaires were collected from professors and university administrators with diverse academic and managerial backgrounds, providing multiple perspectives on the readiness of Algerian universities to adopt Artificial Intelligence Management.

Although the questionnaire was distributed to more than 400 professors and administrators in various Algerian higher education institutions, only 100 valid questionnaires were retrieved for statistical analysis. This can be explained by the varying levels of participant engagement and response conditions; however, the sample size remains acceptable for the descriptive and exploratory analysis used in this study.

4.2 Data Collection

Data were collected between December 2025 and March 2026 using a structured electronic questionnaire distributed to academic and administrative staff in various Algerian higher education institutions. The questionnaire was shared through professional academic communication channels, including email and online platforms, ensuring access to relevant institutional respondents.

4.3 Measures

Artificial Intelligence readiness was measured using a multi-item Likert scale covering three main dimensions: digital infrastructure and tools, human resource competencies, and strategic and organizational framework. Prospects of smart universities were assessed through items related to perceived impacts of AI on performance, innovation, competitiveness, and institutional transformation.

All items were measured on a five-point Likert scale. Internal consistency was assessed using

Cronbach's alpha, with all constructs exceeding the acceptable threshold of 0.70, indicating satisfactory reliability.

4.4 Analysis

Data was analyzed using SPSS software. The analysis began with descriptive statistics (mean and standard deviation) to summarize respondents' perceptions across the study variables. Reliability was confirmed using Cronbach's alpha.

For inferential analysis, the one-sample t-test was used to examine whether the mean values of the study dimensions significantly differed from the neutral midpoint of the five-point Likert scale (test value = 3). Mean scores below the neutral value indicate relatively insufficient levels of readiness, whereas scores approaching or exceeding the midpoint reflect moderate to higher levels of readiness.

Pearson correlation analysis was also employed to investigate the relationship between Artificial Intelligence readiness and smart university prospects in Algerian universities.

Table 1. : Demographic Profile of the Sample (N = 100)

Variable	Categories	Frequency (n)	Percentage (%)
Gender	Male	44	44%
	Female	56	56%
	Total	100	100%
Age group	Less than 35 years	22	22%
	From 35 to 50 years	65	65%
	From 51 to 64 years	13	13%
	65 years and above	0	0%
	Total	**100**	**100%**
Affiliated institution	University (Faculty)	75	75%
	Higher School	22	22%
	Research Center	3	3%
	Total	**100**	**100%**
Current administrative position	Director	5	5%
	Vice Director	2	2%
	Dean	1	1%
	Vice Dean	4	4%
	Head of department	7	7%
	Lecturers	70	70%
	Other	11	11%
	Total	**100**	**100%**
Years of experience	Less than 5 years	45	45%
	From 5 years to 10 years	26	26%
	11 years and more	29	29%
	Total	**100**	**100%**

5 RESULTS

5.1 Study Population, Sample, and Data Collection

The table data indicate that the study sample (N=100) exhibits a relative balance in terms of gender, with a slight predominance of females (56%) compared to males (44%). The predominant age group ranges between 35 and 50 years at a rate of 65%, reflecting the dominance of an active and stable professional stage within the academic environment. In terms of institutional affiliation, most of the sample members belong to universities (75%), followed by those working in higher schools (22%), while research centers represent the lowest percentage (3%). In terms of current position, lecturers constitute the majority (70%), whereas the “other” category includes various academic and administrative roles such as field coordinators, specialization coordinators, business incubator directors, and AI hub managers, in addition to other administrative and academic functions. Finally, concerning professional experience, the largest proportion of respondents has less than 5 years of experience (45%), indicating a relatively young academic profile within the sample.

5.2 Reliability and Aalidity of the Study Tool

The survey's reliability was assessed using Cronbach's alpha test, and the validity and reliability of its axes were assessed using correlation coefficients. If the survey is redistributed multiple times under the same conditions to the sample respondents, the same results would be recorded due to the study tool's reliability. This indicates the degree of stability of the results.

The validity coefficient is a measure of how accurately the scale measures what it is intended to assess. In mathematics, it is referred to as the dependability coefficient's square root.

The following tables display the measures of these tools.

Table 2. *Alpha-Cronbach test results for the questionnaire*

Number of statements	Stability coefficient
23	0.893

It is clear from the table above that the survey has a high reliability coefficient, reaching 0.893 for the total survey statements, which exceeds the acceptable threshold of 0.70. This indicates that the questionnaire has a very high degree of reliability and can be used in the applied field of study.

Table 3. *Reliability and validity coefficients of the survey axes*

Survey axes	Number of statements	Reliability coefficient	Validity coefficient
Digital tools	5	0.711	0.843
The human resources	5	0.785	0.886
The administrative and strategic framework	5	0.858	0.926
The first axis: University readiness to adopt artificial intelligence applications	15	0.883	0.939
The second axis: Prospects and challenges	8	0.836	0.914

Table 3, related to the validity and reliability of the questionnaire dimensions, shows that all dimensions exhibit good levels of reliability and validity. Cronbach’s Alpha reliability coefficients ranged from 0.711 to 0.883, while the validity coefficients ranged from 0.843 to 0.939. It is noted that the administrative and strategic framework dimension recorded the highest reliability, 0.858, and validity, 0.926, whereas the digital tools dimension recorded the lowest value, 0.711, although it remains within acceptable scientific limits.

Moreover, the overall dimensions, particularly the university readiness to adopt artificial intelligence applications dimension (0.883 for reliability and 0.939 for validity) and the prospects and

challenges dimension (0.836 and 0.914), show high levels, confirming that the scale is stable and does not contradict itself.

5.3 Analysis of the Extent of Agreement on the Dimensions of the Study

5.3.1 Analysis of the Level of Agreement on the Dimension of Digital Tools

Table 4, related to the digital tools dimension, shows that the availability and use of these tools in universities remain relatively limited, with an overall mean of 2.51 and a standard deviation of 0.67, reflecting a relatively low degree of agreement among the study participants.

In detail, the statement regarding the availability of digital infrastructure ranked first with a mean score of 2.80, indicating a moderate level of agreement, followed by management's reliance on information systems supported by smart technologies, 2.66, and the availability of artificial intelligence tools in administrative and academic activities, 2.60, both reflecting moderate levels of agreement. In contrast, the statements related to advanced applications of artificial intelligence, such as automated scheduling 2.32 and predictive data analysis 2.17, recorded the lowest scores, indicating limited implementation of advanced AI practices.

Table 4. The attitudes of the sample individuals toward the Digital tools

No.	The phrase	Number of statements	Standard deviation	Degree of agreement	Ranking
1)	The university provides sufficient digital infrastructure (high-speed internet, information systems, electronic devices...) Supports daily use.	2.80	1.08	Moderate	1
2)	The university administration relies on information systems supported by smart technologies to manage various administrative affairs and make decisions.	2.66	0.92	Moderate	2
3)	The university administration uses artificial intelligence systems for automatic scheduling and organization (such as room allocation, schedule planning, etc.)	2.32	0.99	low	4
4)	The university administration relies on predictive data analysis using artificial intelligence to forecast future needs.	2.17	0.88	low	5
5)	The university provides the opportunity to use artificial intelligence tools in administrative and academic aspects.	2.60	1.02	Moderate	3
Overall average		**2.51**	**0.67**	**low**	**-**

These results suggest that Algerian universities possess a relatively acceptable level of basic digital infrastructure; however, the integration of advanced artificial intelligence applications remains limited, particularly in predictive analytics and smart decision-making processes.

Table 5. The attitudes of the sample individuals toward Human Resources

No.	The phrase	Number of statements	Standard deviation	Degree of agreement	Ranking
1)	Professors and administrators possess basic technical skills that enable them to use artificial intelligence applications in making administrative decisions.	2.92	0.98	Moderate	2
2)	The university administration organizes continuous training programs for various administrative and academic bodies on applications of administrative artificial intelligence.	2.48	0.91	Low	5
3)	There are enough specialized competencies in artificial intelligence (engineers, researchers) within the university.	2.78	1.05	Moderate	3

No.	The phrase	Number of statements	Standard deviation	Degree of agreement	Ranking
4)	The university administration adopts mechanisms to encourage employees to use smart solutions in daily operations.	2.71	0.93	Moderate	4
5)	Professors and staff are aware that artificial intelligence is a support tool for administrative management and not a substitute for them.	3.66	0.96	High	1
Overall average		**2.91**	**0.71**	**Moderate**	**-**

5.3.2 Analysis of the Level of Agreement on the Human Resources Dimension

Table 5, related to the human resources dimension, shows that this dimension recorded a moderate overall level, with a mean score of 2.91 and a standard deviation of 0.71, reflecting a moderate degree of agreement among the respondents. In detail, the statement concerning the awareness of professors and staff regarding the role of artificial intelligence as a supportive administrative tool ranked first with a mean of 3.66 and a high level of agreement, indicating a positive perception of the importance of this technology. This was followed by the availability of basic technical skills among academic and administrative staff 2.92, the presence of specialized competencies in artificial intelligence 2.78, and the administration's adoption of mechanisms encouraging the use of smart solutions 2.71, all reflecting moderate levels of agreement. In contrast, the statement related to continuous training programs recorded the lowest mean score, 2.48, indicating a relatively low level of agreement and highlighting limitations in training and professional development efforts.

Accordingly, the results reflect an acceptable level of awareness and basic competencies; however, institutional support through continuous training programs remains relatively insufficient.

Table 6. *The attitudes of the sample individuals toward the administrative and strategic framework*

The phrase	Number of statements	Standard deviation	Degree of agreement	Ranking
1) The senior management supports the integration of artificial intelligence to transform the university into a "smart organization."	3.26	1.02	Moderate	1
2) The university allocates a specific annual budget for the development of administrative AI projects.	2.59	0.88	Low	5
3) The university adopts testing and evaluation mechanisms for smart solutions before generalizing them to various administrative departments.	2.71	0.91	Moderate	4
4) There are partnerships with external entities (Ministry of Higher Education, technology companies, startups, etc); to support the implementation of artificial intelligence at the university.	2.78	0.88	Moderate	2
5) The university has a clear strategic plan that includes goals and timelines for integrating artificial intelligence into administrative processes over the coming years.	2.78	0.88	Moderate	3
Overall average	**2.82**	**0.73**	**Moderate**	**-**

5.3.3 Analysis of the Level of Agreement on the Administrative and Strategic Framework Dimension

Table 6, related to the strategic and administrative framework dimension, shows that this dimension recorded a moderate overall level, with a mean score of 2.82 and a standard deviation of 0.73,

reflecting a moderate degree of agreement among the respondents. In detail, the statement concerning top management's support for integrating artificial intelligence ranked first with a mean of 3.26, indicating a positive orientation toward transforming universities into smart organizations. Other statements also recorded moderate scores, including partnerships with external entities 2.78, the existence of a clear strategic plan for AI integration 2.78, and the adoption of mechanisms for testing and evaluating smart solutions 2.71. In contrast, the allocation of a dedicated annual budget for AI projects recorded the lowest mean score of 2.59, reflecting a relatively limited level of financial support for AI initiatives.

These findings reveal a gap between strategic intention and practical implementation. Although university leadership demonstrates a positive orientation toward smart transformation, this orientation is not yet fully translated into concrete financial and operational support. Therefore, the results suggest that Algerian universities possess an acceptable strategic direction toward adopting artificial intelligence, but still require stronger financial commitment and executive mechanisms to ensure effective implementation.

Table 7. *The attitudes of the sample individuals toward the prospects and challenges dimension*

No.	The phrase	Number of statements	Standard deviation	Degree of agreement	Ranking
1)	AI management can enhance the efficiency and quality of university services in the long term.	4.15	0.67	High	3
2)	The adoption of artificial intelligence will contribute to improving the university's competitiveness and ranking in the future.	4.15	0.75	High	4
3)	Continuous training on artificial intelligence is a priority to ensure future sustainability.	4.20	0.80	Very high	1
4)	Adopting an innovation culture is a key factor in the success of the transition to smart management in universities.	4.14	0.85	High	5
5)	Smart tools improve the speed of processing daily administrative tasks effectively.	4.20	0.86	Very high	2
6)	The university is facing difficulties in instilling a culture of change among many of its employees.	3.76	1.03	High	6
7)	There are clear policies within the university governing the use of artificial intelligence applications and the protection of administrative data privacy.	3.12	1.03	Moderate	8
8)	The limited financial resources and budget allocated for artificial intelligence projects may hinder the implementation of future initiatives.	3.74	1.05	High	7
Overall average		**3.93**	**0.61**	**High**	**-**

5.3.4 Analysis of the level of agreement on the prospects and challenges dimension

Table 7, related to the prospects and challenges dimension, shows that this dimension recorded a high overall level, with a mean score of 3.93 and a standard deviation of 0.61, reflecting a high degree of agreement among the respondents. In particular, the statements concerning the importance of continuous training in artificial intelligence 4.20 and the role of smart tools in improving the speed of administrative task completion 4.20 achieved the highest mean scores, indicating very high levels of agreement. This was followed by statements related to improving the efficiency and quality of university services 4.15, enhancing competitiveness and university ranking 4.15, and promoting a culture of innovation 4.14, all reflecting high levels of agreement.

The findings also demonstrate awareness of several challenges associated with AI

implementation, particularly the difficulty of establishing a culture of change 3.76 and the limitation of financial resources allocated to AI projects 3.74. In contrast, the statement regarding the existence of clear policies regulating the use of artificial intelligence and the protection of administrative data privacy recorded the lowest mean score, 3.12, reflecting only a moderate level of agreement and indicating a relatively limited regulatory and ethical framework.

Overall, the results reflect strong optimism regarding the future role of artificial intelligence in universities. However, this optimism remains accompanied by persistent financial, organizational, and regulatory challenges that may affect the effectiveness of future implementation efforts.

5.4 Hypothesis testing

5.4.1 Testing the First Main Hypothesis (MH1)

MH1: Algerian universities do not demonstrate sufficient readiness to implement artificial intelligence management from the perspective of the study.

The main hypothesis is divided into three sub-hypotheses that must be tested independently first, before verifying the main hypothesis.

5.4.1.1 Testing the first sub-hypothesis

A one-sample t-test was conducted at the significance level of 0.05, which is shown in Table 8, to examine the level of availability of digital tools required for implementing Artificial Intelligence Management in Algerian universities

Table 8. T-test for the digital tools dimension

	Mean	Standard deviation	t	Sig
Digital tools	2.510	0.672	37.400	0.000

The results show that the mean score for the digital tools dimension is 2.51 (SD = 0.67), which is below the neutral value of 3, indicating a relatively low level of digital infrastructure and AI-related technological readiness in Algerian universities.

Although the one-sample t-test indicates a statistically significant difference (t = 37.400, Sig = 0.000), the direction of the mean suggests insufficient availability of digital tools. Therefore, H1a is supported, confirming that digital tools necessary for Artificial Intelligence Management are not adequately available.

5.4.1.2 Testing the second sub-hypothesis

A one-sample t-test was conducted at the significance level of 0.05, which is shown in Table 9, to assess the level of availability of qualified human resources required for Artificial Intelligence Management in Algerian universities.

Table 9. T-test for the human resources dimension

	Mean	Standard deviation	t	Sig
Human resources	2.910	0.711	40.902	0.000

The results indicate that the mean score for the human resources dimension is 2.91 (SD = 0.71), which is slightly below the neutral value of 3, reflecting a moderate but still insufficient level of human capital readiness for Artificial Intelligence implementation.

Despite the statistically significant t-test results (t = 40.902, Sig = 0.000), the findings suggest that human resources are not fully prepared to support AI integration. Therefore, H1b is supported, indicating limited but developing human resource readiness.

5.4.1.3 Testing the Third Sub-Hypothesis

A one-sample t-test was conducted at the significance level of 0.05, which is shown in Table 10, to evaluate the existence of a supportive strategic and administrative framework for Artificial Intelligence Management in Algerian universities.

Table 10. T-test for the strategic and administrative framework dimension

	Mean	Standard deviation	t	Sig
Strategic and administrative framework	2.824	0.734	38.458	0.000

The results show that the mean score for the strategic and administrative framework dimension is 2.82 (SD = 0.73), which is below the neutral

midpoint of 3, indicating a moderate but insufficient level of strategic readiness.

Although the results of the one-sample t-test are statistically significant (t = 38.458, Sig = 0.000), the mean value suggests that strategic and administrative support for Artificial Intelligence implementation remains limited. Therefore, H1c is supported.

Based on the above, and after testing the sub-hypotheses, the main hypothesis must be tested for validity.

A one-sample t-test was conducted at the significance level of 0.05, which is shown in Table 11, to assess the overall readiness of Algerian universities to implement Artificial Intelligence Management.

Table 11. *T-test for the readiness of the Algerian universities' axis*

	Mean	Standard deviation	t	Sig
The readiness of Algerian universities	2.748	0.589	46.579	0.000

Through the above table, the results indicate that the overall mean score is 2.748 (SD = 0.589), which is below the neutral midpoint of 3, reflecting a generally low to moderate level of readiness for Artificial Intelligence implementation in Algerian universities.

Despite the statistically significant t-test result (t = 46.579, Sig = 0.000), the findings confirm that the overall readiness remains insufficient. Therefore, H1 is supported, indicating that Algerian universities do not yet demonstrate adequate readiness for Artificial Intelligence Management implementation.

5.4.2 Testing the Second Main Hypothesis

MH2: Second main hypothesis: There is no statistically significant positive relationship between university readiness and future AI adoption prospects.

To test the validity of this hypothesis, we conducted a Pearson Correlation test at the significance level of 0.05, which is shown in Table 12, to examine the relationship between the readiness of Algerian universities and the prospects of Artificial Intelligence adoption.

Table 12. *Results of the correlation analysis between the readiness of Algerian universities to adopt AIM and prospects.*

	The readiness of Algerian universities	
Prospects	Pearson correlation coefficient	0.589
	Sig	0,000
	N	100

The results of the correlation analysis between the readiness of Algerian universities to adopt Artificial Intelligence Management and prospects indicate a moderate positive correlation, with a Pearson correlation coefficient (r = 0.589). This suggests that higher levels of institutional readiness are associated with more positive perceptions regarding the future adoption of Artificial Intelligence in Algerian universities.

The results also show that the level of statistical significance (Sig = 0.000) is lower than the level of significance adopted in the study 0.05, indicating that the relationship is statistically significant.

Therefore, **H2** is supported, confirming a statistically significant positive relationship between readiness and prospects.

6 DISCUSSION

The findings indicate that the readiness of Algerian universities to adopt Artificial Intelligence Management remains at a weak to moderate level across its three dimensions (digital tools, human resources, and strategic and administrative framework). This reflects a clear gap between the requirements of transitioning toward a smart university model and the current institutional reality. This situation can be attributed to relatively weak digital infrastructure, the need to further develop specialized human competencies, and the absence of a comprehensive strategic vision for the systematic and institutional adoption of Artificial Intelligence.

These findings are consistent with the existing literature emphasizing that the successful integration of Artificial Intelligence in institutions depends not only on technological availability but also on the integration of human resources and strategic governance. In this regard, Kassa and Worku (2025) highlight that the impact of Artificial Intelligence on organizational performance is

achieved when adequate training and clear managerial support are in place, which further supports the present study's results indicating limited human and strategic readiness in Algerian universities.

Similarly, the findings of Hyiamang and Liu (2025) support this trend, demonstrating that institutions adopting clear AI strategies and effectively integrating data, governance, and human resources are better positioned to transform Artificial Intelligence into tangible organizational value. This further highlights the lack of such integration within the university context under study.

In the same vein, the results are consistent with the theoretical perspective of Holmström and Hällgren (2022), who conceptualize Artificial Intelligence as a socio-technical process rather than merely a technical tool. This perspective helps explain that the limited readiness observed in Algerian universities is not solely attributable to technical constraints, but also to organizational and cultural factors influencing the implementation of Artificial Intelligence in higher education institutions.

The findings of Adamik and Sikora-Fernandez (2021) and Abiodun et al. (2023) further support the notion that a "smart organization" is grounded in the integration of technology, human resources, and organizational processes. This level of integration has not been sufficiently achieved in Algerian universities, which helps explain the overall moderate level of readiness identified in this study.

The results related to the strategic and administrative dimension reveal the existence of inconsistency within the strategic framework of Algerian universities, where leadership demonstrates a clear willingness to adopt Artificial Intelligence and move toward a smart university model. However, this intention is not adequately matched by financial commitment, as reflected in the limited allocation of dedicated budgets. This suggests that Algerian universities exhibit a form of declarative readiness, which has not yet been fully translated into operational and financial support.

Regarding the relationship between readiness and prospects, the results show a statistically significant moderately strong positive correlation ($r = 0.589$), which is consistent with previous research suggesting that improving infrastructure and organizational capabilities enhances the ability to adopt technological innovation. However, the moderate strength of the relationship suggests that professors' perceptions of prospects are not solely determined by technological readiness but are also influenced by other factors such as organizational culture, trust in technology, and digital transformation policies.

Thus, the results suggest that the transition toward a "smart university" in Algeria is still in an ongoing transition process, requiring stronger integration between technical, human, and strategic dimensions to ensure effective and sustainable adoption of Artificial Intelligence.

7 CONCLUSION

The study contributes to the literature by providing empirical evidence on Artificial Intelligence readiness in higher education within a developing country context. The findings also indicate a generally positive awareness among university staff regarding the prospects of using Artificial Intelligence in higher education. In addition, the study revealed a moderate positive relationship between readiness and prospects, highlighting the importance of strengthening institutional readiness as a key condition for a successful transition toward an AI-based smart university.

Based on these findings, it is recommended that universities allocate dedicated budgets and establish specialized Artificial Intelligence units to support effective implementation. It is also essential to develop a clear ethical and legal framework governing the use of Artificial Intelligence in Algerian universities, ensuring its responsible, transparent, and secure adoption within the academic environment.

Further recommendations include developing digital infrastructure within Algerian universities to support Artificial Intelligence applications, enhancing the training and qualification of human resources in Artificial Intelligence and digital transformation, integrating Artificial Intelligence into higher education strategies as a cornerstone for smart university transformation, preparing a comprehensive funded executive plan to ensure sustainability of AI projects, encouraging research

and applied innovation through dedicated university hubs and labs, and promoting partnerships with technological institutions at both national and international levels.

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LIQUIDITY-PROFITABILITY TRADE-OFF: EVIDENCE FROM SAUDI ARABIAN FOOD AND BEVERAGES PRODUCTION COMPANIES

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ABSTRACT

The growth and survival of firms depend on liquidity and profitability, which are often in conflict due to the competing allocation of financial resources. This study aims to investigate the liquidity-profitability trade-off in a sample of 21 companies operating in the food and beverage sector and listed on the Saudi Stock Exchange, for the year 2024. Using Data Envelopment Analysis (DEA), the study evaluates the efficiency of the sample firms in managing both liquidity and profitability based on two inputs (total assets, operating expenses) and two outputs (operating cash flow, net profit). Principal Component Analysis (PCA) is then applied; the findings indicate a heterogeneous pattern across firms, with a greater share exhibiting a liquidity-oriented profile compared to those driven by profitability. Only a limited number of firms demonstrate a balanced position between the two dimensions, while a substantial proportion performs weakly in both liquidity and profitability. This pattern reflects a lack of uniform financial behavior among firms and implies that the liquidity–profitability relationship is not systematic and cannot be adequately explained by a simple trade-off mechanism.

1 INTRODUCTION

The performance of any economic activity is primarily conditioned by the existence of liquidity. Liquidity represents a fundamental factor that ensures the continuity of business operations, as firms must maintain sufficient liquid resources to meet their short-term obligations toward suppliers, creditors, and other stakeholders. Firms that fail to maintain adequate liquidity may encounter difficulties in settling their liabilities on time, which may disrupt operational activities, weaken their reputation in the market, and in severe cases lead to financial distress or bankruptcy due to inefficient asset management (Ayoush et al., 2021). At the same time, profitability remains a central objective for any organization, as it reflects the firm's ability to generate returns from its operations and efficiently utilize its available resources.

Liquidity and profitability are two crucial dimensions that organizational management

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continuously evaluates to assess the financial health and sustainability of a firm. However, within the framework of financial management, liquidity and profitability are often characterized by a trade-off relationship. Maintaining an appropriate balance between liquidity and profitability has become a critical challenge for firms operating in increasingly competitive and uncertain environments. While high liquidity ensures the firm's ability to meet short-term obligations and reduces financial risk, it may also imply holding idle resources that could otherwise be invested in profitable opportunities. Conversely, pursuing higher profitability may require reducing liquid assets and increasing investments in long-term or less liquid assets, which can expose the firm to liquidity risk. Consequently, achieving an optimal balance between these two financial objectives constitutes a fundamental challenge for financial managers, as it directly influences both operational efficiency and the strategic sustainability of the enterprise (Sujatha et al., 2025).

This issue becomes particularly significant in the food and beverage production sector, which is characterized by high operational costs, significant inventory requirements, and continuous demand fluctuations. In the context of Saudi Arabia, the food and beverage production industry plays a vital role in supporting economic diversification and ensuring food security. Firms operating in this sector must carefully manage their working capital to maintain sufficient liquidity for day-to-day operations while simultaneously achieving satisfactory levels of profitability in a competitive market environment.

Accordingly, this study aims to investigate the liquidity-profitability trade-off within Saudi Arabian food and beverage production companies. It will be interesting to see if these firms are able to ensure adequate liquidity while achieving profitability. In other words, this study seeks to assess the efficiency of the targeted firms to make a trade-off between liquidity and profitability.

This study addresses the following research question:

RQ: To what extent do Saudi Arabian food and beverage production companies exhibit liquidity-profitability trade-off, and how does this trade-off vary across firms when assessed through Data Envelopment Analysis (DEA) and Principal Component Analysis (PCA)?

Accordingly, the following hypotheses are proposed:

H_1: PCA reveals distinct liquidity–profitability patterns among Saudi Arabian food and beverage production companies.

H_2: DEA-efficient firms exhibit a more balanced liquidity–profitability profile compared to DEA-inefficient firms.

H_3: Firms listed on the Main Market exhibit a stronger liquidity orientation than firms listed on the Nomu Parallel Market.

The rest of this study is organized as follows: section 2 reviews the concept of liquidity and profitability, as well as the extant literature about the relationship between them; section 3 reports the specific procedure of data collection and research method; section 4 provides the results and discussion. The study concludes with a summary of the findings and the directions for future research.

2 THEORETICAL FRAMEWORK AND LITERATURE REVIEW

Liquidity has different meanings across contexts. In this study, it refers specifically to liquidity in non-financial firms. In such context, liquidity means the degree to which an asset or security can be quickly bought or sold in a market without affecting the asset's price (Schwartz et al., 2023). Liquidity refers to the conversion of funds. Almost all of a firm's assets, whether current or non-current, can be converted into cash. However, the time required for this conversion varies depending on the type of asset. Receivables and other short-term assets are typically converted into cash more quickly, whereas long-term assets require a longer period to be transformed into cash. Therefore, liquidity can be understood as a measure of an asset's ability to be transformed into cash (Štangová & Víghová, 2021).

The principal objective of liquidity management is always to maintain liquidity so that a firm can continue to meet its commercial objectives. But there is also the task of managing the liquidity in an optimal way in the best interests of the organisation. The general approach to liquidity

management in practice has already been set out as safety, liquidity and profitability (Moir, 1999).

Profitability is the ability of firm to earn profits in relation to sales, total assets and own capital. The firm's ability to earn profits will describe the level of effectiveness of the firm's management (Wiriastini et al., 2021). Profitability denotes a firm's ability to generate income relative to its expenses over a specific period. It is a measure of efficiency. Profitability is driven by the effective utilization of both the effective long-term and short-term assets to produce goods and services that yield revenue exceeding costs (Sujatha et al., 2025). Profitability refers to the firm's ability to generate revenues more than the cost of generating such revenues (Uremadu et al., 2012). Profitability is a picture that measures how well the firm can generate profits from operational processes that have been implemented to ensure the continuity of the firm in the future (Reschiwati et al., 2020).

Liquidity and profitability are two vital aspects of corporate business life (Vishnani & Shah, 2007). In order to achieve the desired performance, firms must maintain acceptable levels of liquidity (Ayoush et al., 2021). Corporations are required to maintain a daily balance between liquidity and profitability while conducting their operations (Kaddumi & Ramadan, 2012). It is, therefore, essential to maintain an adequate degree of liquidity for smooth running of the business operations. Liquidity should be neither excessive nor inadequate. Excessive liquidity indicates idle funds that do not generate, while inadequate liquidity negatively affects the firm's creditworthiness, disrupts production, and limits earning capacity (Vishnani & Shah, 2007).

While both liquidity and profitability are essential, they are often in conflict due to the allocation of financial resources. Maintaining high liquidity generally requires cash holding or current assets that yield low returns whereas, maximizing profitability involves investing in long-term or higher-return assets, potentially reducing liquidity. This conflict is known as the liquidity-profitability trade-off. This trade-off has attracted considerable attention in various industries, particularly in manufacturing, where financial managers are required to balance risk and return (Safdar et al., 2016).

The relationship between liquidity and profitability has been widely debated in literature, with mixed empirical evidence. Early research on working capital and liquidity management has predominantly centered on the liquidity–profitability nexus (Chen & Yu, 2021) . Much of this literature explores the extent to which liquidity indicators, such as working capital and the current ratio, influence firm profitability (Duan & Niu, 2020).

(Rehman et al., 2015) studied the relationship between liquidity and profitability of firms listed in Saudi Stock Exchange (Tadawul). The overall results revealed that there is only one positive significant relationship between Return on Assets and Current Ratio. Further, it is revealed that there is negative but insignificant relationship between the Return on Assets and Quick Ratio and Cash Ratio. Likewise, in the case of Return on Equity, there is insignificant relationship with the three selected independent variables, namely, Current Ratio, Quick Ratio and Cash Ratio.

A significant stream of empirical studies reports a negative association between liquidity and profitability, arguing that excessive liquidity may reflect inefficient resource allocation, where idle funds generate lower returns (Ayoush et al., 2021, Tan & Tuluca, 2023). In this context, (Syifa et al., 2026) found that profitability has a significant negative effect on cash holding. (Al Barak, 2025) showed that excessive liquidity may reduce profitability due to underutilized resources, while insufficient liquidity increases financial risk despite the potential for higher returns. The study further emphasized the importance of achieving an optimal balance between liquidity and profitability to ensure financial stability and sustainability.

In contrast, other studies suggest the existence of a positive association, indicating that adequate liquidity can enhance a firm's operational flexibility and financial performance. In this regard, (Bibi & Amjad, 2017) found that the current ratio, a key liquidity measure, was significantly positively related to profitability among firms listed on the Karachi Stock Exchange. Similarly, Jaworski and Czerwonka (2021) indicate that in environments with high availability of private sector credit, profitability and liquidity tend to grow together, reflecting a positive dependence. (Shubita, 2023)

found a significant positive relationship between cash flow and profitability in Jordanian banks, indicating that banks can improve their profitability by increasing their cash flow. Jaworski and Czerwonka (2021) conducted a meta-analysis on the relationship between profitability and liquidity across multiple empirical studies and found that the direction and strength of this relationship vary significantly depending on macroeconomic and institutional conditions, indicating that there is no universally consistent effect of liquidity on profitability.

Such inconsistencies suggest that the liquidity–profitability relationship is highly context-dependent rather than structurally fixed. Firm-specific characteristics, industry dynamics, and temporal conditions appear to play a critical role in shaping this relationship (Czerwi ´nska-Kayzer et al., 2021). While (Rodriguez, et al., 2024) explains the liquidity–profitability trade-off, through firm life cycle theory, by showing that young firms prioritize profitability to support growth, while mature firms shift their focus toward maintaining higher liquidity to ensure financial stability and meet operational needs.

Despite the extensive literature examining the relationship between liquidity and profitability, most previous studies have relied primarily on conventional econometric techniques, such as correlation and regression analysis. While these approaches provide useful insights, they may not fully capture the multidimensional nature of firms' financial performance. Moreover, prior research has mainly focused on general manufacturing sectors, with limited attention given to food and beverage production companies, particularly within the Saudi Arabian market. To address these gaps, the present study provides new empirical evidence on the liquidity–profitability trade-off by integrating Data Envelopment Analysis (DEA) and Principal Component Analysis (PCA) methods to evaluate food and beverage production companies listed on the Saudi stock exchange.

3 DATA AND METHODOLOGY

This study uses quantitative research design. The research design is cross-sectional, which means that data is collected at a single point in time. This design is appropriate for investigating the relationship between two variables (liquidity and profitability) in a specific population (Saudi Arabian companies). The sample in this study comprises 21 companies operating in the food and beverage sector and listed on the Saudi Stock Exchange. The sample was selected based on the availability of consistent and complete data and represents 67% of the total number of food and beverage production companies listed on the Saudi Stock Exchange (Tadawul) for the year 2024.

This section describes the DEA method used to assess the efficiency of the sampled firms. The DEA model is a deterministic nonparametric method for estimating the technical efficiency of decision-making units (DMUs). Measurement of efficiency by the DEA model can be done according to two orientations: output orientation, orientation towards the maximization of outputs; and input orientation, oriented towards the minimization of inputs (Benbachir, 2025).

The suitable number of input-output variables is determined by meeting the recommended assumption prior to performing DEA (Cooper et al., 2002):

$$N \geq \text{Max}\ (I \,.\, J,\ 3(I + J)) \qquad (1)$$

Where N = number of DMUs; I = number of inputs; and J = number of outputs.

This study specified two inputs (total assets, operating expenses) and two outputs (operating cash flow, net profit) to evaluate the efficiency of the firms under study in managing liquidity and profitability.

The correlation between the two outputs, operating cash flow and net income is 0.31, indicating a weak relationship. This means that firms with higher liquidity don't necessarily achieve proportionally higher profitability and supports the inclusion of operating cash flow and net income as separate dimensions in the DEA model to capture both liquidity and profitability.

In this analysis, we use the CCR model, initiated by Charnes et al. (1978), and BCC model, initiated by Banker et al. (1984). The CCR model measures the technical efficiency of each DMU, assuming that the returns to scale are constant (CRS), while the BCC model decomposes the technical efficiency into two components, the pure technical

efficiency and the scale efficiency, by considering the variable returns to scale (VRS). Our model is input oriented, which means that it minimizes the level of input for a given level of output. DEA efficiency scores were computed using DEAP (Version 2.1). The results are presented in Table 1.

Table 1. CRS and VRS scores of the sampled companies

Companies	CRS	VRS	Scale
Savola Group	**1.000**	**1.000**	**1.000**
Sadafco	0.540	**1.000**	0.540
Almarai	0.477	**1.000**	0.477
Tanmiah	0.125	0.125	0.999
Naqi	0.405	0.426	0.953
First Mills	0.490	**1.000**	0.490
Modern Mills	0.596	**1.000**	0.596
Arabian Mills	0.478	0.938	0.510
Fourth Milling	0.619	**1.000**	0.619
Entaj	0.146	0.149	0.980
Sinad Holding	0.030	0.034	0.871
Hb	0.313	0.316	0.990
Nadec	0.385	0.736	0.523
Aljouf	0.296	0.298	0.994
Fesh Fash	0.683	**1.000**	**0.683**
Fadeco	0.265	0.488	0.544
Nofoth	**1.000**	**1.000**	**1.000**
Balady	**1.000**	**1.000**	**1.000**
Horizon Food	0.243	0.768	0.317
Sama Water	0.680	0.733	0.928
Smc	0.588	0.687	0.856

Source : Author's calculations using DEAP, version 2.1

Based on the DEA results, the sampled companies can be classified into two categories as follows:

Category 1: Efficient Companies

Group 1: Fully efficient companies (technical and scale efficiency)

A limited number of companies achieved full efficiency under both CRS and VRS assumptions, with scale efficiency equal to unity. These companies operate on the efficiency frontier and serve as benchmark units for the rest of the sample. This group includes Savola Group, Nofoth, and Balady**.**

Group 2: Technically efficient but scale inefficient companies

This group comprises companies that achieved full pure technical efficiency (VRS = 1) but exhibited scale inefficiency (CRS < 1), indicating suboptimal operating size despite sound managerial performance. Companies in this category include Sadafco, Almarai, First Mills, Modern Mills, Fourth Milling and Fesh Fash**.**

Category 2: Inefficient Companies

Group 1: Technically inefficient companies with near-optimal scale

Companies in this group operate at a scale close to the optimal level but display relatively low technical efficiency, suggesting that inefficiency is mainly driven by internal managerial or operational factors. This group includes Tanmiah, Naqi, Entaj, Hb, Aljouf, and Sama Water.

Group 2: Technically and scale inefficient Companies

Several companies suffer from inefficiency in both technical and scale dimensions, as all efficiency scores are below unity, reflecting managerial shortcomings and inappropriate scale of operation. This group includes Arabian Mills, Sinad Holding**,** Nadec, Fadeco, Horizon Food and Smc.

The results derived from DEA are subject to certain limitations, as the computation of a single efficiency score for each firm—based on the simultaneous use of inputs and outputs—primarily reflects the efficiency without clearly distinguishing between liquidity and profitability orientations. Given that the main objective of this study is to examine the trade-off between liquidity and profitability, a more disaggregated approach is adopted. Specifically, efficiency scores are calculated for each possible combination of inputs and outputs using DEA. These scores are subsequently analysed using PCA, thereby enabling a more refined assessment of the liquidity and profitability positions of the firms within the sample.

If total assets are denoted by **A**, operating expenses by **B**, operating cash flow by **1**, and net profit by **2**, this yields nine distinct components based on the possible input–output combinations. The partial efficiency measures (A1, A2, A12, AB1, AB2, AB12, B1, B2, and B12) are computed using VRS assumption of the DEA model, as it allows the isolation of pure technical efficiency by controlling for scale effects. This choice ensures that the subsequent PCA captures managerial performance in generating liquidity and profitability, rather than differences attributable to firm size.

Table 2. Partial Efficiency Scores of the Sampled Companies

Companies	A1	A2	A12	AB1	AB2	AB12	B1	B2	B12
Savola Group	0.299	1.000	1.000	0.299	1.000	1.000	0.148	1.000	1.000
Sadafco	0.903	0.353	1.000	0.903	0.353	1.000	0.378	0.284	0.502
Almarai	1.000	0.124	1.000	1.000	0.238	1.000	1.000	0.238	1.000
Tanmiah	0.123	0.082	0.125	0.123	0.091	0.125	0.058	0.057	0.058
Naqi	0.386	0.252	0.403	0.426	0.294	0.426	0.274	0.241	0.274
First Mills	0.567	0.199	0.596	0.889	0.578	1.000	0.889	0.578	1.000
Modern Mills	0.946	0.319	0.977	0.966	0.559	1.000	0.915	0.559	0.993
Arabian Mills	0.721	0.186	0.728	0.919	0.411	0.938	0.919	0.411	0.938
Fourth Milling	0.963	0.287	0.967	1.000	0.513	1.000	1.000	0.513	1.000
Entaj	0.133	0.050	0.133	0.149	0.080	0.149	0.131	0.080	0.131
Sinad Holding	0.027	0.028	0.034	0.030	0.032	0.034	0.024	0.027	0.027
Hb	0.287	0.135	0.287	0.316	0.135	0.316	0.119	0.083	0.119
Nadec	0.629	0.261	0.727	0.629	0.349	0.736	0.433	0.349	0.617
Aljouf	0.290	0.141	0.290	0.298	0.227	0.298	0.298	0.227	0.298
Fesh Fash	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Fadeco	0.452	0.488	0.488	0.452	0.488	0.488	0.285	0.294	0.294
Nofoth	1.000	0.503	1.000	1.000	0.503	1.000	0.128	0.093	0.128
Balady	1.000	0.660	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Horizon Food	0.229	0.323	0.323	0.662	0.768	0.768	0.662	0.768	0.768
Sama Water	0.680	0.318	0.680	0.733	0.321	0.733	0.380	0.279	0.380
Smc	0.684	0.499	0.684	0.687	0.499	0.687	0.239	0.219	0.239

Source: Author's calculations using DEAP, version 2.1

As shown in Table 2**,** interpreting the efficiency score results, which fall within nine possible combinations (A1, A2, A12, AB1, AB2, AB12, B1, B2, and B12), is difficult. Therefore, the PCA method is employed as a complementary approach to the DEA method in order to improve its ability to distinguish between firms toward liquidity and profitability. This is achieved by reducing the number of variables in a manner that facilitates a clearer analysis of liquidity and profitability indicators of the sampled firms.

4 RESULTS AND DISCUSSION

The application of the PCA method involves several steps, which were implemented using the Statistical Package for the Social Sciences (SPSS), version 20.

4.1 Evaluation of Data Suitability: KMO, Bartlett's Test and communalities

The Kaiser-Meyer-Olin (KMO) Test and Bartlett's test are shown in Table 3 with necessary interpretations.

Table 3. *KMO test and Bartlett's test table*

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy		0.655
Bartlett's Test of Sphericity	Approximate Chi-Square	415.563
	Df	36.
	Bartlett Significance	0.000

Source: Author's calculations using SPSS, version 20

Sampling adequacy is measured using the Kaiser-Meyer-Olkin (KMO) index, which is considered significant if it exceeds 0.5. KMO reached 0.655, indicating an acceptable level of suitability for applying PCA. This value suggests that the correlations among the variables are sufficient to proceed with factor extraction.

In addition, Bartlett's Test of Sphericity was statistically significant (Chi-square = 415.563, df = 36, $p < 0.001$), confirming the presence of significant correlations among the variables. Therefore, the null hypothesis of an identity correlation matrix is rejected. These results collectively indicate that the dataset is appropriate for conducting PCA.

Table 4 shows the proportion of variance explained for each variable by the extracted factors.

The extraction values ranged between 0.732 and 0.967, indicating that the extracted factors explain a high proportion of variance for all variables within the factor structure and supports the adequacy of the model.

Table 4. Communalities

	A1	A2	A12	AB1	AB2	AB12	B1	B2	B12
Initial	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Extraction	0.882	0.834	0.839	0.949	0.967	0.923	0.732	0.915	0.770

Source: Author's calculations using SPSS, version 20

4.2 Determining the Number of Principal Components

The number of principal components can be determined based on total variance of the studied variables. Table 5 shows the eigenvalue of each component, the percentage of explained variance, as well as the cumulative percentages of variance before and after extraction, in addition to the results after rotation.

Table 5. Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	6.319	70.206	70.206	6.319	70.206	70.206	4.531	50.340	50.340
2	1.491	16.568	86.774	1.491	16.568	86.774	3.279	36.434	86.774
3	0.843	9.368	96.142						
4	0.192	2.129	98.272						
5	0.118	1.306	99.577						
6	0.026	0.294	99.871						
7	0.011	0.119	99.990						
8	0.001	0.007	99.998						
9	0.000	0.002	100.000						

Source: Author's calculations using SPSS, version 20

The results of Table 5 indicate that the first two principal components have eigenvalues greater than one (6.319 and 1.491), explaining 70.206% and 16.568% of the total variance, respectively. In accordance with the Kaiser criterion, only these two components were retained, accounting for a cumulative variance of 86.774%, which reflects an adequate level of data representation.

After rotation, the explained variance was redistributed between the retained components, with the first component accounting for 50.340% and the second for 36.434%, while the cumulative explained variance remained unchanged. Overall, the PCA successfully reduced the initial set of nine variables to two meaningful components without significant loss of information.

The calculated Eigenvalue of different components is illustrated in a graphic known as Scree plot.

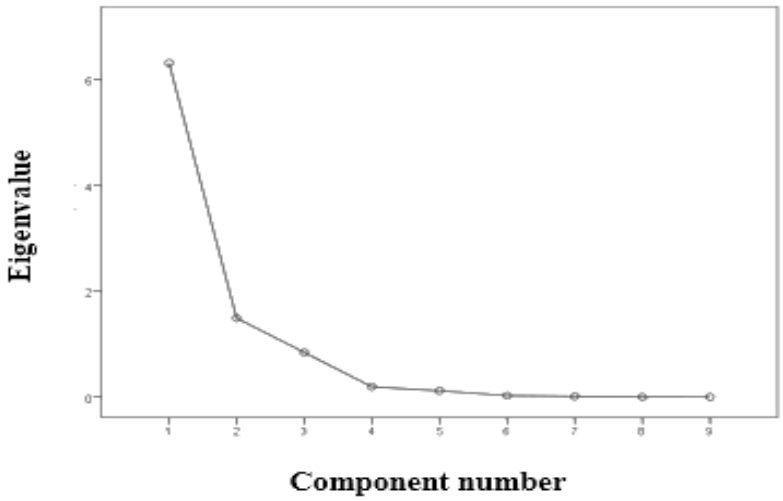


Figure 1. *Scree Plot of Eigenvalues*
Source: Generated using SPSS, version 20

As shown in Figure 1, a clear inflection point (elbow) appears after the second component, followed by a gradual decline in eigenvalues. This indicates that the first two components account for the substantial proportion of the total variance, while the remaining components contribute marginally. The convergence of the Kaiser criterion and the Scree Plot confirms the robustness of retaining two principal components.

4.3 Principal Components and Distribution of Companies

This section presents the principal components matrix before and after rotation (Table 6), followed by the distribution of the companies in a scattered pattern (Figure 2).

The component matrix presented the initial loadings of each variable on the extracted components. As shown in Table 6, most variables have high values on the first component, before rotation, indicating that it accounts for a large portion of the variance. The axes were rotated using the varimax method to achieve a simpler and more interpretable factor structure. After rotation, the high loadings became higher and the low loadings became lower than they were before rotation. Negative loadings also disappeared. Therefore, the rotation improved the interpretation of the two extracted principal components. The variable with the strongest correlation with the first component is AB1, followed by A1, which means that liquidity represents the first principal component. As for the second component, the variable with the strongest correlation is AB2, followed by B2, and then A2, which means that profitability represents the second principal component.

Table 6. *Partial Efficiency Scores of the Sampled Companies*

	Before Rotation		After Rotation	
	Component		Component	
	1	2	1	2
AB1	0.868	-0.443	0.958	0.177
A1	0.821	-0.456	0.929	0.138
AB12	0.950	-0.146	0.843	0.462
B1	0.779	-0.305	0.820	0.244
A12	0.902	-0.156	0.811	0.426
B12	0.877	0.008	0.691	0.540
AB2	0.829	0.529	0.336	0.924
B2	0.798	0.527	0.313	0.904
A2	0.665	0.626	0.147	0.901

Source: Author's calculations using SPSS, version 20

In light of the foregoing, the liquidity-profitability trade-off in Saudi Arabian food and beverages production companies can be examined by analysing the position of each firm on the coordinate system, where the horizontal axis represents liquidity and the vertical axis represents profitability. Based on the Figure 2, out of 21 Saudi Arabian food and beverages production companies, only two companies

achieved a balance between liquidity and profitability and were positioned in the upper-right quadrant of the scatter plot. Eleven companies exhibited a liquidity-profitability trade-off; among them, two demonstrated a profitability-oriented profile, and were located in the upper-left quadrant, while nine showed a liquidity-oriented orientation and were positioned in the lower-right quadrant. The remaining eight companies did not display a clear orientation due to weak performance in both liquidity and profitability dimensions and were located in the lower-left quadrant.

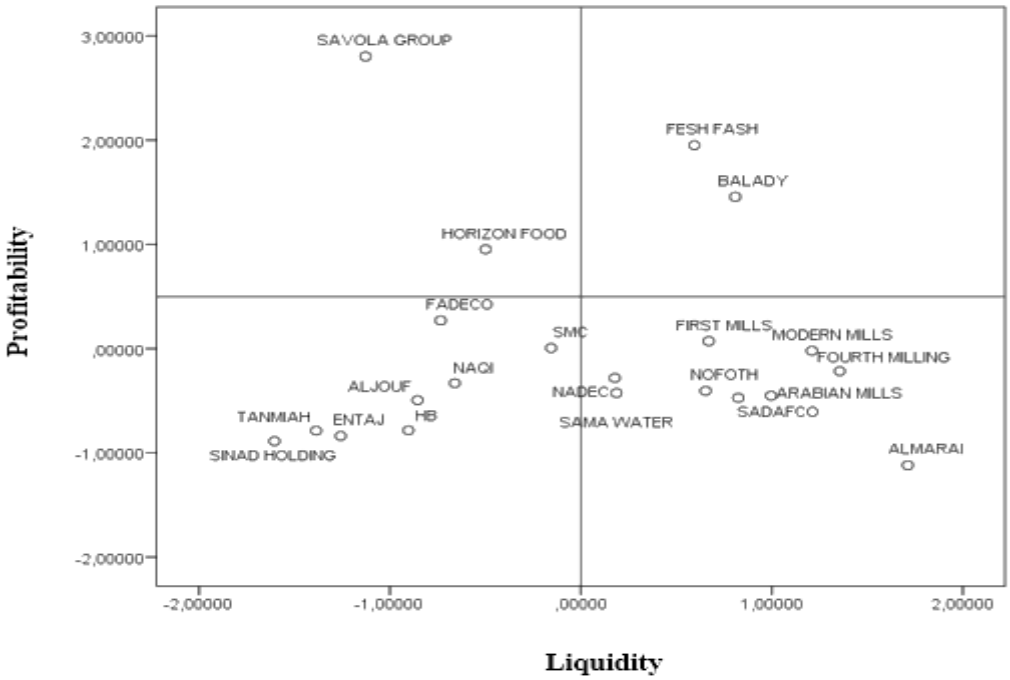


Figure 2. *Screen Plot of Eigenvalues*
Source: Generated using SPSS, version 20

According to these findings, Hypothesis 1 (H_1) is accepted, as PCA successfully identified distinct liquidity–profitability patterns among Saudi Arabian food and beverage production companies. Firms were clearly classified into balanced, liquidity-oriented, profitability-oriented, and weak-performance groups, reflecting substantial heterogeneity in financial behavior across firms.

The PCA results reveal the structural orientation of firms along the liquidity–profitability dimensions. Fesh Fash and Balady were identified as balanced, exhibiting intermediate positions on both liquidity and profitability. These firms correspond to the first DEA category, indicating that relative efficiency aligns with a balanced financial profile. This result is consistent with studies that have demonstrated a positive relationship between liquidity and profitability (Rehman et al., 2015, Bibi & Amjad, 2017, Jaworski and Czerwonka, 2021, and Shubita, 2023).

The remaining efficient firms according to DEA, represented by Nofoth, Sadafco, Almarai, First Mills, Modern Mills, and Fourth Milling, primarily emphasize liquidity, while Savola demonstrate a profitability-focused profile. These orientations reflecting that firms prioritizing either dimension can still achieve relative technical efficiency.

However, there are notable exceptions, including Arabian Mills, Nadec**,** Sama Water**,** and Horizon Food, which fall into the completely inefficient DEA category, despite their orientation toward liquidity or profitability in the PCA. This discrepancy highlights that DEA measures technical efficiency in resource conversion and optimal scale, whereas PCA captures the structural financial orientation independent of absolute efficiency. Such cases illustrate that some firms may pursue one dimension successfully yet remain inefficient overall. These observations are consistent with findings of studies that have demonstrated a negative relationship between liquidity and profitability (Rehman et al., 2015, Ayoush et al.,

2021, Tan & Tuluca, 2023, Syifa et al., 2026, Al Barak, 2025). The remaining inefficient firms according to DEA, which constitute the majority of this category, including Sinad Holding, Smc, Tanmiah, Naqi, Entaj, Hb, and Aljouf**,** exhibit poor performance in both liquidity and profitability dimensions, confirming their overall inefficiency.

In light of these findings, Hypothesis 2 (H2) is rejected, as the results do not provide sufficient evidence that firms fully efficient according to DEA exhibit a lower liquidity–profitability trade-off compared to inefficient firms. While some DEA-efficient firms exhibited a balanced liquidity–profitability profile, other efficient firms demonstrated either liquidity-oriented or profitability-oriented strategies. This indicates that DEA efficiency may be achieved through different financial orientations rather than through a perfectly balanced liquidity–profitability position.

The findings of this study reveal a clear divergence in financial behavior between firms listed on the Main Market (Savola Group, Sadafco, Almarai, Tanmiah, Naqi, First Mills, Modern Mills, Arabian Mills, Fourth Milling, Entaj, Sinad Holding, Hb, Nadec, Aljouf) and those in the Nomu Parallel Market (Fesh Fash, Fadeco, Nofoth, Balady, Horizon Food, Sama Water, and Smc). Firms in the Main Market generally demonstrate a liquidity-oriented strategy, reflecting a more conservative financial approach aimed at ensuring stability and reducing financial risk, with the notable exception of Savola Group, which appears more profitability-driven due to its expansion and investment-oriented strategy. In contrast, firms listed on the Nomu Parallel Market tend to prioritize profitability, likely driven by growth pressure and limited financial flexibility. However, Balady and Fesh Fash deviate from this pattern by exhibiting a balanced position between liquidity and profitability, suggesting an optimal financial management strategy that aligns with efficient working capital utilization.

These findings support for Hypothesis (H3), as firms listed on Main Market generally display a higher liquidity-oriented strategy compared to Nomu-listed firms, which tend to prioritize profitability. However, the presence of limited deviations, particularly Savola Group on the Main Market, suggests that firm-specific strategies may partially explain deviations from this general pattern.

These results are consistent with the liquidity–profitability trade-off theory and further support the firm life cycle perspective, which posits that financial priorities shift from profitability in early stages toward liquidity preservation as firms mature Rodriguez et al. (2024).

5 CONCLUSIONS

This study examines the existence of a liquidity–profitability trade-off among Saudi Arabian food and beverages production companies by integrating DEA and PCA. The results reveal a heterogeneous distribution of firms. A relatively larger proportion are oriented toward liquidity compared to those focused on profitability, while only a small number achieve a balanced position. In addition, a considerable group of firms exhibits weakness in both dimensions.

This pattern indicates the absence of a uniform financial behavior across firms and suggests that the relationship between liquidity and profitability cannot be reduced to a simple trade-off mechanism. The firm life cycle perspective further supports this interpretation, as variations in financial behavior may reflect different stages of development rather than a unified strategic choice. Overall, the evidence suggests that the liquidity–profitability relationship is not systematic. Instead, it appears to be context-dependent and influenced by firm-specific characteristics, including their position within the life cycle, as well as operational and financial conditions.

Finally, future research should extend this analysis by incorporating additional variables, examining other sectors and countries, and covering longer time periods. Moreover, combining non-parametric techniques (DEA and PCA), which capture efficiency and structural patterns, with econometric models that test causal relationships may provide a more comprehensive understanding of the liquidity–profitability relationship.

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ORIGINAL RESEARCH ARTICLE
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PANEL EVIDENCE ON FINANCIAL DRIVERS OF ALGERIAN FIRM'S RETURNS (2019-2024)

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ABSTRACT

This study investigates the influence of key financial variables on the profitability of Algerian firms using panel data from 37 companies spanning 2019–2024. Return on Assets (ROA) and Return on Equity (ROE) serve as dependent variables, while long-term debt ratio, financial leverage, liquidity, and firm size constitute the primary explanatory factors. Panel regression analysis reveals a significant negative association between long-term debt and ROA, indicating reduced asset efficiency under high indebtedness, whereas firm size exerts a positive effect on both profitability measures. Liquidity shows no significant impact, and financial leverage displays mixed effects across models. Robustness is confirmed through comprehensive diagnostic tests including heteroskedasticity, autocorrelation, and multicollinearity assessments. These findings offer critical implications for financial decision-making and policy formulation within Algeria's dynamic business environment. The analysis employs fixed effects models to control for firm-specific heterogeneity, providing reliable evidence on debt-profitability dynamics in an emerging market context. Such insights aid managers in optimizing capital structures amid economic volatility.

1 INTRODUCTION

In recent decades, global financial markets have experienced profound changes driven by increasing globalization, rapid technological innovation, and shifting regulatory environments. These developments have reshaped how capital is allocated, risk is managed, and firms operate across diverse economic landscapes. Emerging economies, including Algeria, confront both significant challenges and promising prospects as they navigate this complex milieu. Understanding the multifaceted factors that influence firm-level outcomes, such as profitability and market valuation, is essential to comprehending broader economic dynamics and enhancing financial market efficiency.

While extensive research has focused on financial indicators like leverage, liquidity, size, and

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performance metrics in advanced economies, the specific interplay of these variables within Algeria's unique market setting demands further examination. Between 2019 and 2024, Algerian financial markets endured notable fluctuations due to a combination of internal policy shifts, external economic shocks, and evolving industry patterns. Investigating how key financial metrics impact firm outcomes during this turbulent period provides valuable insights that reflect the nuanced realities faced by firms operating in transitional economies. Such analysis contributes to enriching the empirical literature on financial performance determinants specific to Algeria's economic context.

1.1 Study Problem

The problem addressed in this study is the need to understand how key financial variables influence the profitability of Algerian companies in a rapidly evolving market environment. Despite the critical role of financial management in corporate success, there is limited empirical evidence on the impact of factors such as long-term debt, financial leverage, liquidity, and company size on the economic and financial performance of firms in Algeria. This gap hinders effective decision-making by managers and policymakers aiming to enhance company performance and strengthen the overall economy. Therefore, this study seeks to analyze the effects of these financial variables on Return on Assets (ROA) and Return on Equity (ROE) to provide valuable insights for better financial management and economic policy formulation in Algeria.

This raises a key research question.

RQ: To what extent do fundamental financial variables explain the variability in returns of Algerian firms?

This research seeks to address a central concern:

- Are financial factors—such as Return on Assets (ROA), Return on Equity (ROE), financial leverage, long-term debt-to-assets ratio, firm size, and liquidity—meaningful and statistically significant predictors of how well companies perform in Algeria's markets?
- How do these variables individually and collectively influence firm profitability and market performance?

Answering these questions is critical for investors seeking optimal portfolio strategies, managers aiming to improve financial health, and regulators designing policies to foster capital market.

1.2 Hypotheses of the Study

This study formulates the following hypotheses to empirically test these relationships:

$H0_1$: Financial variables do not significantly affect Algerian firms' returns, measured by Return on Assets (ROA) at $\alpha = 0.05$.

$H0_2$: Financial variables do not significantly affect Algerian firms' returns, measured by Return on Equity (ROE) at $\alpha = 0.05$.

1.3 Importance of the Study

This research is timely and significant because it bridges a gap in the literature on Algerian capital markets and their functioning within an emerging economy framework. By dissecting the roles of financial indicators on firm returns during a recent 6-year period that saw economic transformations, it provides relevant insights for multiple stakeholders. Successful identification of key determinants supports improved financial decision-making within firms, encourages more informed investment, and aids regulatory bodies in crafting supportive policies. Furthermore, the econometric approach, employing advanced software like EViews, ensures robust and reliable analysis that adds scientific rigor.

1.4 Objectives of the Study

The main objectives of this study are:

- To examine how selected financial variables—specifically, financial leverage, the long-term debt-to-assets ratio, firm size, liquidity, Return on Assets (ROA), and Return on Equity (ROE)—influence the stock returns of Algerian firms
- To empirically test and validate the statistical significance of these variables' effects on firm profitability using econometric techniques.
- To deepen the understanding of firm financial dynamics in Algeria by providing context-specific evidence that contributes to the global body of research on emerging markets.
- To offer practical recommendations for corporate governance, management, and regulatory frameworks that can strengthen

firm performance and market development in Algeria.

2 LITERATURE REVIEW

A large stream of empirical research has investigated the effects of financial variables—such as profitability ratios, leverage, and earnings per share—on stock returns. These studies commonly focus on markets in emerging economies, providing nuanced theoretical and practical insights.

(Devita & Arviana, 2022) examined Indonesian automotive sector firms listed on the Indonesia Stock Exchange between 2016 and 2021. Their study focused on the effects of Return on Assets (ROA), Return on Equity (ROE), and Earnings Per Share (EPS) on stock returns. They found that ROA had a significant positive effect on stock returns, highlighting the importance of efficient asset utilization. Interestingly, ROE demonstrated a negative effect on stock returns when considered individually, which may suggest that higher equity returns do not always translate into higher market returns, particularly when profits are allocated to debt repayments. EPS alone did not significantly impact returns; however, jointly, ROA, ROE, and EPS positively influenced stock returns, underscoring the importance of a holistic approach in financial performance evaluation.

Similarly, (Mutumanikam & Adelin, 2024) explored financial leverage effects in emerging markets such as Indonesia, India, and Brazil. Using debt-to-equity ratios as measures of leverage, they identified a significant negative relationship between leverage and operational performance measured by ROA. The relationship with ROE was inconsistent, indicating that leverage can either amplify returns for equity holders or increase financial distress risks, depending on market conditions and firm characteristics. The study also found that firm size positively affects both ROA and ROE, suggesting that larger firms may benefit from better access to resources and economies of scale.

In another study, (MortezaZadeh et al., 2025) analyzed firms listed on the Tehran Stock Exchange, finding that profitability and liquidity ratios are positively correlated with stock returns, while leverage ratios negatively affect returns. This aligns with the view that profitability and liquidity foster shareholder value creation, whereas elevated debt levels may undermine it.

Complementing profitability studies, (Magribi et al., 2023) investigated how asset structure, dividend policy, and sales growth affect stock prices in the Indonesian automotive sector. The findings indicated that dividend policy positively and significantly influences stock prices, supporting theories that emphasize dividends as signals of firm health and managerial confidence.

Closer to the Algerian context, (Boussiki, 2023) examined the impact of capital structure on the financial performance of companies listed on the Algerian Stock Exchange, focusing specifically on the Saidal Group (case of the Saidal group, 2010–2021), referencing the trade-off theory and pecking order theory to examine the cost and risk implications of different financing sources. The study uses ROA, ROE, and EPS as performance indicators, relating them to different types of debt and control variables (asset tangibility, firm size, liquidity). The results suggest a statistically significant negative effect of long-term debt on financial performance, consistent with trade-off theory expectations for emerging market environments where high debt levels are riskier.

Recent Algerian panel data confirms, (Benachour, 2024), investigated the internal factors influencing the financial performance of 78 large Algerian companies over four sectors (construction, trade, industry, and services) from 2018 to 2021, using panel data regression. The study situated its research within theories on firm performance determinants, highlighting the trade-off theory and agency costs theory regarding debt and profitability. It underscores that higher debt ratios and asset tangibility negatively affect profitability, while capital turnover and company age positively influence performance. The research frames its hypotheses in the context of financial structure and operational efficiency as determinants of firm sustainability and profitability.

Internationally, (Källebring, 2025) investigated the role of Environmental, Social, and Governance (ESG) scores on stock returns and volatility among European firms. The study revealed a positive correlation between ESG performance and stock returns, particularly in sectors like energy and utilities, although the magnitude of the effect varied across industries.

Consistent with leverage concerns, (Abu-Abbas et al., 2019) investigated the relationship between financial leverage and firm performance by examining measures such as short-term and long-term debt, as well as debt-to-equity ratios, in relation to key profitability indicators like Return on Assets (ROA) and Return on Equity (ROE). Their analysis revealed that higher financial leverage generally exerts a negative impact on ROA, indicating that increased reliance on debt can hinder asset-based performance. However, the effect of leverage on ROE was found to be mixed, reflecting variations that may depend on firm-specific and contextual factors. These findings underscore the complexity of capital structure decisions and their implications for firm profitability in different market environments.

Focusing specifically on Nepalese commercial banks, Lamichhane and Shrestha (2022) conducted a comprehensive empirical analysis to evaluate how firm-specific variables—particularly financial leverage and other internal financial metrics—influence stock returns. Their findings reveal that these firm-level characteristics exert a statistically significant impact on stock performance, with the magnitude and direction of the effects varying considerably across different financial indicators such as leverage ratios, profitability measures, and liquidity positions. This variability suggests that no single financial variable universally determines returns; rather, their combined influence shapes the overall risk-return profile of banking stocks. Consequently, their study underscores the critical importance of adopting a multifaceted approach that incorporates multiple internal financial indicators when assessing the key drivers of stock returns within the banking sector, particularly in emerging markets where firm-specific factors often dominate macroeconomic influences.

Comparative studies reinforce and extend these findings across international contexts. For instance, Tas and Aydogan (2017) in Turkey found that ROA, ROE, and EPS have significant positive effects on stock returns, with leverage and company size also showing substantial influence; however, the effects and directions may vary depending on the specific financial environment. In Egypt and Nigeria, researchers Kotb and Mansour (2017) and Rufai and Audu (2017) found similar positive effects of profitability and valuation ratios on stock returns were reported, though context and market-specific factors continue to play a role in moderating these relationships.

3 METHODOLOGY

3.1 Variables Definition

In this study, there are two main variables.

3.1.1 The Dependent Variables

We selected the "Return on Assets" (ROA) and "Return on Equity" (ROE) as the dependent variables because they measure how efficiently a company's management generates earnings from its resources. These indicators assess the effectiveness of using assets and equity to produce profits, thus enabling an objective evaluation of the financial and managerial performance of companies while maintaining the original meaning.

***Table 1**. Dependent Variables*

Variables	Expression
ROA (Return on Assets)	Operating Income/ Economic Assets
ROE (Return on Equity)	Net Income/ Equity

Source: Prepared by the author

3.1.2 The Independent Variables

These four exogenous variables, expressed as ratios, have an impact on return. They are detailed in Table 2.

***Table 2**. Independent Variables*

Variables	Expression
LEV (Financial leverage)	Total Debt /Equity
LTDR (Long term debt ratio)	Long Term Debt / Total Assets
SIZE (Firm Size)	Logarithm of Total Assets
LIQ (liquidity ratio)	Current Assets / Current Liabilities

Source: Prepared by the author

These ratios are derived from the annual financial data—such as balance sheets and income statements—of various companies chosen for this study, covering a specific period

- *Return on Assets (ROA):* ROA is a profitability indicator that shows how effectively a company

utilizes its assets to generate net income. It is calculated by dividing net income by total assets and reflects management's efficiency in using the company's asset base to produce profits. (Penman, 2013, p. 232)

- *Return on Equity (ROE):* ROE measures the profitability generated from shareholders' equity. It is calculated by dividing net income after taxes by the shareholders' equity and serves as an indicator of how efficiently management is using equity capital to generate earnings (Abu-Abbas, Alhmoud, & Algazo, 2019, p. 212)
- *Financial Leverage:* Financial leverage refers to the extent of a firm's use of debt financing in its capital structure, usually measured by the debt-to-equity ratio. While leverage can increase investment capacity and potential returns, it also raises financial risk due to mandatory interest and principal repayments (González, 2013, p. 172).
- *Long-term Debt to Assets Ratio:* This ratio measures the proportion of a firm's total. Assets financed with long-term debt. (Mutumanikam & Adelin, 2024)
- *Firm Size:* Firm size is typically measured by total assets or total sales. It acts as a control variable in financial studies because it affects access to capital markets, economies of scale. (Astakhov et al., 2019, p. 1473)
- *Liquidity Ratio:* Liquidity ratios—such as the current ratio—are key indicators used to evaluate a firm's short-term solvency and its capacity to honor obligations as they come due using readily available resources. These ratios compare elements of current assets, like cash, marketable securities, receivables, and inventories, to current liabilities, thereby providing insight into whether the firm can meet its financial commitments without disrupting normal operations. (Özbek & Gözkonan, 2024, p. 340)

Here is a clearly structured summary table of previous studies that used similar variables (ROA, ROE, financial leverage, long-term debt to assets, firm size, liquidity) to analyze firm returns, including each study's main results and reference. This compilation provides a comprehensive overview of the empirical evidence linking these financial indicators to firm performance across various industries and regions.

All these findings are presented in Table 3, which summarizes the previous studies, the variables used, their main findings.

***Table 3**. Summary of Prior Studies on Financial Ratios and Firm Returns*

Study	Variables Used	Main Findings
Devita & Arviana (2022)	ROA, ROE, EPS	ROA positive on stock returns, ROE negative, EPS jointly positive
Mutumanikam & Adelin (2024)	Financial Leverage, ROA, ROE, Firm Size	Leverage negatively related to ROA, mixed effects on ROE; firm size positive
MortezaZadeh et al. (2025)	Profitability ratios, Leverage, Liquidity	Profitability & liquidity positively impact returns, leverage negative
Abu-Abbas et al. (2019)	Financial Leverage, ROA, ROE, Debt Ratios	Leverage negatively affects ROA; debt ratios with mixed effects on ROE
Shrestha & Lamichhane (2022)	ROA, Stock Returns	Negative relationship between ROA and stock returns in Nepalese banks

Source: Prepared by the author

3.2 Data Collection

The companies included in this study were selected based on their size and their compliance with the financial accounting system, focusing specifically on the industrial sector due to its significant role in Algeria's ongoing transition to a market economy. Data collection began by identifying the relevant companies, their activities, and their sizes through the National Statistics Office. Subsequently, the necessary information was gathered from the National Center of Trade Register.

In total, thirty-seven companies were identified, and annual reports from thirty of these firms, covering a six-year period (2019–2024), were used for the analysis. Altogether, this resulted in 222 company-year observations, providing a

substantial dataset for evaluating the financial performance of industrial enterprises during this crucial economic transition.

3.3 Research Method

The regression approach used in this study is a multiple linear model that incorporates the dependent variable alongside five independent (explanatory) variables. This model is estimated using the statistical software package EViews, version 12, known for its advanced econometric tools and ability to address econometric analysis requirements efficiently.

Given that the study sample consists of 37 companies, and the data involve both cross-sectional (data from multiple companies) and time series elements (covering the years 2019–2024), the dataset is best described as panel data. This results in a total of 222 company-year observations.

This study adopts a panel data regression framework, which exploits both the cross-sectional and time-series dimensions of the dataset to enhance the efficiency and explanatory power of the estimates. Within this framework, the Ordinary Least Squares (OLS) estimation technique is employed as a baseline estimator, providing consistent and interpretable coefficient estimates under the standard assumptions of linearity, exogeneity, homoscedasticity, and absence of perfect multicollinearity. The empirical analysis is implemented using EViews software, which offers a comprehensive environment for specifying, estimating, and diagnosing linear panel data models, in addition to facilitating the computation of robust standard errors and panel-specific diagnostic tests. This platform is particularly suited for such analysis because it supports advanced panel data procedures, flexible model specification (including fixed and random effects), and a wide range of post-estimation tools, thereby ensuring reliable estimation outcomes and allowing the researcher to address common statistical issues such as heteroscedasticity, serial correlation, and cross-sectional dependence. (Greene, 2003, p. 305)

4 DATA VALIDITY TESTING FOR STATISTICAL ANALYSIS

Applying the General Linear Model (GLM) requires several conditions to ensure the validity of the data for statistical analysis. One of the essential requirements is that the data should follow a normal distribution.

4.1 Normality Test

To check whether the data is normally distributed, this study uses the Jarque-Bera (J-B) test. According to the test's decision rule, if the p-value is greater than 0.05, we accept the null hypothesis, which means the data can be considered normally distributed. On the other hand, if the p-value is less than or equal to 0.05, the null hypothesis is rejected, suggesting the data does not follow a normal distribution. (Al-Sartawi, 2013, p. 840)

$$\mathrm{JB} = n\,[\frac{SK^2}{6} + \frac{(ku-3)^2}{24}]$$

Where *SK*: Skewness; *ku*: Kurtosis.

The assessment also relies on the values of skewness and kurtosis tests. When the kurtosis value is close to zero and the skewness value is near three, the data distribution is considered normal. This indicates that the data exhibit a balanced symmetry and an expected level of peakedness, which together suggest a typical, well-behaved distribution (Patrick, 2011, p. 42)

Table 4 presents the normality distribution test for the study variables using Jarque-Bera (J-B), probability, skewness, and kurtosis statistics.

***Table 4**. Results of the Normality Test*

Vars	Ku	Sk	Prob	J-B
ROA	10.8497	2.4704	0.0000	795.77
ROE	8.3057	2.0983	0.0000	423.30
LEV	14.9890	3.1086	0.0000	1687.28
LTDR	93.4212	-7.4535	0.0000	77683.40
SIZE	80.3616	7.3424	0.0000	57382.50
LIQ	2.4817	0.3566	0.0275	7.18922

Source: Prepared by the author using EViews 12 output

Table 4 shows that the distribution of the variables is not normal. This conclusion is supported by the

significant Jarque-Bera (J-B) test statistics and the p-value of 0.0000, indicating strong statistical significance. Additionally, the values of both kurtosis and skewness do not meet the previously mentioned criteria for normality. Since the significance level for all variables in the study is below 0.05, these findings confirm the rejection of the null hypothesis and acceptance of the alternative hypothesis—that is, the data do not follow a normal distribution

However, these results do not affect the validity of the study's model because the sample size exceeds thirty observations (n > 30), which typically mitigates concerns regarding non-normality in large samples.

4.2 Time Series Stability Study

Including time series data in a regression model without testing for stationarity can produce misleading results, commonly referred to as spurious regression, where relationships appear statistically significant despite being non-meaningful. Therefore, it is crucial to assess the stability and stationarity of each variable's time series to ensure the validity and reliability of the regression outcomes. To achieve this, the Phillips-Perron (PP) unit root test was employed, as it provides a nonparametric correction to the Dickey-Fuller test, addressing issues of serial correlation and heteroscedasticity in the error terms. The test results, summarized in Table 5.

Table 5 shows that the null hypothesis (H_0), which states the presence of a unit root (indicating a non-stationary series), is rejected. Instead, the alternative hypothesis (H_1) is accepted, confirming that the time series for the study variables are stationary. This implies that the variables are stable over time and suitable for standard econometric testing.

In other words, the unit root test results show that the p-values for all variables are below the significance level of 0.05. Therefore, we reject the null hypothesis and accept the alternative hypothesis, concluding that the time series variables are stationary and do not exhibit autocorrelation. This confirms their suitability for use in the regression analysis.

Table 5. *Phillips-Perron Fisher unit root test on variables*

Null Hypothesis: Unit root		
Exogenous variables: Individual effects		
Newey-West automatic bandwidth selection and Bartlett kernel		
ROA		
Method	Statistic	Prob.**
PP - Fisher Chi-square	287.938	0.0000
PP - Choi Z-stat	-9.19675	0.0000
ROE		
Method	Statistic	Prob.**
PP - Fisher Chi-square	242.878	0.0000
PP - Choi Z-stat	-6.98200	0.0004
LEV		
Method	Statistic	Prob.**
PP - Fisher Chi-square	157.229	0.0000
PP - Choi Z-stat	-1.50019	0.0053
LTDR		
Method	Statistic	Prob.**
PP - Fisher Chi-square	233.129	0.0000
PP - Choi Z-stat	-5.83365	0.0466
SIZE		
Method	Statistic	Prob.**
PP - Fisher Chi-square	214.404	0.0000
PP - Choi Z-stat	-4.37841	0.0000
LIQ		
Method	Statistic	Prob.**
PP - Fisher Chi-square	156.018	0.0000
PP - Choi Z-stat	-3.05111	0.0011

Source*: Prepared by the author using EViews 12 output.*

4.3 Multicollinearity Test

To ensure the validity of the study model and to check for the problem of multicollinearity, the Collinearity Diagnostics test is conducted. This involves calculating the Variance Inflation Factor (VIF) and Tolerance for each independent variable. The VIF value is calculated using the following formula:

$$VIF = \frac{1}{\text{Tolerance}} = \frac{1}{1 - R^2}$$

Table 6 presents the multicollinearity test results.

The multicollinearity test results in Table 6 indicate that there is no serious multicollinearity problem among the independent variables. All Variance Inflation Factor (VIF) values are well below the critical threshold of 10, ranging from 1.0516 for LEV to 1.2323 for LIQ, suggesting that the variables are not highly correlated with each other. Correspondingly, the tolerance values are all above 0.10, ranging from 0.8121 to 0.9509, which further confirms the absence of multicollinearity concerns. The R^2 values for each independent variable are relatively low (below 0.20), indicating that each predictor contributes unique variance to the model without substantial overlap with other variables. These results suggest that the regression model is robust and that the estimated coefficients are reliable for interpretation

***Table 6**. Multicollinearity Test Results*

Independent Variable	(R^2)	Tolerance	VIF
LEV	0.0491	0.9509	1.0516
LTDR	0.1232	0.8768	1.1405
SIZE	0.0587	0.9413	1.0623
LIQ	0.1879	0.8121	1.2323

Source: Prepared by author based on EViews 12 outputs regarding R^2

5 ANALYSIS OF RESULTS

5.1 Descriptive Statistics of the Study Variables

This section presents the key statistical indicators for the main variables used in the study, including the mean, minimum, maximum, median, and standard deviation.

These measures offer a clear snapshot of the data's overall distribution and variability, helping to better understand the characteristics and behavior of the variables before diving deeper into the analysis. As shown in Table 7, the descriptive statistics of the variables are reported

Table 7 presents the descriptive statistics for the study variables and shows that the Return on Assets (ROA) is positive, averaging around 6%. This suggests that the companies included in the study were able to generate a satisfactory return on their assets throughout the study period. However, this return exhibits volatility, as evidenced by the statistics for the highest and lowest values, with a standard deviation of 0.0754.

Table 7. *Descriptive statistics of variables*

Var	Mean	Max.	Min.	SD
ROA	0.0629	0.4554	-0.0767	0.0754
ROE	0.1439	0.8534	-0.0845	0.1437
LEV	2.1344	19.4039	0.0772	2.6861
LTDR	0.1114	0.5996	-2.3114	0.2026
SIZE	9.3726	10.6723	8.6262	0.4407
LIQ	1.6262	20.6692	0.1718	1.6586

Source: Prepared by author based on EViews 12 outputs

Similarly, the companies achieved a favorable average Return on Equity (ROE) of approximately 14%, indicating that, on average, shareholders earned a reasonable return on their invested capital. This level of profitability suggests efficient use of equity financing in generating net income. However, similar to the performance pattern observed in Return on Assets (ROA), the ROE values varied considerably among the sampled firms.

Furthermore, the other descriptive statistics reveal that the mean values of all the explanatory variables are positive. This variability in results (table 7) may reflect the absence of a unified strategic approach among the companies studied, which can be elaborated as follows:

The companies primarily rely on self-financing and short-term loans to meet their financial needs. This reliance is evident in the average leverage ratio (LEV), which has a high standard deviation of 2.6861, reflecting significant differences in companies' ability to service their debts through internal financing. This suggests a lack of unified financial planning, with each company operating independently:

- The average long-term debt ratio (LTDR) is 0.1114, meaning that these companies, on average, depend on long-term debt for about 11.1% of their financing
- The average company size (SIZE) is 9.3726, with little variation between the minimum and maximum values, indicating that the companies are relatively similar in size

- The average current liquidity ratio (LIQ) stands at 1.6262, which approximates the widely accepted benchmark ratio of 2:1, indicating that the sampled companies maintain reasonably sound liquidity positions.

  This near-optimal ratio suggests that these firms have implemented appropriate working capital management practices, ensuring that short-term financing sources are adequately aligned with short-term operational requirements. The ratio reflects a balanced approach to managing current assets and current liabilities, demonstrating that companies in the sample generally maintain sufficient liquid resources to meet their immediate financial obligations without holding excessive idle current assets that could otherwise be deployed more productively

5.2 Correlation Analysis Between Study Variables

Table 8 presents the correlation coefficients among the main study variables, indicating both the strength and direction of their relationships. This provides an initial understanding of how the variables are related—whether positively or negatively—and the extent of their association; the following conclusions can be drawn:

- There is a strong positive correlation of 0.8349 between Return on Assets (ROA) and Return on Equity (ROE), which is both logical and expected. This strong relationship makes sense because both measures reflect profitability and share common financial components.
- There is a weak positive correlation between ROA and the current liquidity ratio (LIQ), with a correlation coefficient of 0.1725. The relationship between LIQ and ROE is even weaker.
- Both ROA and ROE show positive correlations with the size of the company (SIZE), at 0.298637 and 0.199856, respectively. This suggests that the impact of company size is more significant on economic performance than on financial performance.
- Financial leverage (LEV) has an inverse relationship with ROA as well as with the long-term debt ratio (LTDR), reflecting the negative impact of indebtedness on economic performance. In contrast, ROE does not exhibit a strong or even moderate correlation with any of the variables (LEV, LIQ, LTDR).
- Financial leverage (LEV) is inversely correlated with both LIQ and SIZE, meaning an increase in leverage typically leads to a decrease in these variables. For example, higher reliance on borrowing to finance investments (increased LEV) tends to reduce liquidity (LIQ), which is a logical outcome.

Table 8. *Correlation Matrix of Study Variables Based on Pearson Correlation Coefficient*

	ROA	ROE	LEV	LTDR	LIQ	SIZE
ROA	1	0.8349	-0.2655	-0.1283	0.1725	0.2986
ROE	0.8349	1	0.0437	0.0037	0.0128	0.1998
LEV	-0.2655	0.0437	1	0.1910	-0.2072	-0.0707
LTDR	-0.1283	0.0037	0.1910	1	0.1221	0.1881
LIQ	0.1725	0.0128	-0.2072	0.1221	1	0.1881
SIZE	0.2986	0.1998	-0.0707	0.1881	0.1881	1

Source: EViews 12 outputs

5.3 Hypotheses Testing

To test the formulated hypotheses of the study, panel data analysis will be used with the EViews software. This approach is commonly applied in financial and economic research as it allows analyzing data across multiple firms (or units) and over multiple time periods simultaneously.

Table 9. *Regression Model*

Dependent Variable: ROA				
Method: Panel Least Squares				
Date:07/06/2025 Time : 21:03				
Sample: 2019 2024				
Periods included: 6				
Number of cross-sections used: 37				
Total panel (balanced) observations: 222				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.333295	0.103293	0-3.226678	0.0014
LEV	-0.002408	0.002665	-0.903383	0.3673
LTDR	-0.099726	0.039347	-2.534546	0.0120
SIZE	0.046604	0.010791	4.318783	0.0000
LIQ	0.002106	0.003213	0.655559	0.5128
R-squared	0.179951	Mean dependent var		0.062966
Adjusted R-squared	0.160969	S.D. dependent var		0.075377
S.E. of regression	0.069044	Sum squared resid		1.029686
F-statistic	9.479811	Durbin-Watson stat		1.513391
Prob (F-statistic)	0.000000			

Source. EViews 12 outputs

.3.1 Testing the First Hypothesis

The initial hypothesis proposed that: “Financial variables have no significant effect on the returns of Algerian firms, as measured by ROA (α = 0.05)”.

Table 9 presents the regression model results, including coefficients, significance tests, and fit statistics.

The results displayed in Table 9 show a significance level of 0.00, which is below the 0.05 threshold. This indicates that the financial variables collectively have a statistically significant impact on the Return on Assets (ROA) of Algerian firms. The model’s adjusted R-squared of 0.16 suggests that these variables explain 16% of the variation in ROA.

Furthermore, the Durbin-Watson statistic of 1.51 falls within the acceptable range of 1.5 to 2.5, indicating no presence of autocorrelation and confirming the reliability of the regression results.

As a result, the null hypothesis is rejected in favor of the alternative hypothesis:

There is a statistically significant effect of financial variables on the returns of Algerian firms, as measured by ROA, at the 0.05 significance level.

Accordingly, the model estimated by this study can be expressed as follows:

$$\mathrm{ROA} = -0.333 - 0.099\mathrm{LTDR} + 0.04\ \mathrm{SIZE}$$

The results of the multiple regression analysis indicate an inverse relationship between economic profitability (ROA) and the long-term debt to assets ratio (LTDR). This means that increased reliance on long-term debt reduces a company’s efficiency in utilizing its economic assets. This finding aligns with prior Algerian studies, such as Boussiki (2023), who found a statistically significant negative relationship between medium- and long-term debt to assets and financial performance measures—including ROA and ROE—in Algerian companies. Similarly, the study by Benachour (2024) found that debt ratios have a strong and significant negative impact on economic profitability for Algerian firms.

On the other hand, the analysis reveals a statistically significant positive relationship between company size (SIZE) and economic profitability as measured by return on assets (ROA). This finding suggests that larger companies demonstrate superior capability in enhancing their profitability through more efficient utilization of their asset base and greater capacity

to expand their operational activities and market reach. The positive coefficient indicates that as companies increase in size, they tend to achieve higher returns on their assets, potentially due to economies of scale, enhanced bargaining power with suppliers and customers, greater access to financial resources, and improved operational efficiency resulting from better resource allocation and management systems.

This empirical result aligns with and corroborates the findings documented in several recent studies examining the determinants of corporate financial performance in similar contexts. For instance, Boussiki (2023) incorporated company size as a control variable in the regression model and identified a statistically significant influence on various measures of financial performance, confirming that firm size plays a crucial role in explaining performance variations across companies. Similarly, the comprehensive study conducted by Benachour (2024) emphasizes the fundamental role of internal firm-specific characteristics, including organizational size, in determining financial outcomes and performance differentials among Algerian companies operating in diverse industrial sectors.

However, these conclusions may differ from other studies such as Abuamsha and Shumali (2022), which found a positive impact of long-term debt on ROA for industrial sectors.

5.3.2 Testing the Second Hypothesis

The second hypothesis stated that: "Financial variables have no significant effect on the returns of Algerian firms, as measured by ROE (α = 0.05)"

Table 10 presents the regression model results, including estimated coefficients, significance tests, and fit statistics, with return on equity (ROE) as the dependent variable. The table displays the regression coefficients for each independent variable, which represent the magnitude and direction of their relationship with ROE, along with standard errors that measure the precision of these estimates. Additionally, the table includes t-statistics and p-values to determine the statistical significance of each independent variable's effect on return on equity, as well as the R-squared coefficient that indicates the proportion of variance in ROE explained by the independent variables collectively. The F-statistic presented in the table tests the overall significance of the regression model.

***Table 10**. Regression Model*

Dependent Variable: ROE				
Method: Panel Least Squares				
Date:07/06/2025 Time : 21:03				
Sample: 2019 2024				
Periods included: 6				
Number of cross-sections used: 37				
Total panel (balanced) observations: 222				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.564109	0.211650	-2.665289	0.0083
LEV	-0.002208	0.005462	-0.404368	0.6863
LTDR	-0.069753	0.080622	0.865188	0.3879
SIZE	0.069771	0.022111	3.155490	0.0018
LIQ	0.002701	0.006583	0.410329	0.6820
R-squared	0.052379	Mean dependent var		0.143861
Adjusted R-squared	0.030443	S.D. dependent var		0.143676
S.E. of regression	0.141472	Sum squared resid		4.323112
F-statistic	2.387850	Durbin-Watson stat		1.565012
Prob (F-statistic)	0.039121			

Source: EViews 12 outputs

The results shown in Table 10 indicate that the significance level is 0.03, which is less than the threshold of 0.05. The adjusted R-squared value is 0.03, meaning that the variables included in the model explain approximately 3% of the variations in return on equity (ROE). Additionally, the regression model does not suffer from autocorrelation, as the Durbin-Watson (DW) statistic is 1.56—a value within the optimal range of 1.5 to 2.5—which enhances the reliability of the results.

As a result, the null hypothesis is rejected, and the alternative hypothesis is accepted:

"There is a statistically significant effect at the 0.05 level of the financial variables on the returns of Algerian companies, as measured by return on equity (ROE)."

The regression model can thus be written as follows:

$$\mathrm{ROE} = -0.564 + 0.069\ \mathrm{SIZE}$$

The multiple regression analysis demonstrates a positive relationship between company size (SIZE) and return on equity (ROE), confirming that these companies are expanding their operations while maintaining attention to shareholder interests. This finding is consistent with the results of Boussiki (2023), found a significant positive impact of firm size on ROE for Algerian companies—indicating that larger firms typically enjoy better equity returns in the Algerian context. Similarly, Benachour (2024) highlights the important role of firm-specific factors—particularly size—in shaping financial performance among large Algerian firms.

However, these results differ from the findings of some international research, such as Abuamsha and Shumali (2022), who in a broader MENA regional context reported that the impact of company size on ROE can vary significantly based on sectoral and national circumstances.

6 CONCLUSIONS

In conclusion, this study contributes to the empirical literature by rigorously analyzing the impact of select financial variables on the business outcomes of Algerian industrial companies during a crucial phase of economic transition. The research employed robust econometric techniques using panel data across multiple years and companies, ensuring the reliability and credibility of the findings.

The results demonstrate that long-term debt has a statistically significant negative effect on economic profitability, as measured by return on assets (ROA). This implies that excessive reliance on long-term borrowing may erode a firm's ability to efficiently utilize its assets and, consequently, affect overall performance. Conversely, company size (SIZE) was found to exert a positive influence on both ROA and return on equity (ROE), highlighting that larger firms are better positioned to leverage their resources, expand operations, and fulfill stakeholder interests more effectively.

The explanatory power of the regression models, while moderate, reflects the multifaceted origins of financial performance and indicates that other qualitative and contextual factors may also play a role in shaping business outcomes. Importantly, the diagnostic tests confirm the validity and stability of the models: issues of normality, stationarity, and multicollinearity were adequately addressed, and the absence of autocorrelation further strengthens the robustness of the conclusions.

The practical implications of these findings are highly relevant for company management, policymakers, and regulatory bodies. Firms should adopt prudent borrowing strategies and focus on scalable growth to maximize economic and financial performance. For policymakers, the results reaffirm the imperative for policies that facilitate efficient capital allocation, encourage responsible leverage, and support the sustainable expansion of the industrial sector.

Overall, this research underscores the value of sound financial management and strategic planning in driving the success and resilience of Algerian companies as they navigate the shift to a market-oriented economy. The insights derived serve as a foundation for future research and a reference point for decision-makers seeking to enhance corporate performance in emerging market contexts.

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REVIEW ARTICLE
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OPERATIONAL RISK MANAGEMENT AS A DRIVER OF BUSINESS SUSTAINABILITY

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ABSTRACT

In the context of increased competition, digital transformation, and uncertainty, sustainable development is a strategic objective for businesses. Employee well-being, ethical management, and customer and stakeholder trust, as the social aspect, can be undermined by unaddressed operational risks. Inefficient use of resources, environmental incidents, and failure to comply with environmental standards, as environmental aspects, pose risks that impact long-term stability and market position. An effective operational risk management system increases management transparency, strengthens accountability and the distribution of responsibilities, and improves the internal control system, thereby enhancing the governance component. The purpose of this study is to determine how operational risk management can support sustainable business development and contribute to strengthening competitiveness. The research combines theoretical analysis with quantitative approaches, including the evaluation of operational risks through key risk indicators and their relationship with sustainability metrics. The results indicate that embedding operational risk management into core business processes increases organizational resilience and lowers exposure to disruptions. The article may be useful for managers, risk specialists, researchers, and policymakers.

1 INTRODUCTION

In the context of the modern economy, which is characterized by high instability, the introduction of digital technologies and increased global competition, completely new challenges for the functioning and development of enterprises are emerging. In the context of such challenges, traditional approaches to enterprise management are insufficient, since they do not cover all aspects and require proactive actions. At the same time, sustainable development is acquiring the role of not only a modern trend, but a strategically necessary point for organizations that seek to maintain and develop their competitiveness and long-term viability. The practice of sustainable development, which integrates Environmental, Social, and Governance aspects of enterprise activity, has received wide recognition in recent decades both in the scientific community and in

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practice. Due to a holistic view of business development prospects, this topic remains relevant. The social component of sustainable development plays an important role in modern management. Creating conditions for employees' well-being, fostering a mature corporate culture that fully adheres to principles of ethics and fairness, and ensuring the trust of customers, partners, and investors are fundamental to sustaining organizational competitiveness. At the same time, the sustainability of this area directly depends on a correctly constructed system of operational risk management, since personnel errors, insufficient qualifications, ineffective management decisions, or defective communication lead to a decrease in the level of the company's adaptability to changes in the external environment. Thus, the aspect of the social factor of sustainable development is inextricably linked with risk management, which forms the basis for the stable, uninterrupted functioning of the enterprise. At the same time, the environmental aspect of sustainable development is no less significant, due to global climate change, the trend of responsible use of resources, and the tightening of environmental legislation. Risks arising from the irrational use of energy resources, environmental pollution, or non-compliance with environmental standards lead to significant financial losses, deterioration of reputation, and, ultimately, to a decrease in the competitiveness of the organization. Systematic operational risk management in this area is becoming an important tool that allows minimizing the likelihood and impact of environmental incidents and, as a result, strengthening the long-term viability of the enterprise.

In analyzing the UN Sustainable Development Goals (SDGs), it is important to highlight the link between enterprise-level operational risk management and the achievement of strategic global objectives. Systematic risk management supports the realization of goals such as responsible consumption and production (SDG 12), decent work and economic growth (SDG 8), and innovation and industrialization (SDG 9). In this context, enterprises are viewed not as isolated units but as integral parts of a global system. Operational risk management thus functions not only as a safeguard against losses but also as a strategic driver of business development, capable of creating new competitive advantages and fostering growth.

2 LITERATURE REVIEW

Classic risk management studies, presented by Michel Crouhy, Dan Galai, and Robert Mark in The Essentials of Risk Management (2014), and by Paul Hopkin in Fundamentals of Risk Management (2018), emphasize the need for a systematic approach to identifying, assessing, and mitigating risks as the foundation of organizational resilience. While these approaches were initially focused on loss prevention, they laid the foundation for the subsequent integration of risk management into strategic management.

The development of this concept is also linked to the work of Robert S. Kaplan and Anette Mikes (2012) in Managing Risks: A New Framework, which identifies various risk categories and emphasizes their impact on the quality of management decisions and the long-term sustainability of companies. Within the framework of the Enterprise Risk Management (ERM) concept, research by Mark L. Frigo and Richard J. Anderson (2014) in Strategic Risk Management examines risk management as an element of strategic and corporate governance, directly linked to the governance (G) component of ESG.

From a sustainable development perspective, operational risk management (ORM) plays a key role in ensuring business continuity, protecting stakeholder interests, and enhancing trust in the organization. Terje Aven (2015) notes in Risk Analysis that risk analysis is the foundation of decision-making under uncertainty, while Nicholas Taleb (2010) in The Black Swan emphasizes the importance of considering rare but highly disruptive events that can significantly impact business resilience.

Despite the significant contribution of existing research to understanding the role of operational risk management, a gap remains in the scientific literature between theoretical approaches and their practical implementation in the context of sustainable development. Most studies examine ORM either as a loss minimization tool or as an element of an overall ERM system, but insufficient attention has been paid to its role as an independent driver of business resilience.

3 DATA AND METHODOLOGY

This research takes a conceptual-analytical perspective and seeks to provide a theoretical

foundation for the relationship between operational risk management and sustainable organizational development. System and process approaches are used as a methodological basis, allowing us to consider operational risk not as an isolated phenomenon, but as an element of the entire corporate management system. A theoretical analysis and synthesis of scientific sources was carried out, and enterprises from various industries were considered to build a relationship between key risk indicators and key indicators of business sustainability. In addition, corporate social programs and environmental initiatives were analyzed, which made it possible to establish a relationship between operational risk management, the implementation of the ESG initiatives, and the achievement of strategic goals of sustainable development. Thus, this methodological approach made it possible to comprehensively consider the problem and determine practical mechanisms and tools for increasing the competitiveness of enterprises by integrating operational risk management into the development strategy.

4 RESULTS AND DISCUSSIONS

The sustainability of business processes, which determines the ability of enterprises to maintain business continuity in the face of external shocks and uncertainty, is constantly influenced by operational risks. Their manifestations vary: from incorrect process design to their execution, various technological failures, violation of the regulatory framework, and crises caused by external factors. At the same time, process risks arise in the event of duplication of functions, inefficient allocation of resources, or lack of standardization of processes, which ultimately leads to increased costs. In the context of digitalization, technological and information risks arise from failures of IT systems, breakdowns of equipment used in activities, and, as a result, are the reason for the suspension of key operations. Cyberattacks and data distortions are also an important factor, which is especially critical in digitalization. Human risks expressed in personnel errors, insufficient qualifications, or deliberate actions (frauds) also affect the sustainability of business processes and directly depend on the corporate culture. It is worth noting that external events can also paralyze the activities of an enterprise, for example, in the context of a pandemic, natural disasters, or supply chain disruptions. At the same time, in the event of non-compliance with regulatory requirements, legal and compliance risks arise, expressed in fines and sanctions, which not only lead to direct losses but also undermine the company's image. Figure 1 schematically shows operational risk factors and their impact on the duration of business processes.

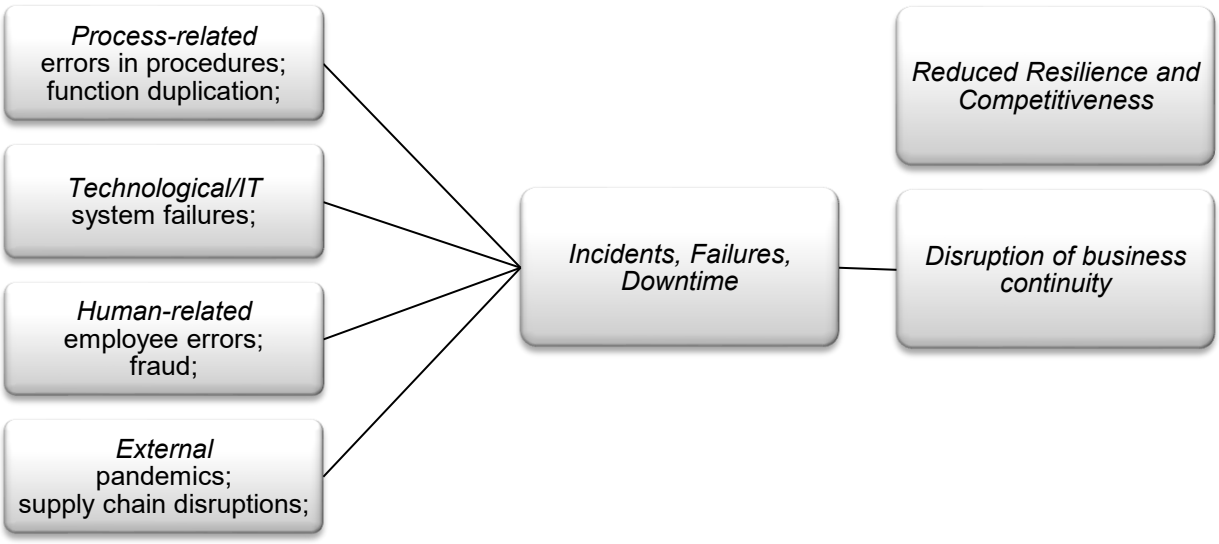


Figure1. *Sources of operational risks and their impact on business process resilience*
Source: developed by the author

It is important to note that the impact of operational risks on business processes is multiplicative. Thus, one incident can lead to a whole set of other failures in related systems, increasing the impact and scale of damage. For example, failure of an information system in a financial institution can not only stop transaction processing but also cause a massive outflow of customers and regulatory intervention. All this will ultimately lead to an increase in reputational risks. The COVID-19 pandemic has demonstrated that enterprises that did not have continuity plans faced greater losses: disruptions in logistics, a drop in production volumes, and labor shortages. Thus, an urgent restructuring of the business model was necessary. This provides grounds for threatening operational risk management not as an isolated process, but as a complex system of business sustainability. Accordingly, mature operational risk management systems that provide regular staff training, investments in cybersecurity, and the integration of continuity plans into the enterprise development strategy can significantly reduce the frequency and impact of incidents, as well as strengthen the trust of stakeholders.

4.1 Social Aspects of Sustainable Development and Operational Risk Management

Operational risk management is closely linked to the social aspect of sustainable development, as employees and stakeholders enable businesses to maintain business continuity and adapt to challenges. The findings of this study suggest that one of the most important tools for reducing the vulnerability of business processes is corporate social programs, as they affect the quality of human capital and the level of staff engagement, which plays a very important role in ensuring the effective operation of the organization.

One aspect of social initiatives is caring for the health of employees. According to a study by Deloitte (2024), the costs of UK employers associated with the consequences of poor mental health of staff amount to about £51 billion annually. At the same time, it is noted that every pound invested in supporting employee well-being can bring the employer up to £4.70 in return due to increased productivity and reduced turnover (Deloitte, 2024). Using this data, we can conclude that investments in corporate social programs directly reduce operational risks associated with labor absence, errors, and reduced quality of work. At the same time, social initiatives also affect the trust of customers and investors. According to the results of the Edelman Trust Barometer (2023), business turned out to be a unit that most respondents assess as ethical: 62% of study participants trust companies more than governments, the media, or NGOs (Edelman, 2023). Based on this, it can be concluded that the socially responsible policy of organizations strengthens the image, reduces reputational risks, and forms long-term relationships with stakeholders. The report of the European Banking Authority (EBA, 2023) notes that operational resilience remains a priority: significant losses from the implementation of operational risk incidents force banks to build enhanced internal controls, train employees, and develop a risk-oriented culture of behavior. Thus, the banking sector is also susceptible to and confirms the relationship between social responsibility, operational risk management, and resilience. The evidence presented supports the view that human capital and social corporate programs for its development are part of a comprehensive risk management model, which ultimately leads to increased competitiveness of enterprises and increased sustainable development. Table 1 provides examples of the applied effect of social programs on reducing operational risks and increasing sustainability in various industries.

The study contends that operational risk management and sustainable development are in a two-way cause-and-effect relationship. On the one hand, social initiatives help reduce risks (according to the case studies presented in the table), and on the other hand, the operational risk management system itself requires the implementation of corporate social programs. This approach is reflected in international standards (ISO 31000, recommendations of the Basel Committee on Banking Supervision), which link the health and safety of personnel, human resource management, and operational risks. Thus, the integration of labor protection programs, employee training, and discrimination prevention into the control system or risk management system is a mandatory tool for reducing risks.

Table 1. *Corporate and social programs' impact on operational risks and enhancing resilience*

Sector/Source	Social Program or Initiative	Employee Effect	Impact on Risks and Resilience
Banking sector (EBA, 2023)	Regular staff training on operational risk, compliance, and cybersecurity	Improved competence; reduction of errors in operations	Internal incidents decreased by 25–30% in banks with systematic programs compared to those with ad-hoc training (EBA, 2023)
Manufacturing sector (Deloitte Insights, 2022)	Health & Safety programs, regular training, psychological well-being support	Employee turnover reduced by 18%, higher satisfaction	Workplace incidents reduced by nearly 40%, strengthening process continuity (Deloitte, 2022)
IT / Technology sector (Edelman Trust Barometer, 2023)	Diversity & inclusion programs, flexible work, work-life balance support	Increased employee engagement and loyalty	Reduction in HR-related incidents and reputational risks; 60% of consumers prefer companies with visible social responsibility

Source: developed by the author

The hypothesis of the relationship between operational risk management and sustainable development within the framework of the study is also confirmed by the fact that a mature operational risk management system assumes that companies have business continuity plans, and these plans cannot be implemented in the event of a crisis without social elements that involve training personnel in actions, psychological stability of employees, and programs for retaining personnel. These results point to the conclusion that operational risk management tools or processes themselves are transformed into social programs necessary to ensure sustainability.

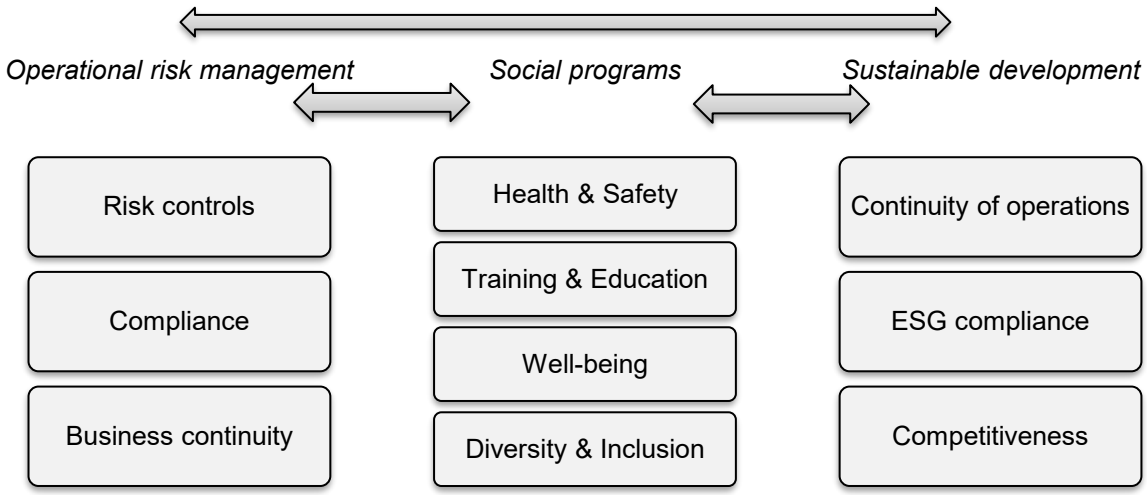


Figure 2. *Bidirectional relationship between ORM, social programs, and sustainable development*
Source: developed by the author

4.2 Operational Risk Management as a Driver of Environmental Sustainability

Ensuring the environmental sustainability of enterprises is also carried out through the use of modern risk management methodologies. When considering the environmental aspect of sustainable development, the operational risk management system becomes a factor that forms the framework for the implementation of environmentally responsible practices and ensures their integration into the company's strategy.

Methods of controlling the consumption of energy, water, and raw materials are assessed as a factor in reducing operational risks: supply disruptions, rising resource prices, and dependence on external suppliers can lead to interruption of activities. A risk management system that includes the identification of such threats encourages

organizations to switch to more energy-efficient technologies, optimize resource use, and implement the principles of "green" production. In these conditions, risk management contributes to the transition to a cyclical economy and increases the company's adaptability in the face of environmental and market changes. Taken together, these suggest that operational risks are directly related to the likelihood of accidents, leaks, pollution, or non-compliance with environmental legislation. At the same time, implementation of environmental audit procedures, regular equipment maintenance, and personnel training, including behavior in crisis situations, can help to reduce the inherent risks. Risk management in the context of international sustainable development standards provides a methodological basis for meeting requirements, from assessing the likelihood of environmental threats to developing measures to prevent them. The ISO 14 0001 standard is aimed at creating systems for managing a company's impact on the environment, which requires systematic risk analysis and continuous improvement.

The implementation of energy efficiency programs allows enterprises to reduce costs by 10-25%, according to the report of the International Energy Agency (IEA, 2022). At the same time, it helps reduce dependence on external suppliers of energy and raw materials. These results lead to the conclusion that this is directly related to operational risk management, since the transition to renewable energy sources reduces the likelihood of interruptions in the organization's activities in the context of energy crises.

The results of major disasters demonstrate the importance and necessity of risk management systems in preventing environmental risks. For example, the BP Deepwater Horizon accident (2010) brought more than $ 65 billion in direct and indirect costs, including fines and compensation. To prevent such incidents, companies use monitoring and preventive maintenance systems. This mechanism allows a reduction in environmental incidents. According to the European Commission, companies that have implemented ISO 14 001 and integrated the principles of the EU Green Deal are better positioned to attract investment. What emerges from analysis of these cases is that operational risk management becomes a driver of environmental sustainability through the efficient use of resources, incident prevention, and compliance with standards.

4.3 Methods of Operational Risk Management as a Factor in Sustainable Development

The process of operational risk management involves a cyclical approach, which includes key stages: risk identification, assessment, monitoring, response, and control.

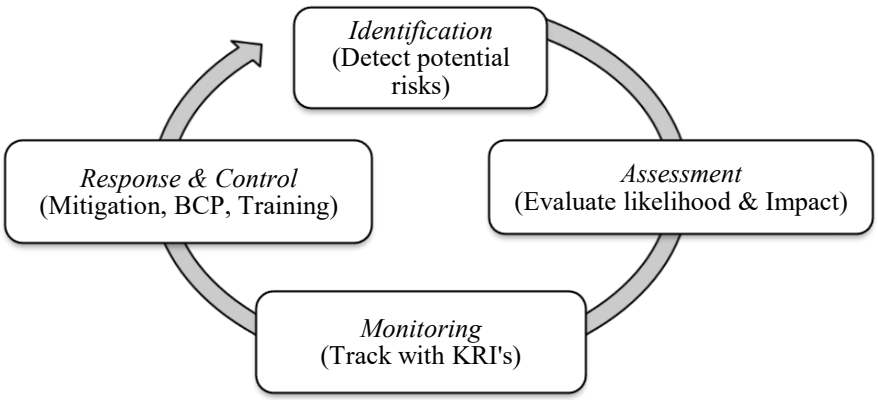


Figure 3. *Risk management process cycle*
Source: Developed by the author based on information from the European Banking Authority (2023).

As important tools, developing and continuously or periodically monitoring key risk indicators allow us to predict threats before they materialize. For example, an increase in staff turnover can be an indicator of a decrease in employee satisfaction and, as a result, a potential increase in errors. At the same time, an increase in energy consumption signals the inefficiency of processes. Thus, key risk indicators allow us to analyze the ESG components and ensure the preservation of

operational security and the sustainability of the organization. Table 2 shows examples of the correlation of KRI and some indicators of enterprise sustainability.

Table 2. Correlation between KRIs and sustainability indicators

KRI	Sustainability KPI	Analytical Link/Correlation
Employee turnover (%)	Employee satisfaction index / ESG “S”	High turnover → lower engagement → reduced resilience;
Average energy consumption per unit of output	Energy efficiency / CO2 emissions	Rising energy consumption directly correlates with higher carbon footprint;
Number of downtimes (hours)	Business continuity index	More downtime → weaker resilience;
Number of cybersecurity incidents	Customer trust index / ESG “S”	Cyber incidents undermine trust;
Number of compliances / environmental violations	ISO 14001 / EU Green Deal compliance	Direct negative correlation: more violations → lower sustainability rating, higher regulatory risk, restricted access to ESG financing.

Source: developed by the author

Also, this research takes the view that in order to implement KRI for sustainable development, it is necessary to integrate environmental, social, and governance factors into it. Thus, simultaneously with measuring equipment downtime or the number of internal incidents, it is necessary to track the level of energy consumption per unit of production, the volume of CO2 emissions, or other resources used. This, in turn, will create a direct link between the risk management system and the organization's sustainable development strategy. It is worth noting that each indicator must be measurable, specific, and tied to threshold values. For example, the threshold value of the "red" zone for the employee turnover indicator can be set at 20% per year. Exceeding it will signal threats to sustainability as a result of increased social risks. It is important to note that it is necessary to monitor the indicator considering its cumulative nature throughout the year. The dynamics of energy consumption or an increase in the number of violations of environmental standards also become an indicator of future reputational or regulatory risks.

It is the position of this paper that for successful performance of key risk indicators, they must be integrated into corporate dashboards and monitoring systems. This, in turn, will allow monitoring indicators in real time and will help make timely management decisions. This approach ensures transparency in decision-making and allows us to adjust the strategy depending on possible threats. At the same time, it is necessary to conduct regular reporting on the level of key risk indicators.

Another tool of operational risk management is crisis recovery plans that help minimize the impact of incidents and ensure the sustainability of the organization. A company's continuity plan is a set of measures that will ensure the continuity of critical functions during and after incidents. The process of forming a continuity plan consists of several stages: analyzing the impact on the business, identifying critical processes, establishing acceptable downtime, and determining the amount of data that can be lost without critical damage. Within the framework of sustainable development, BCP is important, as it ensures the continuity of the enterprise's social obligations - protecting the health of employees, preserving jobs, and maintaining the confidence of customers and investors in crisis situations.

A recovery plan, being part of a continuity plan, focuses on restoring resources after a crisis. This may include data backup, the availability of alternative data centers, etc. What emerges from this analysis is that to maintain sustainable development, DRP is very important because, in the context of digitalization, information security and data integrity are not only an operational necessity, but also a social aspect, since

customers associate trust in a company with their ability to protect information.

The present study maintains that the use of operational risk management methods not only helps reduce the likelihood of incidents but also ensures compliance with the sustainable development strategy, which is based on ESG principles. In order for the operational risk management process to be effective and efficient, it is necessary to create a system of measures that will ensure a comprehensive approach to risk management. Particular attention should be paid to the development and monitoring of key risk indicators that are directly related to sustainability indicators, the integration of risk mapping into planning, stress testing, and scenario analysis. The development of continuity and recovery plans after crises, their regular testing, and the formation of a risk culture through employee training also play an important role. Table 3 presents practical recommendations and specific risk management tools, as well as their effect on sustainable development.

Table 3. *Practical recommendations and their effect on sustainable development*

Recommendation	ORM tool / Method	Effects on Sustainable Development
Integrate risk identification and mapping into strategic planning	Risk maps, root cause analysis	Focus on critical threats; better resource allocation; alignment with ESG priorities;
Implement Key Risk Indicators linked to ESG	Staff turnover %, energy consumption, CO2 emissions, compliance breaches;	Early warning signals; reduced social risks; lower carbon footprint;
Maintain and test BCP and DRP regularly	Business Continuity planning, simulation exercises;	Ensured business continuity; stakeholder trust during crises; reduced financial loses;
Build risk culture and employee training programs	Corporate training; ESG-awareness workshops; cross-functional risk teams;	Reduced error rates; improved social responsibility; stronger employee engagement.
Digitalize risk management	AI – driven monitoring, Big Data analytics	Real-time risk detection; predictive maintenance; reduced environmental impact.
Risk assessment and scenario analysis	Stress testing, climate risk scenarios, supply chain vulnerability analysis	Resilience to crises; ability to adapt to regulatory and climate challenges.
Introducing continuous improvement mechanisms	Regular risk reviews; post-incident analysis; benchmarking	Adaptive organization; ability to evolve with new regulations and market changes.
Establish transparent reporting and stakeholder communication	ESG reporting frameworks; integrated risk reports	Increased investor confidence; accountability

Source: developed by the author

Considered as a whole, the analysis and the recommendations point to determining that with the correct application of operational risk management tools, it becomes possible not only to provide early warning, which helps to minimize operational risks, but also to increase resource efficiency, strengthen stakeholder confidence, and create strategic advantages in the context of global competition.

5. CONCLUSIONS

Synthesizing the above, this paper concludes that with the increasing impact of non-financial risks on organizations, operational risk management is becoming a key factor in sustainable development. This study demonstrated the conceptual link between operational risk management and organizational sustainability and confirms that developing a system for monitoring, managing, and controlling operational risk not only reduces the likelihood of events but also leads to their proactive management. Together, this creates a sustainable business model capable of adapting to changes in a dynamic external environment. Developing a risk management system and strategic governance allows

organizations to strengthen corporate governance, increase stakeholder trust, and enhance operational transparency. The cumulative weight of the analysis supports the conclusion that operational risk management should not be viewed as an isolated process, but as a basis for the sustainable development of enterprises. Combining control mechanisms with external sustainability requirements will form a comprehensive system that will ensure business continuity even in conditions of uncertainty. Companies that integrate the operational risk management system into their development strategy strengthen their market positions, create long-term value, and simultaneously respond to emerging threats.

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ORIGINAL RESEARCH ARTICLE
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THE ROLE OF FINANCIAL EDUCATION IN SME DEVELOPMENT: INSIGHTS FROM ROMANIAN FINANCE PROFESSIONALS

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ABSTRACT

Small and medium-sized enterprises (SMEs) are essential to the entrepreneurial ecosystem, yet uneven financial literacy continues to limit access to funding, innovation uptake, and operational resilience. This study examines how finance professionals perceive the relevance and usefulness of financial education for SMEs, situating these views within the institutional context and role-specific responsibilities. Based on a questionnaire administered to specialists from Romania's banking and non-bank lending institutions, our study investigates how professionals assess educational initiatives that shape SMEs' behavior and preferences for training formats (online courses, seminars, customized programs, and applied simulations). Findings indicate distinct perceptual orientations - from an innovation-driven stance that assigns a central role to financial education to a more traditional, cautious view marked by lower openness to alternatives - together with clear differences in learning preferences across professional groups. Moreover, financial education is perceived in close connection with attitudes toward financing instruments and organizational culture. Recommendations addressed to policy makers, training providers, and lending institutions emphasize differentiated, context-sensitive educational approaches tailored to institutional settings, professional roles, and the specific needs of targeted audiences, rather than uniform interventions.

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1 INTRODUCTION

Financial education plays a crucial role in shaping the capacity of SMEs to navigate complex economic environments, make informed decisions, and engage effectively with financial institutions. In Romania, SMEs form a cornerstone of the economy, contributing substantially to employment and value creation, yet the level of financial literacy among entrepreneurs remains uneven. The perceptions of financial professionals - both from banking and non-banking sectors - are therefore strategically important: their understanding of financial education, their evaluation of entrepreneurs' preparedness, and their assessment of educational needs directly influence institutional decisions and the design of support policies.

Research shows that financial perceptions vary along latent dimensions such as trust in educational programs, openness to innovative learning formats, and orientation toward consolidation or entrepreneurial expansion (Tripa et al., 2025; Badulescu et al., 2025). These dimensions are shaped by demographic factors such as job role, work experience, institution type, and geographic context. Understanding these perceptual patterns is essential for tailoring interventions that enhance financial competencies among SMEs.

Our study examines the perceptual profiles of Romanian financial professionals concerning financial education, aiming to identify homogeneous respondent groups based on their views about training programs, financial competencies, innovation readiness, and the role of education in entrepreneurial development. The analysis supports the formulation of recommendations for policies and institutional practices aligned with the real needs of SMEs.

The present article builds upon a broader research project examining the perceptions of Romanian financial professionals regarding the SME environment. The first set of results, focusing on access to finance, has been published separately (Bozintan (Cosma-Guler), et al., 2026). The current paper addresses a distinct yet complementary dimension of the study, namely the role and perception of financial education. In emerging entrepreneurial ecosystems, such as those in Central and Eastern Europe, the interplay between educational resources, financing opportunities, and institutional support critically influences SME performance. Enhanced financial education amplifies the benefits of these ecosystem components by improving managerial decision-making, innovation readiness, and firms' ability to access diverse funding mechanisms.

2 LITERATURE REVIEW

2.1 Financial Literacy and Economic Behavior

Financial education is widely recognized as a key determinant of informed economic decision making. Brau et al. (2019), using a sample of 1,500 American students, show that formal financial training and direct experiences significantly improve financial literacy levels. Interestingly, family influence appears weaker than expected, while university courses and extracurricular activities play a major role in developing financial competencies. In the context of SMEs, financial education shapes financial attitudes, behaviors, and organizational performance (Graña-Alvarez et al., 2022). Rekha et al. (2024) note the absence of standardized tools for assessing SME financial literacy, despite its proven impact on managerial decision-making and access to diverse financial instruments. Financial knowledge enhances rational decision making and sustainability in micro enterprises (González-Prida et al., 2025) and is considered a strategic capability that improves budgeting, creditworthiness, and fintech adoption (Molosiwa & Holland, 2025).

According to Herte et al. (2021), firms' access to innovative resources is influenced not only by financial factors but also by entrepreneurs' educational levels and their proximity to scientific and institutional infrastructures. This reinforces the role of financial competencies as both an economic and innovation-enabling resource.

2.2 The Role of Institutions and Public Policies in Financial Education

International institutions reaffirm the crucial role of SMEs in global economies, yet highlight persistent administrative and market barriers, insufficient support, and limited financial knowledge (OECD,

2024). Financial education can mitigate these challenges; however, current approaches remain fragmented, and national strategies should explicitly include SMEs as a priority target group (Atkinson, 2017).

In Romania, the level of financial education among entrepreneurs and SME managers remains a significant determinant of business performance and sustainability (Badulescu & Badulescu, 2014). A study by the Institute for Financial Studies (2022) highlights the obstacles SMEs face in understanding and using non-bank financial instruments, as well as the need for continuous training adapted to their business realities. The study also confirms the importance of interactive consultation and educational platforms that respond to SMEs' evolving needs. The National Bank of Romania (NBR) and the Romanian Banking Association (RBA) promote financial education through multisectoral initiatives targeting entrepreneurs, youth, and the public. According to the NBR, low financial literacy among Romanian adults affects the functioning of the economy and requires coordinated and urgent educational measures (Isărescu, 2023).

The National Strategy for Financial Education 2023–2030 proposes an integrated approach with actions addressing children, youth, adults, and economic operators. It aims to increase financial literacy through structured programs, digital platforms, and teacher training (Ministerul Educației, 2024).

Since the literature highlights significant differences in professionals' perceptions of the role of financial education and in how they approach learning and financial instruments, we formulate the following research hypotheses, which derive logically from these findings:

H1. A type of financial institution influences professionals' perceptions of the importance of financial education in SME development.

H2. Preferences for financial education formats vary according to occupational position and institutional environment.

H3. Perceptions of financial education are structured along distinct latent dimensions that reflect both innovation-oriented and traditional financial orientations.

H4. Financial professionals exhibit consistent differences in how they relate to financial education.

3 METHODOLOGY

The research methodology is based on a questionnaire administered to Romanian financial professionals between January and March 2025. The questionnaire included items on (a) perceptions of the influence of financial education on SME success and resilience, (b) preferences for educational programs (online, mentoring, simulations), and (c) perceptions of the usefulness of educational initiatives in shaping financial decisions among SMEs.

The sample consisted of 74 respondents employed in banking and non-banking financial institutions, occupying positions such as branch managers, credit analysts, consultants, and EU-funding specialists. Their professional experience ranged from less than 5 years to over 20 years, allowing for comparative analysis by seniority and institution type.

The survey instrument covered perceptions regarding financial education and assessed the usefulness of learning formats for SME managers formats, alongside broader attitudes toward financing instruments. For the purposes of this article, we analyze two key items: the perceived impact of financial education on SMEs' confidence and ability to obtain appropriate financing (Q16: "To what extent do you believe that financial education has enhanced SMEs' confidence and their ability to obtain appropriate financing for the businesses you manage?") and the perceived usefulness of financial-education programs for SME managers (Q17: "Which types of financial education programs do you consider most useful for SME managers?"). The available response options included online courses, seminars/workshops, customized training, industry-specific simulations, and mentoring/consultancy. Responses were recorded on a five-point Likert scale ranging from "to a very small extent" to "to a very large extent."

A conceptual flow describing how contextual determinants and perceptual components shape financial-education outcomes is presented in Figure 1.

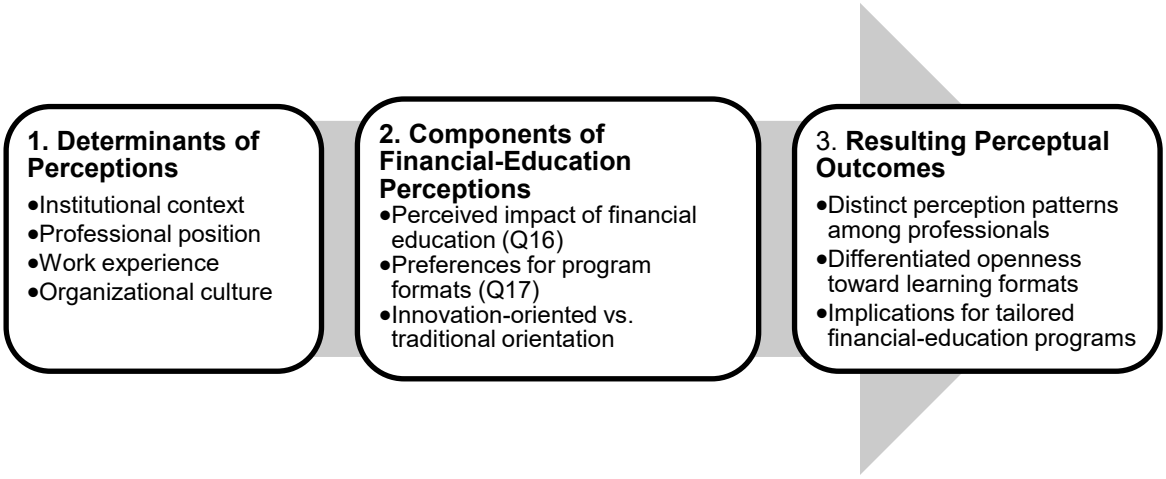


Figure 1. *Financial-Education Perception Flow*

To analyse the data, three statistical techniques were employed: Fisher's exact test, used to assess associations between demographic variables and perceptions of financial education; Exploratory Factor Analysis (EFA), used to identify latent perceptual dimensions; and K-means clustering, used to group respondents into homogeneous profiles based on their integrated perceptual structure. Data suitability for factor analysis was verified prior to extraction, and factors and clusters were retained based on standard criteria and conceptual interpretability.

Although the primary focus of this article is the analysis of financial education, the perceptual variables related to educational preferences emerged conceptually interlinked with respondents' broader attitudes toward financing instruments. Consequently, the Exploratory Factor Analysis captured an integrated perceptual structure in which financial education is naturally connected to orientations toward both traditional and alternative financing mechanisms.

Given the exploratory purpose of the study, the analysis was intentionally focused on a reduced number of core items capturing central perceptions regarding financial education and financing orientations, instead of developing extensive measurement scales.

4 RESULTS AND DISCUSSION

4.1 Associations Between Demographic Characteristics and Perceptions of Financial Education

The Fisher's Exact Test revealed several relevant associations between demographic variables and financial professionals' perceptions of the role of financial education in SME success (Table 1). The most significant result concerns the type of institution ($p = 0.014$), indicating that professionals working in commercial banks perceive financial education as having a significantly greater impact on SME performance compared to those from nonbanking financial institutions. In contrast, professional experience ($p = 0.487$) and level of formal education ($p = 0.722$) did not produce significant differences, suggesting a surprisingly uniform consensus: regardless of tenure or educational background, professionals acknowledge the importance of financial education for SMEs.

Table 1. *Impact of Professional Background on Perceptions of Financial Education*

Demographic Characteristic	Fisher Exact p-value
Experience in the field	0.487
Type of education completed	0.722
Type of institution	0.014

Source: Authors' analysis based on questionnaire responses

These findings support the assumption that institutional context shapes perceptions of financial education more strongly than individual factors, as mentioned by OECD (2024) and Badulescu & Badulescu (2014). Because banking professionals are directly exposed to SMEs' financing practices, they tend to recognize more clearly how SME focused financial education can support creditworthiness, reduce insolvency risk, encourage the informed use of instruments, and improve decision making within firms.

4.2 Preferences for Financial Education Formats

The analysis of perceived usefulness for SME decision makers for financial education formats revealed additional significant associations (Table 2). Occupational position shapes the way professionals rate the usefulness of online courses for SME managers ($p = 0.025$), with those in managerial roles more inclined to regard flexible, digital formats as effective options for SME learning. The same variable also shows a marginal association with preferences for simulations and case studies ($p = 0.097$), suggesting that individuals in managerial positions are more open to flexible and modern learning formats, while analysts whose work is oriented toward procedures and risk assessment tend to prefer applied and structurally organized formats (e.g., simulations, case studies) as particularly useful for SME managers.

Institution type is also associated with preferences for seminars/workshops ($p = 0.071$) and simulations ($p = 0.063$). Respondents from banking institutions more often value interactive formats to be effective for SMEs, possibly reflecting organizational cultures focused on operational training and continuous competence updates when advising clients.

Table 2. *Preferences for Specific Financial Education Formats by Demographic Characteristics (Fisher's Exact p-values)*

Type of Financial Education Program	Position	Experience	Education	Institution	Locality
Online courses	0.025	0.670	0.256	0.103	0.802
Seminars, workshops, etc.	0.433	**0.084**	0.943	**0.071**	0.568
Customized training	0.314	0.326	0.869	0.558	0.623
Simulations and case studies	**0.097**	0.914	0.633	**0.063**	0.589
Mentoring and consultancy	0.767	0.969	0.320	0.239	0.588

Source: Authors' analysis based on questionnaire responses

Divergent preferences between banks and non-bank financial institutions, as well as between hierarchical levels within organizations, highlight the need for customized financial education programs instead of uniform interventions. Managers tend to benefit from flexible digital formats; credit analysts and consultants from simulations and case studies; and staff in non-bank institutions, training oriented toward complex financial products and SME behavioral patterns. Implications for program design, as perceived by professionals, suggest matching SME audiences to formats: flexible digital modules for owner managers with time constraints; simulations and case studies or applied, scenario-based learning for teams; while SMEs considering non-bank financing could benefit from training focused on understanding alternative funding options.

4.3 Latent perceptual dimensions (EFA)

The Exploratory Factor Analysis (EFA) applied to items concerning financing instruments and financial education identified two key conceptual dimensions (Table 3).

Factor 1: Orientation Toward Innovation and Financial Education

This factor exhibits high loadings on crowdfunding (1.05), business angels (1.03), and financial education (0.47). Professionals who value alternative financial instruments are also those who highly value financial education, indicating an innovation and learning mindset. This alignment between innovation-oriented financing preferences and openness toward financial education is consistent with prior findings linking education to innovation readiness and adaptive financial behavior (Graña-Alvarez et al., 2022; Molosiwa & Holland, 2025). This cluster includes professionals likely to become "hybrid advisers" adapted to digitalization and collaborative finance.

Factor 2: Orientation toward Traditional Financing and Low Openness to Alternatives

This factor shows negative loadings for EU funds (-0.78), leasing (-0.36), and commercial banks (- 0.40). Lower appreciation of financial education is associated with a more traditional funding orientation. These professionals may view financial education as implicit or embedded in

established financial processes instead of as a distinct learning component.

These findings indicate that financial education is not treated as an isolated construct but situated within broader orientations toward financing instruments and innovation and influenced by educational expectations and openness to learning.

Table 3. *Latent Dimensions of Integrated Perceptions (EFA): Key Indicators and Interpretation*

Latent dimension (EFA)	Key indicators (loadings)	Interpretation (financial-education focus)
Factor 1: Innovation & education orientation	Crowdfunding (1.05); Business Angels (1.03); Financial education (0.47)	Openness to innovative instruments co-occurs with stronger valuation of financial education, suggesting an "innovation-and-learning" mindset among professionals.
Factor 2 – Traditional / institutional orientation	EU funds (-0.78); Leasing (-0.36); Commercial banks (-0.40)	A more traditional orientation tending to see SME-directed financial education as less salient or as implicitly embedded within established financing routines, rather than as a distinct learning need.

Source: Authors' analysis based on questionnaire responses

As shown in Table 3, financial education aligns with a broader innovation-linked orientation, while the second factor reflects a more traditional/institutional stance. This structure supports interpreting educational perceptions as situated within professionals' wider cognitive frames regarding financial instruments.

4.4 Perceptual clusters (K-means)

Based on the factor scores, the cluster analysis identified three distinct perceptual profiles. Figure 2 visualizes how the three respondent clusters position within the integrated perception space. This representation supports an intuitive reading of profiles as innovation-leaning, traditional-leaning, or reserved in their overall orientation.

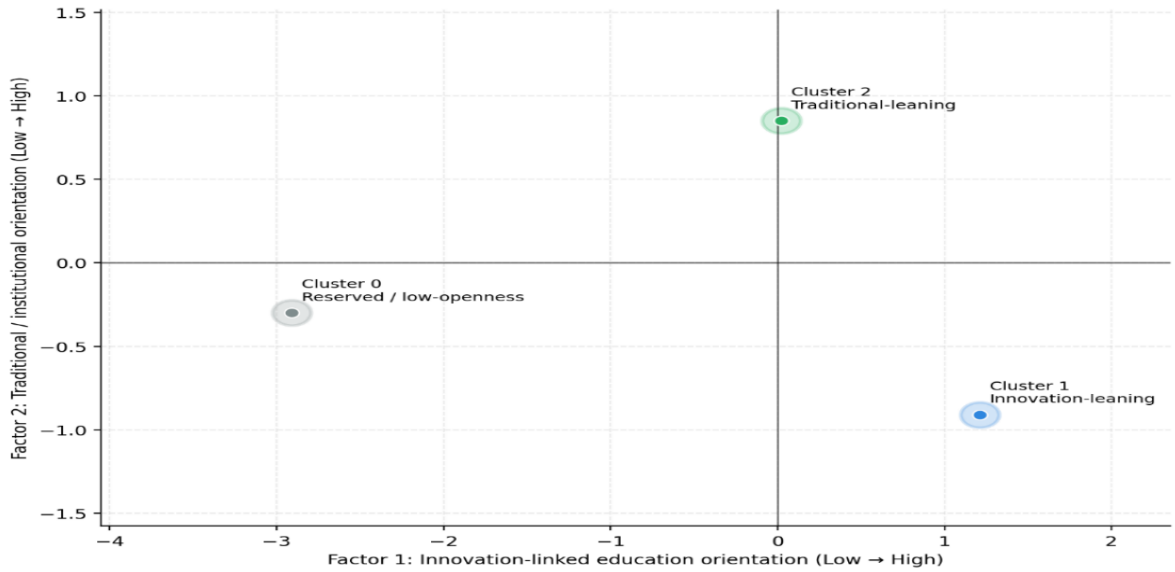


Figure 2. *Cluster Profiles in the Integrated Perception Space (EFA Factors)*
Source: Authors' analysis based on questionnaire responses

Given that the factor structure integrates both financial education variables and respondents' broader orientations toward financial instruments, the resulting clusters should be interpreted as reflecting comprehensive perceptual profiles. They describe not only attitudes toward financial education itself, but the wider positioning of professionals within the financial ecosystem, ranging from innovation& financial education -oriented, to traditionalist or skeptical stances.

Cluster 1 – Innovators: consistently endorse SME directed financial education, alongside alternative

instruments, and strong advocates of financial education. They tend to have substantial professional experience (often >15 years) and are natural promoters of educational initiatives within institutions.

Cluster 2 – Traditionalists: moderately value SME education (and its role in SME development) and prioritize conventional instruments. Typically have 10–15 years of experience.

Cluster 0 – Skeptics. Reserved toward both alternative financing instruments and less convinced about the added value of SME focused education. They are predominantly risk analysts with extensive experience (often >20 years) in banking institutions, whose roles emphasize procedural caution and risk assessment (Herte et al., 2021; OECD, 2024).

An alternative explanation for this reserved stance may relate less to resistance toward education per se and more to organizational roles emphasizing risk control, compliance, and procedural stability.

An integrated interpretation indicates that perceptions of financial education are systematically associated with broader professional orientations, work experience, and job responsibilities; specifically, exposure to dynamic SMEs and innovative products is positively related to viewing education as essential, whereas more procedural or risk-averse roles are associated with greater reluctance

This integrated interpretation strengthens the analytical coherence of the results: rather than treating financial education as an isolated behavioral dimension, the clustering indicates that educational perceptions are embedded within a broader cognitive framework conditioned by institutional culture, professional experience, and exposure to diverse financial instruments. The findings indicate that the institutional environment strongly shapes how professionals evaluate SME-oriented financial education. In addition, occupational position influences the formats they consider most suitable for SME learners, while their broader perceptual orientation (innovation versus traditionalism) predicts openness toward such educational initiatives.

Financial education thus emerges as a strategic component, yet one that is not uniformly perceived across professional groups - thereby requiring differentiated programs tailored to specific professional profiles.

Taking together, the results confirm the study's working hypotheses: the determinant role of institutional context in shaping perceptions of financial education (H1), the existence of differences in preferences for educational formats (H2), the presence of coherent latent perceptual dimensions (H3), and the manifestation of consistent perceptual differences among professionals, correlated with their broader financial orientations (H4).

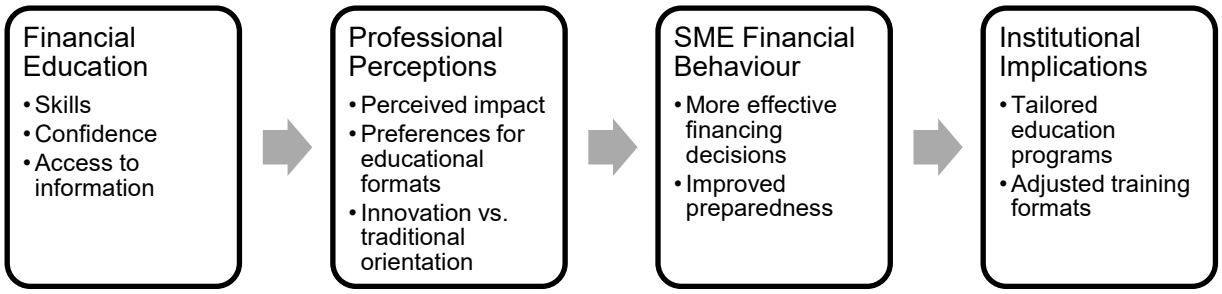


Figure 3. *Financial Education Pathway*

Figure 3 illustrates the sequential logic emerging from the study: financial education strengthens key cognitive and behavioral capacities (skills, confidence, and access to relevant information), which in turn shape financial professionals' perceptions regarding the usefulness, impact, and preferred formats of educational programs. These perceptions influence how SMEs navigate financial decisions, improving their ability to identify suitable financing options and manage financial risks. Ultimately, this pathway highlights the institutional need for differentiated and better targeted financial education programs aligned with the perceptual profiles identified in the analysis.

5 CONCLUSIONS

This study examined the perceptions of Romanian financial professionals regarding the role of financial education in shaping SMEs' financial

behavior, access to financing, and strategic decision making. The results show that perceptions of financial education are strongly influenced by institutional context, professional position, and broader orientations toward financial instruments. The identification of three perceptual clusters - Innovators, Traditionalists, and Skeptics - provides a nuanced understanding of how financial professionals evaluate the relevance and impact of financial education.

The findings confirm that financial education is widely recognized as a strategic determinant of SME sustainability. Professionals working in commercial banks- who interact more frequently with SMEs' financial decisions - tend to attribute greater importance to SME directed education, seeing it as integral to creditworthiness, prudent risk behavior, and product selection. By contrast, those in more conservative, risk focused roles demonstrate greater reluctance, treating financial competencies as implicit and not as separate learning priority. Instead of assessing the effectiveness of financial education itself, this study contributes by highlighting how institutional actors perceive, filter, and prioritize educational initiatives directed at SMEs.

The study also highlights clear differences in perceived usefulness for SME decision makers for educational formats. Respondents in managerial roles more often recommend flexible, digital formats for SME learners, while analysts and consultants tend to favor applied methods (simulations, case studies) when advising on SME training options. These patterns suggest that a uniform approach to financial education is ineffective. Instead, tailored programs aligned with institutional culture, professional responsibilities, and learning expectations are needed to enhance the relevance and impact of financial education initiatives.

The integrated perceptual structure revealed by the Exploratory Factor Analysis indicates that financial education is not perceived in isolation but is closely linked to professionals' broader orientations toward financial instruments and institutional routines toward financing instruments, innovation, and institutional routines. This reinforces the importance of designing educational policies that address not only knowledge gaps but also the cognitive frameworks and professional environments in which financial decisions are made.

These insights have important implications for policymakers, financial institutions, and educational providers. Strengthening financial education for SMEs requires differentiated, context-sensitive programs that reflect the diversity of professional roles within the financial sector.

Among the limitations of this study, we acknowledge that the findings rely on a relatively small, non-random sample of financial professionals, which may limit the breadth of perspectives captured. Also, the use of self-reported perceptions and a cross-sectional design constrain the ability to infer longer-term dynamics or behavioral outcomes. In addition, the analysis relies on a limited set of core survey items, which reflects the exploratory nature of the study and may constrain the explanatory depth of factor and cluster structure. These aspects suggest the value of future research involving larger and more diverse samples, as well as longitudinal or qualitative approaches. Upcoming research would benefit from expanding the sample to include entrepreneurs themselves, enabling a comparative analysis between SME needs and financial professionals' expectations, as well as from incorporating qualitative methods to capture deeper perceptual nuances. This study deliberately focuses on financial professionals' perceptions rather than objective SME performance indicators. Although this approach does not allow for direct causal conclusions about SME outcomes, it reflects how financial education is understood and mediated by financial institutions before reaching SMEs.

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MAPPING THE INTELLECTUAL STRUCTURE OF OPEN INNOVATION IN SMEs: A BIBLIOMETRIC ANALYSIS (2009–2025)

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ABSTRACT

This study provides a bibliometric analysis of research on open innovation in small and medium-sized enterprises (SMEs) over the period 2009–2025. Using a dataset of 500 journal articles indexed in the Web of Science, the study maps the field's intellectual structure, publication trends, influential sources, leading authors, country productivity, collaboration patterns, and thematic evolution. The results show a steady growth in scientific production, particularly after 2017, indicating the increasing consolidation of open innovation in SMEs as a distinct research domain. The literature concentrates on a limited number of influential journals, especially Technovation and Technological Forecasting and Social Change, while a small group of highly cited publications forms the conceptual foundation of the field. Thematic analysis reveals that the field is primarily structured around open innovation, SMEs, performance, research and development, absorptive capacity, and knowledge. Thematic evolution further indicates a shift from foundational concerns related to firm performance, manufacturing, and strategy towards more recent interests in business models, eco-innovation, digitalization, and empirical contextualization.

1 INTRODUCTION

Small and medium-sized enterprises (SMEs) play a central role in economic growth, employment generation, and the strengthening of national competitiveness. In an increasingly knowledge-based and highly dynamic business environment, innovation has become a critical factor in ensuring the survival and long-term sustainability of SMEs (Janković & Golubović, 2019). Within this context, open innovation has emerged as a prominent paradigm that enables firms to purposefully use both internal and external knowledge flows to accelerate innovation processes and enhance market performance (Odriozola-Fernández et al., 2019).

For SMEs in particular, open innovation offers important opportunities to overcome internal limitations by accessing external ideas,

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technologies, expertise, and collaborative networks. However, the adoption of open innovation is not without challenges. SMEs often face barriers related to limited financial and human resources, weak organizational structures, insufficient managerial capabilities, and difficulties in managing knowledge and intellectual property (Spithoven et.al., 2013; Almeida, 2024). These constraints make the implementation of open innovation more complex in SMEs than in large organizations.

To address these challenges, intellectual capital has increasingly been recognized as a strategic enabler of open innovation in SMEs. Human capital, structural capital, and relational capital can strengthen firms' ability to identify, absorb, share, and exploit knowledge from external sources (Phonthanukitithaworn et al., 2023). Empirical evidence also suggests that open innovation practices can positively influence innovative performance through the development of intellectual capital, particularly by enhancing human and organizational capabilities within SMEs (Sibhato, 2018). In this regard, open innovation is not only a mechanism for accessing external knowledge, but also a pathway for reinforcing the internal competences needed to transform such knowledge into competitive outcomes.

Over the past decade, research on open innovation in SMEs has expanded significantly. Previous review studies have shown that this field has grown rapidly, with growing attention being paid to the effects of open innovation on firm performance, new product development, organizational structure, and knowledge management (Hossain, 2015; Odriozola-Fernández et al., 2019). More recently, bibliometric studies have contributed to mapping the evolution of this body of knowledge, identifying its principal contributors, influential journals, collaboration networks, and emerging themes (Yulianti et al., 2023; Gulia et al., 2024). These developments reflect the increasing maturity of the field and the need for a more systematic understanding of its intellectual structure.

However, what distinguishes the present study from existing bibliometric efforts is twofold. First, while previous reviews have mapped the literature up to 2022 or 2023, this study extends the temporal scope to 2025, capturing the critical post-pandemic period where digital transformation and eco-innovation radically reshaped SME strategies. Second, unlike purely descriptive bibliometric profiles, this study places a strong emphasis on longitudinal thematic evolution and Bradford's law of scattering, offering a dynamic mapping of how the intellectual core of the field has transitioned from basic adoption motives towards complex ecosystem configurations. This updated and dynamic perspective provides a necessary bridge between past foundational theories and contemporary technological imperatives in SME open innovation.

Despite this progress, the intellectual landscape of open innovation in SMEs remains fragmented, particularly about the evolution of themes, conceptual linkages, and research clusters over time. Given the growing volume of publications in this area, it is essential to investigate how the field has developed, which themes have dominated scholarly attention, and what future directions may shape its advancement. Against this background, the present study seeks to address the following questions:

- How has research on open innovation in SMEs evolved during the period 2009–2025?
- What are the major themes and intellectual clusters that have shaped this field?
- How is research in this area distributed across authors, institutions, countries, and journals?
- What patterns of collaboration and knowledge production can be identified?
- Which topics have emerged as the most influential and which areas remain underexplored?
- What future research directions can be derived from the bibliometric structure of the field?

By examining these issues, this study aims to provide a comprehensive overview of the intellectual structure of open innovation research in SMEs. It also seeks to highlight the principal trends, research hotspots, and future pathways that may guide scholars, practitioners, and policymakers interested in the continued development of this important field.

2 MATERIALS AND METHODS

This study adopted a bibliometric approach to examine the development of research on open innovation in small and medium-sized enterprises (SMEs). The bibliographic data were retrieved from the Web of Science Core Collection, which was deliberately selected over other databases such as Scopus or Google Scholar to ensure transparency and analytical rigor. WoS is widely recognized for its strict indexing standards and rigorous peer-review requirements, which guarantees a highly curated dataset of premium scholarly literature. By focusing exclusively on WoS, this study mitigates the risk of "noise" and low-quality publications that often characterize broader databases, thereby providing a more reliable foundation for mapping the true intellectual core of the field.

The search process was based on a keyword-driven strategy combining the core concepts of open innovation and small and medium-sized enterprises (SMEs). The following Boolean query was used:

TS=("open innovation" AND ("small and medium enterprise" OR SME*)) AND DT=Article AND LA=English AND PY=2009-2025*

To improve the relevance and consistency of the dataset, the search was limited to English-language journal articles only. Other document types, such as reviews, conference papers, book chapters, editorials, and notes, were excluded.

After applying the selection criteria and screening the retrieved records for relevance, the final dataset was retained for bibliometric analysis.

The bibliographic data were analyzed exclusively using RStudio through the bibliometrix package and its web-based interface Biblioshiny. This analytical environment was chosen because it provides a reliable and reproducible framework for conducting bibliometric studies and science mapping.

After importing the BibTeX file into Biblioshiny, the dataset was processed to generate the main bibliometric outputs related to publication trends, source productivity, authorship patterns, citation structure, keyword occurrence, and collaboration networks. In addition, the software supported the mapping of the conceptual and intellectual structure of the field based on the metadata extracted from the selected publications.

This procedure enabled a systematic exploration of the literature on open innovation in SMEs and facilitated the identification of its main research patterns and thematic developments.

Some limitations of this study should be critically acknowledged. First, the deliberate restriction to the Web of Science Core Collection, while ensuring high quality, implies a trade-off, as it may have excluded relevant studies indexed in other prominent databases like Scopus. Second, restricting the sample to English-language journal articles may have introduced a linguistic bias, potentially overlooking valuable insights published in local or regional journals. Third, the dataset reflects the state of the database at the time of retrieval; therefore, publications indexed after this date were not included. Despite these limitations, the adopted methodology provides a coherent, rigorous, and transparent basis for examining the evolution and structure of research on open innovation in SMEs.

3 RESULTS

The descriptive overview of the dataset indicates that research on open innovation in SMEs has developed steadily over the period 2009–2026, with a final corpus of 500 journal articles published across 170 sources. Literature appears relatively recent, as reflected by a document average age of 6.27 years, while the average of 42.59 citations per document suggests a noticeable scientific impact of the field. In total, the dataset contains 23,426 references, pointing to a well-established and interconnected knowledge base. From a conceptual perspective, the presence of 1,453 authors' keywords and 800 Keywords Plus indicates considerable thematic diversity and richness in the research domain. In terms of authorship, the field involves 1,300 authors, but only 46 documents were single-authored, with just 39 authors contributing individually, which confirms that the field is largely collaborative. This is further supported by an average of 3.15 co-authors per document and an international co-authorship rate of 36.8%, highlighting a moderate but meaningful level of international research collaboration. Overall, these indicators suggest that the literature on open innovation in SMEs is

both growing and increasingly collaborative, with a solid intellectual foundation and broad thematic scope.

As illustrated in Figure 1, research on open innovation in SMEs has grown steadily over time, although with some fluctuations across the study period. The field recorded a limited number of publications between 2009 and 2012, followed by a gradual increase from 2013 onward and a more pronounced expansion after 2017. Scientific output reached its highest level in 2023, with 63 articles, reflecting the growing academic interest in this topic. Although a slight decline is observed in 2024 and 2025, this decrease may be related to database indexing delays rather than an actual reduction in research activity. In terms of citation impact, earlier publications show relatively higher mean total citations per year, particularly those published in 2009 and 2010, mainly because they have had more time to accumulate citations. By contrast, more recent publications display lower citation averages due to their shorter exposure time. Overall, Figure 1 confirms that the literature on open innovation in SMEs is expanding and gradually maturing as a research field.

***Table 1**. Descriptive Statistics*

Description	Results
Timespan	2009:2026
Sources (Journals, Books, etc)	170
Documents	500
Document Average Age	6.27
Average citations per doc	42.59
References	23426
DOCUMENT CONTENTS	
Keywords Plus (ID)	800
Author's Keywords (DE)	1453
AUTHORS	
Authors	1300
Authors of single-authored docs	39
AUTHORS COLLABORATION	
Single-authored docs	46
Co-Authors per Doc	3.15
International co-authorships %	36.8
DOCUMENT TYPES	
Article	500

Source: Elaborated by author based on R Studio using biblioshiny

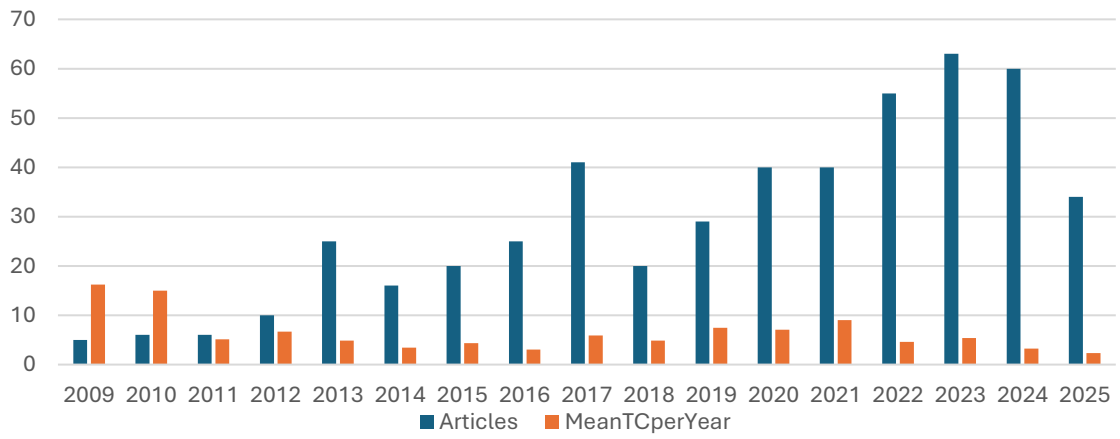


***Figure** 1. Annual Trends in Scientific Production and Mean Citations per Year (2009–2025)*
Source: Compiled by the author based on Web of Science data using Excel

Table 2 shows that research on open innovation in SMEs is concentrated in a relatively small group of influential journals. Technovation and Technological Forecasting and Social Change stand out as the most impactful sources, recording the highest citation counts and strong h-index and g-index values, which confirms their central role in shaping the field. Technological Forecasting and Social Change is particularly notable for its high h-index (19) and substantial productivity since 2017, whereas Technovation achieved the highest total citations (TC = 2693) and has contributed continuously since 2009. Other journals, such as the Journal of Knowledge Management and Journal of Business Research, also show strong citation performance, indicating their importance in connecting innovation studies with management and business perspectives. Overall, the table suggests that literature is anchored in high-impact innovation and management journals, reflecting both the maturity and interdisciplinary nature of research on open innovation in SMEs.

***Table 2**. Source Impact Indicators and Productivity Metrics of Major Journals (2010–2025)*

Source	H_Index	G_Index	M_Index	Tc	Np	Py_Start
Technological Forecasting and Social Change	19	25	1.9	1981	25	2017
Technovation	17	21	0.944	2693	21	2009
Technology Analysis & Strategic Management	13	15	0.929	627	15	2013
European Journal of Innovation Management	12	16	1.2	558	16	2017
International Journal of Innovation Management	12	21	0.667	471	24	2009
Journal Of Knowledge Management	12	16	1.2	1375	16	2017
IEEE Transactions on Engineering Management	11	16	1.571	368	16	2020
Journal of Business Research	10	10	1.25	1408	10	2019
R & D Management	10	13	0.588	677	13	2010
Management Decision	9	11	0.818	316	11	2016

Source: Compiled by the author based on Web of Science data using Biblioshiny

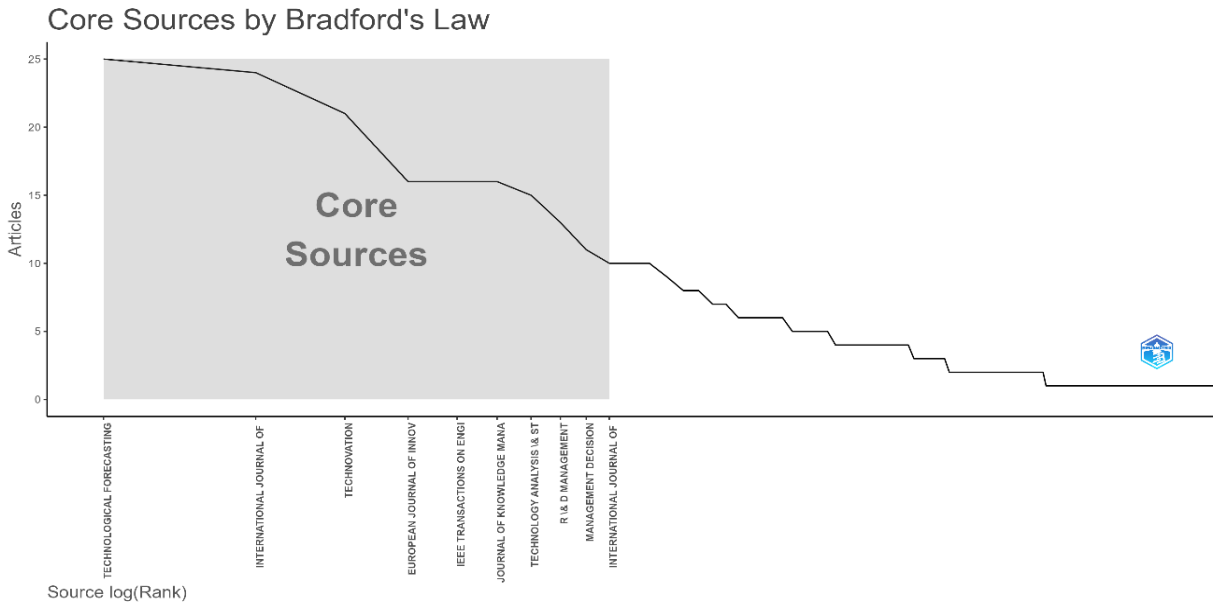


***Figure 2**. Core Journal Concentration According to Bradford's Law*
Source: Elaborated by author based on R Studio using biblioshiny

Based on Bradford's Law, Figure 2 demonstrates that research on open innovation in SMEs is concentrated within a limited number of core journals, followed by a wider dispersion across less productive sources. The core zone (Zone 1) includes the most influential and prolific journals, such as Technological Forecasting and Social Change, International Journal of Innovation Management, and Technovation, which constitute the primary outlets for scholarly contributions in this field. Beyond this nucleus, the second zone comprises a broader set of journals that contribute a moderate number of publications, mainly within the domains of innovation, management, and entrepreneurship. Finally, the third zone is characterised by many journals with only one or two publications each, indicating a high level of dispersion. This distribution confirms that while the field is anchored in a small group of leading journals, it is also widely disseminated across diverse sources, reflecting both the maturity and interdisciplinary nature of research on open innovation in SMEs.

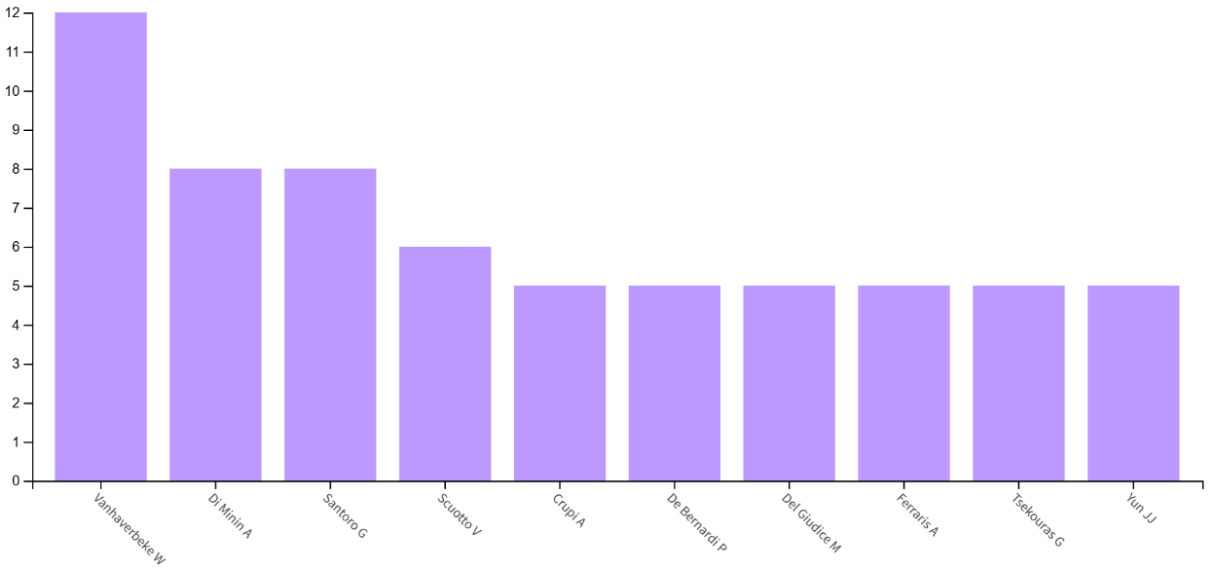


***Figure 3**. Most Relevant Authors*
Source: Author's elaboration based on Web of Science data.

Figure 4 illustrates the most relevant authors in the field of open innovation in SMEs, based on their number of publications. As shown, Vanhaverbeke W. emerges as the most prolific contributor, with the highest number of publications, highlighting a leading role in shaping the research domain. This author is followed by Di Minin A. and Santoro G., who also demonstrate strong research productivity and consistent contributions to the field. A second group of authors, including Scuotto V., Crupi A., and De Bernardi P., show moderate but significant involvement, indicating their growing influence. The remaining authors, such as Del Giudice M., Ferraris A., Tsakalerou G., and Yun J.J., contribute with a comparable number of publications, reflecting a relatively balanced distribution among emerging contributors. Overall, the figure suggests that while the field is led by a few highly productive scholars, it is also supported by a broader group of active researchers, indicating both consolidation and expansion in this research area.

Table 3. Most Globally Cited Documents in Open Innovation Research in SMEs

Paper	DOI	Total Citations	TC per Year
Van De Vrande V, 2009, Technovation	10.1016/j.technovation.2008.10.001	1310	72,78
Lee S, 2010, Res Policy	10.1016/j.respol.2009.12.009	890	52,35
Cenamor J, 2019, J Bus Res	10.1016/j.jbusres.2019.03.035	593	74,13
Parida V, 2012, J Small Bus Manag	10.1111/j.1540-627X.2012.00354.x	535	35,67

Paper	DOI	Total Citations	TC per Year
Brunswicker S, 2015, J Small Bus Manag	10.1111/jsbm.12120	480	40,00
Spithoven A, 2013, Small Bus Econ Group	10.1007/s11187-012-9453-9	429	30,64
Singh Sk, 2021, J Bus Res	10.1016/j.jbusres.2019.04.040	413	68,83
Popa S, 2017, Technol Forecast Soc Chang	10.1016/j.techfore.2017.02.014	304	30,40
Scuotto V, 2017, Creat Innov Manag	10.1111/caim.12221	300	30,00
Spithoven A, 2010, Technovation	10.1016/j.technovation.2009.08.004	290	17,06

Source: Elaborated by author based on R Studio using biblioshiny

Table 3 An examination of the titles of the most globally cited documents confirms that the intellectual structure of open innovation in SMEs is organized around three major thematic pillars. First, a foundational stream defines the concept, motives, challenges, and organizational models of open innovation in SMEs, as illustrated by seminal studies such as Open Innovation in SMEs: Trends, Motives and Management Challenges and Open innovation in SMEs-An intermediate network model. Second, a performance-oriented stream links inbound openness, external knowledge sourcing, knowledge sharing, and innovation climate to firm and innovation performance. Third, a more recent digitalization-oriented stream extends the field towards digital platforms, digital business, and ambidexterity in entrepreneurial SMEs. Accordingly, the field appears to have evolved from conceptual and structural discussions of open innovation in SMEs towards more dynamic concerns related to organizational performance, digital transformation, and strategic capability development.

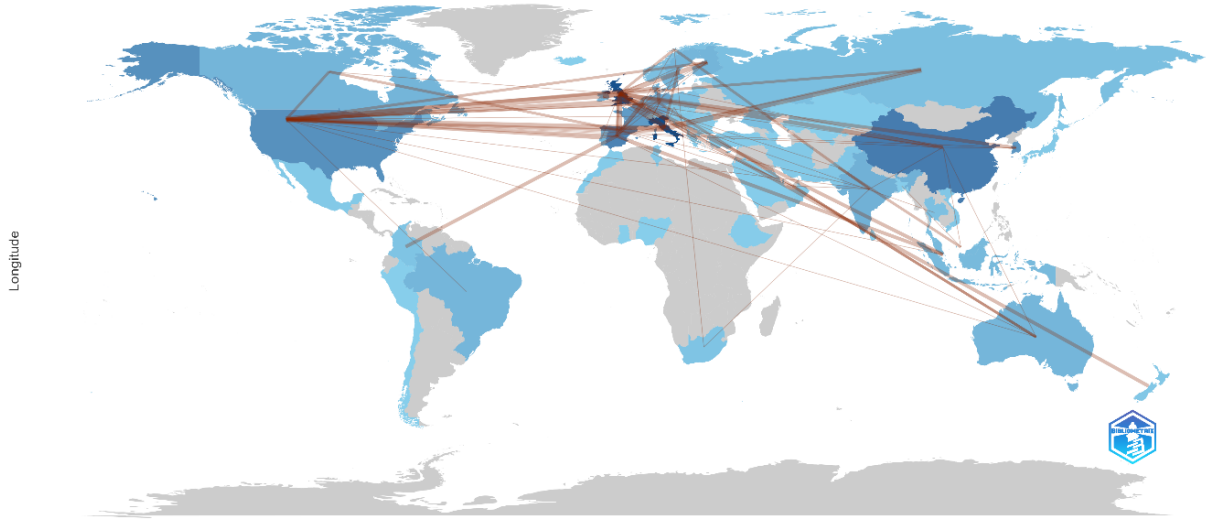


Figure 4*. Global Country Collaboration Network in Open Innovation Research in SMEs (2009–2025)*
Source: Elaborated by the author based on bibliometric data from the study dataset and visualized using Biblioshiny (Bibliometrix package) in R Studio.

The country analysis reveals a strong concentration of research output in a limited number of countries, led by Italy (238), the United Kingdom (178), China (133), South Korea (109), and Spain (106). This indicates that the field of open innovation in SMEs is driven primarily by a small group of highly productive countries, with a particularly strong European presence. The collaboration map further shows that international cooperation is organized around a few major hubs, notably the United Kingdom, Italy, the United States, China, and India, which occupy central positions in the global collaboration network. Hence, the field is characterized not only by unequal publication productivity but also by a core-periphery collaboration structure in which a limited number of countries dominate international knowledge exchange.



Figure 5. *Keyword Treemap of Open Innovation Research in SMEs (2009–2025)*
Source: Prepared by the author using Biblioshiny (Bibliometrix package) in R Studio, based on the study dataset.

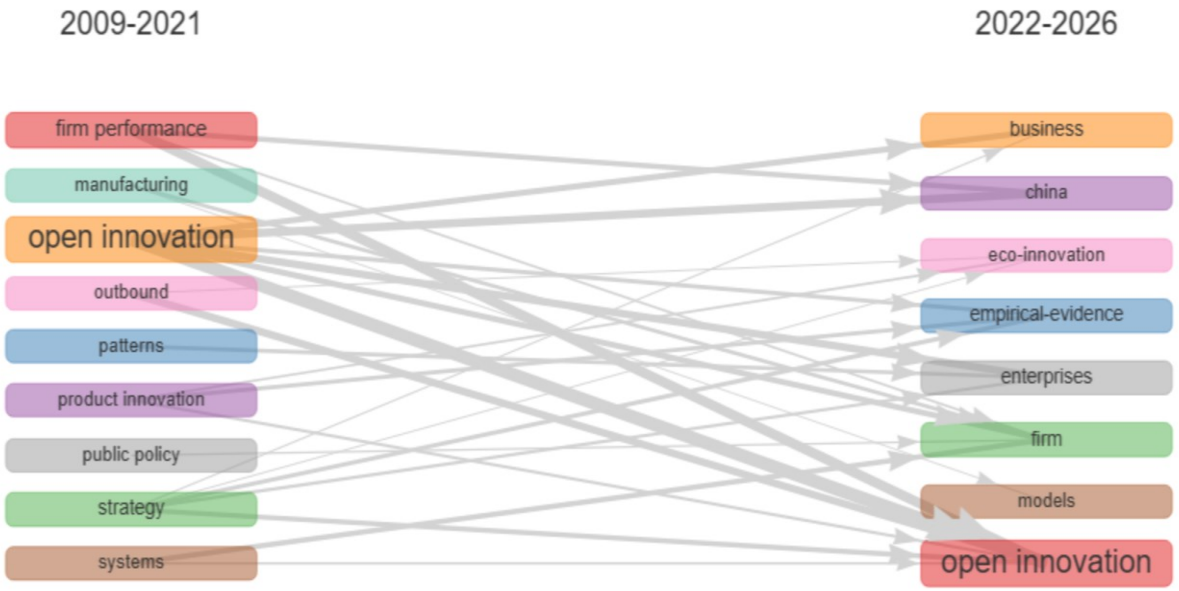


Figure 6. *Thematic Evolution of the Intellectual Structure of Open Innovation Research in SMEs (2009–2021 vs. 2022–2025)*
Source: Prepared by the author using Biblioshiny (Bibliometrix package) in R Studio, based on the study dataset

Figures 5 and 6 illustrate the main thematic configuration of the literature on open innovation in SMEs. As shown in Figure 6, the most frequent keyword is open innovation (325; 11%), followed by SMEs (234; 8%) and performance (227; 8%), which confirms that the field is primarily structured around openness, firm type, and performance-related concerns. Other prominent themes include

research and development (159; 5%), absorptive capacity (123; 4%), knowledge (118; 4%), innovation (92; 3%), collaboration (84; 3%), and technology (76; 3%), indicating the importance of knowledge-based capabilities and inter-organizational interaction within the field. In addition, Figure 6 shows that the thematic evolution of literature is marked by both continuity and change. During the 2009–2021 period, the field was associated with themes such as firm performance, manufacturing, outbound, patterns, product innovation, public policy, strategy, and systems. In the 2022–2025 period, the thematic structure shifted towards business, China, eco-innovation, empirical evidence, enterprises, firm, and models, while open innovation remained the central and persistent theme across both periods. These results indicate that the field has expanded from its earlier emphasis on performance and operational dimensions towards a broader and more diversified thematic structure.

4 DISCUSSION

The findings indicate that research on open innovation in SMEs has moved from an emerging topic to a consolidated research field. The steady increase in publications, the relatively high average citations per document, and the broad dispersion across 170 sources suggest both maturation and diversification.

Analytically, the pronounced expansion of scholarly output after 2017 can be explained by broader macro-economic and technological shifts. The widespread integration of Industry 4.0 technologies and the rise of platform ecosystems during this period forced SMEs to realize that internal R&D was no longer sufficient to remain competitive. Consequently, researchers intensified their focus on how SMEs leverage open innovation to survive digital disruption, thereby driving the observed spike in academic production.

This pattern is consistent with earlier bibliometric evidence showing a sustained rise in scholarly interest in open innovation in SMEs. For example, Odriozola-Fernández et al. (2019) described the field as expanding but still structurally concentrated, while Nuryakin et al. (2022) and Sabando-Vera et al. (2022) likewise reported a continuous growth trajectory in publications on open innovation and SMEs. At a broader level, Gao et al. (2020) also showed that open innovation research has expanded considerably over time, which helps explain why the SME-focused stream has become more visible and theoretically developed in recent years. Taken together, the present results confirm that open innovation in SMEs is no longer a peripheral topic, but a stable and increasingly specialized area within innovation and management research.

The source and citation analyses further show that the field is anchored in a relatively small set of influential journals and seminal publications. The centrality of *Technovation*, *Technological Forecasting and Social Change*, *Journal of Business Research*, and *Journal of Small Business Management* suggest that the literature has developed at the intersection of innovation management, strategic management, and SME studies. This result broadly aligns with Odriozola-Fernández et al. (2019), who also identified *Technovation* as a particularly high-impact outlet and highlighted the importance of *Research Policy* and *Journal of Small Business Management* in shaping the field. The dominance of highly cited works by van de Vrande et al. (2009), Lee et al. (2010), Parida et al. (2012), Spithoven et al. (2013), and Brunswicker and Vanhaverbeke (2015) confirms that the intellectual foundations of this domain are built around three closely related concerns: the diffusion of open innovation practices in SMEs, the role of networked and intermediary-based collaboration, and the internal organisational conditions required to benefit from external knowledge. This also echoes the broader open innovation literature, which has long framed the phenomenon around obtaining, integrating, and commercialising knowledge beyond firm boundaries (West & Bogers, 2014).

A major contribution of the present study lies in showing that the field remains strongly performance- and capability-oriented. The prominence of keywords such as *performance*, *research and development*, *absorptive capacity*, *knowledge*, *collaboration*, and *technology* indicates that open innovation in SMEs is still largely interpreted through a resource- and capability-based lens. This is highly consistent with prior empirical work. Parida et al. (2012) showed that different inbound open innovation activities benefit different innovation outcomes,

while Spithoven et al. (2010) and Spithoven et al. (2013) emphasized absorptive capacity as a key precondition for organizing and benefiting from inbound openness, especially in resource-constrained firms. In a similar vein, Popa et al. (2017) demonstrated that innovation climate positively supports both inbound and outbound open innovation and that both forms contribute positively to firm performance. Singh et al. (2021) further reinforced this line of argument by showing that top management knowledge value and knowledge-sharing practices strengthen open innovation and, through it, organizational performance. Accordingly, the current keyword structure suggests that the field has not moved away from its core concern with SME competitiveness; rather, it has deepened the explanation of *how* external openness translates into improved innovation and organizational outcomes.

At the same time, the thematic evolution analysis indicates that the field is undergoing an important shift from foundational and operational issues towards more contextualized and contemporary concerns. Earlier themes such as *firm performance*, *manufacturing*, *outbound*, *strategy*, and *systems* reflect a stage in which scholars were mainly concerned with defining open innovation in SMEs, identifying its motives and barriers, and testing its effects on innovation outputs.

By contrast, the more recent emergence of themes such as business models, eco-innovation, and China provides analytical evidence of how exogenous shocks-such as the COVID-19 pandemic and global sustainability mandates-have redirected the research agenda. The shift towards "eco-innovation" reflects an increasing awareness that open innovation is an essential mechanism for SMEs to achieve circular economy goals, while the focus on "business models" underscores the realization that technological openness must be accompanied by value-capture mechanisms to be profitable.

This interpretation is fully in line with van de Vrande et al. (2009), Lee et al. (2010), and Brunswicker and Vanhaverbeke (2015), who concentrated on motives, management challenges, intermediary mechanisms, and external knowledge sourcing strategies. By contrast, the more recent emergence of themes such as *business*, *eco-innovation*, *empirical evidence*, *models*, and *China* suggests that the field is becoming more application-driven, geographically diversified, and sensitive to digital and sustainability transitions. This evolution corresponds closely to Cenamor et al. (2019), who linked digital platform capability and network capability to SME performance, and to Scuotto et al. (2017), who examined how SME innovation processes are shifting towards digital business. More generally, Bogers et al. (2018) identified digital transformation as one of the key contemporary trends reshaping open innovation research, while Sabando-Vera et al. (2022) found that the intellectual structure of open innovation in SMEs increasingly revolves around firm performance, R&D networks, business management, business models, capabilities, and knowledge transfer. In this sense, the present findings suggest that the field is evolving from a focus on whether SMEs adopt open innovation to a more nuanced interest in how openness is configured in digitally mediated and sustainability-oriented business environments.

The country analysis also provides an important insight into the geography of knowledge production in this field. The strong presence of Italy, the United Kingdom, Spain, France, Portugal, Germany, and Belgium confirm the continued dominance of Europe, while the major roles of China and South Korea point to a strong East Asian contribution.

This geographic concentration can be analytically explained by underlying policy frameworks. The European dominance is heavily driven by institutional funding schemes (such as the EU's Horizon 2020 and Horizon Europe programs) that explicitly mandate SME collaboration with universities and cross-border partners, structurally embedding open innovation into the European SME fabric. Conversely, the rise of China and South Korea reflects aggressive state-backed investments in technology parks and innovation clusters designed to integrate local SMEs into global tech supply chains.

This pattern is broadly consistent with the earlier Web of Science-based study of Odriozola-Fernández et al. (2019), who found that the UK, Italy, South Korea, and Belgium were among the

leading contributors and that European countries clearly dominated the field. However, the present results also indicate a stronger rise of China and a more visible multi-polar structure than earlier studies reported, suggesting that the field has become more internationally diffused over time. The collaboration map strengthens this interpretation by showing that international research is organized around a limited number of hubs, especially the United Kingdom, Italy, the United States, China, and India. This core-periphery structure is theoretically coherent with the SME open innovation literature, which has long stressed the importance of networks, intermediaries, and collective capability-building for smaller firms facing internal resource constraints (Lee et al., 2010; Spithoven et al., 2010). Thus, the international collaboration structure identified here is not merely a bibliometric pattern; it also reflects the substantive logic of open innovation itself, namely that value creation increasingly depends on cross-boundary linkages and collaborative knowledge exchange.

Overall, the discussion suggests that the literature on open innovation in SMEs has developed along a coherent but increasingly diversified trajectory. The field began with foundational efforts to demonstrate that SMEs also engage in open innovation and to explain the motives, barriers, and organizational implications of such openness. It then expanded towards performance-oriented and capability-based explanations, particularly around absorptive capacity, knowledge sharing, and collaboration. More recently, it has entered a new phase characterized by digitalization, business model concerns, eco-innovation, and broader empirical validation across countries and contexts. Therefore, the present study not only confirms the core pillars already identified in previous research but also shows that the field is becoming more mature, more international, and more closely connected to contemporary strategic challenges faced by SMEs.

5 CONCLUSIONS

This bibliometric study mapped the development of research on open innovation in SMEs over the period 2009–2025. The findings show that the field has evolved into a well-established and increasingly dynamic research domain, characterized by steady growth in scientific production, a relatively high citation impact, and a collaborative authorship structure. Although literature remains dispersed across a wide range of journals, it is clearly anchored in a limited number of high-impact sources, particularly those specializing in innovation, technology management, and business research. This confirms that open innovation in SMEs has developed as an interdisciplinary field situated at the intersection of innovation studies, strategic management, and entrepreneurship.

The analysis also demonstrates that the intellectual structure of the field is built around a small number of highly influential publications that have shaped its conceptual and empirical foundations. In particular, the most cited documents reveal that the field initially focused on explaining the motives, forms, and managerial challenges of open innovation in SMEs, before expanding towards performance-related issues, knowledge sourcing, absorptive capacity, and collaboration. More recent developments indicate a growing interest in digital platforms, business models, eco-innovation, and context-specific applications, showing that the field is becoming more diversified and better aligned with contemporary business transformations.

From a geographical perspective, the results reveal a strong concentration of scientific production in a limited number of countries, with a particularly prominent European contribution, alongside the increasing role of Asian countries such as China and South Korea. International collaboration is structured around a small number of central hubs, suggesting that the field is characterized by a core-periphery knowledge network. This finding highlights the importance of cross-border collaboration in advancing the field and suggests that international partnerships remain a key mechanism for knowledge diffusion and scholarly visibility.

The thematic analysis further confirms that open innovation, SMEs, and performance constitute the core pillars of the literature, while research and development, absorptive capacity, knowledge, collaboration, and technology represent its most important supporting themes. At the same time, the thematic evolution analysis shows that the field has moved from a more foundational and operational orientation towards a broader agenda

that increasingly incorporates sustainability, business model innovation, and empirical contextualization. This thematic shift reflects the growing maturity of the field and its capacity to respond to emerging managerial and societal challenges.

From a theoretical standpoint, this study contributes to the literature by demonstrating how the conceptualization of open innovation in SMEs has transitioned. It advances the resource-based view (RBV) and dynamic capabilities theory by revealing that open innovation is no longer viewed merely as a compensatory mechanism for resource-poor SMEs, but as a proactive, endogenous dynamic capability essential for navigating digital transformation and sustainability transitions. By mapping the thematic shift towards eco-innovation and digital business models, this study provides scholars with a clear roadmap of where the theoretical frontiers of SME open innovation currently lie.

In practical terms, the findings offer actionable insights for SME managers and policymakers. For SME managers, the persistence of "absorptive capacity" as a dominant keyword signals the imperative to invest in internal human capital and knowledge-sharing routines; external partnerships will fail if the internal capacity to assimilate knowledge is weak. For policymakers, the core-periphery geographic collaboration map underscores the need to design inclusive innovation policies. Governments should foster intermediate platforms and digital clusters that help peripheral SMEs connect with global innovation hubs, thereby democratizing access to open innovation networks.

Looking forward, several promising avenues for future research emerge from this bibliometric mapping. First, as the literature increasingly intersects with digitalization, future empirical studies should investigate how Artificial Intelligence (AI) and blockchain technologies alter the cost and mechanisms of inbound and outbound open innovation for SMEs. Second, given the rising prominence of eco-innovation, scholars should explore the role of open innovation in accelerating SMEs' transition toward the circular economy. Finally, to overcome the geographic concentration identified in this study, future research must prioritize comparative analyses of open innovation practices in emerging economies, exploring how institutional voids and informal networks shape SME collaboration outside the dominant Euro-Asian clusters.

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ORIGINAL RESEARCH ARTICLE
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THE ROLE OF THE NATIONAL OFFICE OF WAQF AND ZAKAT IN MOBILIZING WAQF AND ZAKAT RESOURCES IN ALGERIA

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ABSTRACT

This study aims to highlight the role of the National Office for Waqf and Zakat in mobilizing Waqf and Zakat resources in Algeria. The Office was established by decree No. 21-179 to establish an institutional structure responsible for managing Waqf and Zakat resources and directing them towards community development. The study reached several conclusions, the most important of which is that the Office is a tool for mobilizing, managing, exploiting, developing, and investing waqf properties. During its activities in the period 2021-2023, it included more than 4,200 waqf properties. The National Office is also a mechanism for collecting, disbursing, and developing zakat, as it collects zakat resources from three main sources, which has led to a continuous increase in its annual revenue, reaching more than 1.649 billion dinars in 2024. Among the study's recommendations is the need to strengthen community confidence in the importance of takaful institutions and their pivotal role in supporting the charitable sector.

1 Introduction

Considering recent crises, the Islamic financial industry has attracted widespread international attention, particularly about its non-profit instruments such as waqf and zakat, which are considered two forms of charitable giving aimed at providing money to those who deserve it without compensation, motivated by religious beliefs and ethical considerations within the Islamic framework. Their resources represent a fundamental pillar for supporting bonds of compassion and solidarity among members of

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society, thereby achieving economic and social development.

Consequently, many Islamic countries have moved towards establishing an institutional structure concerned with adopting mechanisms and means to mobilize and collect waqf and zakat resources, to invest and employ them for the benefit of society. In Algeria, the first steps towards creating an institutional framework for these resources were taken in 2003 with the establishment of the Zakat Fund, which was recently transformed by Decree 21-179 to the National Office for Waqf and Zakat so that waqf properties and zakat resources could be managed by a single institutional structure. Previously, waqf management had been entrusted to central and local bodies at the level of the Ministry of Religious Affairs and Waqf, while zakat was supervised by the Zakat Fund, a special body also operating under the auspices of the same ministry.

1.1 Research Problem

From the above, the research problem emerges as follows:

What is the role of the National Office for Endowments (Waqf) and Zakat in mobilizing endowment and zakat resources in Algeria?

This leads to the following questions:
- What are the forms and sources through which endowment and zakat resources are mobilized in Algeria?
- What are the most important determinants of the regulation of waqf property and zakat resources by the Algerian legislature?
- What are the tasks entrusted to the National Office for Waqf and Zakat regarding the mobilization of Waqf and Zakat resources?

1.2 Research Hypotheses

To answer the research question, the following hypotheses have been formulated:
- Waqf in Algeria varies between charitable waqf for charitable and benevolent causes, private or civil waqf for the cause designated by the waqf founder, and joint waqf. Zakat, on the other hand, is mobilized from three main sources: zakat al-Fitr, zakat on crops and fruits, and zakat on money.
- The Algerian legislature has contributed to the establishment of a set of laws and decrees that have resulted in the creation of an institutional framework for the control of waqf property and zakat resources, represented by the National Office for Waqf and Zakat.
- The National Office for Waqf and Zakat is a tool for mobilizing, managing, exploiting, developing, and investing public waqf property in accordance with the wishes of the waqf founder and the provisions and objectives of Islamic law. It is also a mechanism for collecting, disbursing, and developing zakat in accordance with the provisions of Islamic law.

1.3 Research Importance and Objectives

This study is important because it sheds light on the role of the National Office for Waqf and Zakat in mobilizing waqf and zakat resources with a view to promoting waqf and zakat for the development of society and injecting new dynamism into the social and economic spheres.

This study seeks to achieve the following objectives:
- Defining the nature of waqf and zakat and their sources of mobilization.
- Explain the role of the Algerian legislator in creating an institutional structure for the management and administration of waqf and zakat resources.
- Highlight the role of the National Office for Waqf and Zakat in mobilizing waqf and zakat resources.

1.4 Research Methodology and Structure

To understand the various aspects of the study, a descriptive and analytical approach was adopted, and the necessary data were collected from the official website of the National Office for Waqf and Zakat for the period 2021-2024. The study was then structured around two main themes, as follows:
- The theoretical and legislative framework for waqf and zakat in Algeria.
- The contribution of the National Office for Waqf and Zakat mobilization in Algeria.

2 THE THEORETICAL AND LEGISLATIVE FRAMEWORK FOR WAQF AND ZAKAT IN ALGERIA

To determine the development of the theoretical and legislative framework for waqf and zakat in Algeria, we will first shed light on the nature of waqf and zakat and the features of their emergence and development.

2.1 Overview of Algerian Waqfs

Endowments in Algeria were known as a long-standing social and religious institution during the Islamic period that preceded the arrival of the Turks to power. They continued to spread and expand throughout the Ottoman period, gaining particular importance in the late Ottoman era and the early French occupation, and acquiring a large proportion of property inside and outside cities, thus forming a system. The following section will explain what a waqf is, its types, and its resources in Algeria.

2.1.1 The Nature and Development of Algerian Waqf

In linguistic terms, waqf means to promise something, to hold on to something, to remain still, or to prevent abandonment. The original meaning of the two terms is to prevent and refrain, and their general meaning is then specified by Sharia law as a specific prohibition, which is the detention of sale and gift, the prohibition of inheritance of specific property, and the expenditure of its benefits for a specific purpose. (Ben Tounes, 2024)

According to fiqh terminology, we find that the jurists of the four schools of thought differed in their definition of waqf due to their differences regarding its essence. The common ground in their definitions was the agreement that: “Waqf is the withholding of property and the use of its benefits for good, righteousness, and charity.” (Arabi, 2023) Economically, waqf is defined as: “the transfer of funds from consumption and their investment in productive capital assets that generate benefits and revenues to be consumed collectively or individually in the future.” (Maayouf, 2022)

In Algerian legislation, waqf is defined as: "the permanent restriction of ownership of property and the confirmation of its benefit to the poor or to some form of charity or good cause. A waqf is a contract of donation issued by an individual and does not represent the property of a natural or legal person. It enjoys legal personality, and the Algerian state ensures that the will of the donor is respected and implemented." (Law No 91-10, 1991)

From this perspective, Algeria was no different from other Islamic societies, where waqfs represented an important source of solidarity and social cohesion. The development of Algerian waqfs can be illustrated by the following historical milestones (National Office for Waqf and Zakat) :

- *Algerian waqfs during the Ottoman era:* The Ottoman era in Algeria witnessed the beginning of the documentation of waqfs through contracts, deeds, and waqf bonds, at a time when waqfs were expanding throughout the country, contributing to the coverage of charitable expenses, particularly the wages of teachers and those in charge of religious affairs. Among the most prominent charitable waqf institutions at that time were: the waqfs of the Two Holy Mosques, the waqfs of the Great Mosque, the Sabil al-Khairat Foundation, the waqfs of the zawiyas, saints, shaykhs, and marabouts, and the waqfs of the displaced people from Andalusia.
- *Algerian endowments during the colonial era:* As soon as French colonialism arrived in Algeria, the authorities considered the endowment system to be an obstacle to their colonial projects. and worked to undermine the foundations of the waqf system, disperse its members, and demolish its landmarks through various decrees, the first of which was the Decree of Berman on September 8, 1830, which ruled to confiscate and seize Islamic waqfs and gave the French administration the right to manage, dispose of, and lease waqf properties. This was followed by numerous decrees that enshrined the liquidation of waqfs and their seizure by Europeans.
- *Algerian waqfs after independence:* After Algeria gained independence and national sovereignty, waqfs remained unchanged, affected by a lack of care and maintenance, and confined to a very limited area. The first decree to regulate them was Decree 63-80 of March 4, 1963, which organized the Ministry of Endowments and appointed directors of national property. This was followed by Decree 64-283 of 1964, which established the system of public endowment property. Under Presidential Decree 71-73, which included the Agricultural Revolution Law, all agricultural land, including waqf land, was nationalized. This had a negative impact on the size and number of waqf properties, until Algerian Family Law No. 84-11 was enacted, which established the general legal framework for waqf in Chapter III, entitled “Donations (bequests, gifts, waqf).”

The 1989 Constitution is considered an important gateway for the protection and constitutional recognition of waqf, as reflected in Law No. 90-25, which contains real estate guidelines and considers waqf property to be a separate category within national property, and Law No. 91-10 on waqf, which is considered the first law to regulate waqf in Algeria. This law sets out the general rules for the organization, management, preservation, and protection of waqf property, and provides for the restitution of property that was previously nationalized. This was followed by executive decrees and ministerial decisions that facilitated the various processes of organizing, managing, exploiting, investing, and developing waqf property.

2.1.2 Types of waqf

There are three types of waqf in Algeria, namely (National Office for Waqf and Zakat):

- *General (charitable) waqf:* This is what is set aside for charitable and benevolent causes, either initially or ultimately, and is divided into two categories:
  - *General waqf without a specific beneficiary*: no specific beneficiary is designated for its proceeds, which are spent on public welfare and charitable causes.
  - *General waqf with a specific beneficiary*: a specific beneficiary is designated for its proceeds, which may not be spent on other charitable causes unless the designated beneficiary is exhausted.
- *Private (family) waqf:* This is what the waqf founder reserves for his male and female descendants or for persons designated by the waqf founder. The private waqf is transferred to the entity designated by the waqf founder after the death of the beneficiaries, and if there are no beneficiaries, it is transferred to a public waqf.
- *Joint waqf:* This is what the waqf founder initially restricts to a public entity and to one or more persons designated by him.

2.1.3 Forms of Waqf Property

Waqf takes many forms, all of which demonstrate the breadth of the concept of waqf in Islam and its practical purpose. In general, waqf resources or property in any Islamic society can be mobilized from the following forms or sources (Ben Tounes, 2024):

- *Fixed assets*: such as land, buildings, gardens, orchards, mosques, factories, warehouses, shops, etc.
- *Semi-fixed assets*: these are attached to and necessary for fixed assets, such as doors and windows for real estate, trees for gardens and orchards, and so on. And anything that cannot be used without its asset.
- *Tradable offerings (movable assets)*: These are offerings that can be traded and transferred, such as animals and cars, from one place to another without being damaged.
- *Offerings in the form of prices (deposited money):* These are deposited cash funds such as gold, silver, banknotes, instruments, investment certificates, and the like, which are locked up and yield returns for good and charitable causes.
- *Intellectual property rights*: These are intangible assets that generate income for their owner, such as copyrights and patents.

2.2 Basic Concepts of Zakat

Zakat occupies a central position in the Islamic system, representing an important financing tool for rationalizing economic and social development in Islamic societies. This section, therefore, focuses on defining its concept, sources of collection, and distribution channels.

2.2.1 The Concept of Zakat

Zakat is defined in the language as: “purity, growth, blessing, and praise, all of which are used within the Islamic framework.” In the same context, zakat has been defined by diligent researchers in Islamic jurisprudence as: "Specific money taken from specific money under specific conditions, to be spent under specific conditions. Specific money is the amount of money that is required to be given, such as one-quarter of a tenth of gold and silver, for example. The specific money from which it is taken is the money defined according to Islamic law for the payment of zakat, such as gold, silver, and livestock. The specific conditions are the conditions of zakat for the payer and the money being given, such as reaching the nisab (minimum amount), and so on. The specific recipients are those specified in the Islamic religious texts, foremost among them the poor and the needy". (AL- Hafdaoui, 2013)

Economically, zakat is defined as: “A financial grant that is mobilized by the state or its representatives, whether public or private,

definitively, and without any specific benefit in return. It is collected by the state according to the taxpayer's ability to pay and is used to cover the eight expenses defined according to the Islamic religious texts and to fulfill the requirements of Islamic public financial policy." (Zidan & Ghalmi, 2014)

From the above, zakat is one of the components of free Islamic finance. It is given according to specific conditions, must be paid in specific types of money to be spent on the eight categories specified in Islamic doctrine, without compensation.

2.2.2 Sources of Zakat Resources

In the context of Islamic law, zakat is considered the third pillar of Islam and one of its most important pillars. It is given that wealth is growing or in estimation. Wealth that is growing includes livestock, crops, fruits, and trade goods. Estimated growth includes gold and silver. Even if they are not used in trade, they are growing even if they are idle, because they can be traded whenever desired.

In general, zakat is given on the following types of wealth (Zidan & Ghalmi, 2014):

- *Money of all kinds*: This includes gold, silver, and securities, in addition to trade and industry offerings.
- *Crops and fruits*: The rate of zakat on fruits varies depending on the method of irrigation. It is estimated at 10% for crops irrigated without machinery, such as rain or springs, while the rate of zakat is 5% for crops irrigated with machinery.
- *Livestock (camels, cows, and sheep)*: They are acquired for the purpose of growth and reproduction.
- *Minerals and ores:* There is no specific threshold for zakat on ores, and the price of ores is estimated at one-fifth, or 2.5%.

Table 1 shows the nisab for different types of wealth on which zakat is due, which represent outlets for collecting zakat resources in any Islamic country.

The conditions under which zakat becomes due are as follows (Baraq & Krouche, 2012):

- *Full ownership*: Zakat is due on money that is fully owned, i.e., that can be disposed of without entitlement to others.
- *Growth*: The money must be growing or in value.
- *Reaching the threshold*: This is the amount specified by Sharia law, below which zakat is not required.
- *Exceeding basic needs*: Zakat is not required on items acquired for basic needs, such as housing, tools of trade, etc.
- *Passing of the year*: This means that twelve lunar months have passed since the money reached the minimum amount required for zakat, except for crops and minerals.
- *Prevention of double zakat*: This is the process of paying zakat on the same money after it has changed in nature (zakat is not due on crops after they have been sold or on livestock after they have been sold).

Table 1. Nisab for Zakat

Zakat Type	Nisab (Minimum Amount)	Rate
Zakat on Gold and Silver	85 grams of gold / 595 grams of silver	2.5%
Zakat on Fruits (Dates, Barley, Wheat, Raisins)	300 Saa' (1 Saa' = 2.05 kg)	10% or 5%
Trade Goods / Financial Balances	Treated as cash	2.5%
Zakat on Camels	5	1 sheep
Zakat on Cattle	30	1 tabi'a (young cow)
Zakat on Sheep	40	1 sheep
Rikaz (Buried Treasure)	---	One-fifth (20%)

Source: (Gandouz, 2019)

2.2.3 Zakat Disbursement Categories

The distribution of collected zakat resources follows the provisions set out in Islamic texts, which specify eight categories for its allocation.

Hence, zakat resources are spent in eight ways, which can be divided into two categories as follows: (Manasera, 2020)

- *The first category*: those who take according to their needs, based on the severity and abundance or scarcity of those needs, namely: the poor and the needy, those in bondage (slaves or maidservants), and travelers (strangers who are stranded).
- *Section Two*: Those who take for their benefit, namely those who work on it (those who collect zakat), those whose hearts are to be

reconciled (those whose hearts are to be reconciled by persuading them to receive it or by preventing them from harming Muslims), those in debt (those who owe money) to reconcile between them, and those fighting in the way of Allah. If the recipient is not in need and there is no benefit to Muslims, then he has no share in the zakat.

2.3 The Legislative Framework for Waqf and Zakat in Algeria

The Algerian legislature has issued a series of laws and executive decrees that broadly frame the mobilization, management, and investment of waqf and zakat resources to serve the development process on the one hand and to support the pillars of the Islamic financial industry in the country on the other.

The most important stages in the development of Algerian legislation in this regard are as follows:

- *March 4, 1963*: The Ministry of Endowments was established under the provisions of Executive Decree No. 80-63 to undertake the task of managing religious affairs and endowment properties.
- *September 17, 1964*: An executive decree was issued containing the system of public endowments. However, the absence of a national policy to take care of endowments led to the disappearance of the endowment system and the absence of its culture in Algerian society. The management of endowments at the national level was limited to a sub-directorate within the Ministry of Religious Affairs, from which the term “waqf” was removed, and since 1965, it has been under the supervision of a main inspectorate for waqfs directly linked to the general secretariat of the ministry, while its management is handled by the sub-directorate for waqf funds under the Directorate of Religious Affairs. (Bouziane, 2016)
- *June 9, 1984*: The Algerian Family Code was issued, establishing the general legal framework for waqf in its third chapter on donations (charity, gifts, waqf).
- *April 27, 1991*: Enactment of Waqf Law No. 91-10, which sets out the general rules for the organization, management, preservation, and protection of waqf property.
- *December 1, 1998:* Enactment of Executive Decree 98-381, which sets out the conditions and procedures for the management and protection of waqf property.
- *May 22, 2001*: Law No. 01-07 was issued, amending and supplementing Law No. 10-91, which defined the conditions and methods for the exploitation, investment, and development of waqf property through the adoption of a sharecropping contract or a lease contract if the waqf is agricultural land or trees, and the investment of other waqf property on the basis of a contract of enterprise or a barter contract. This law also allows for the development of public waqf property by converting the collected funds into productive investments using various modern investment methods, such as interest-free loans and waqf-benefit deposits, which enable the owner who does not need them for a certain period to hand them over to the authority in charge of waqf in the form of a deposit that can be recovered whenever he wishes. This authority then invests the deposit along with its other waqf assets and waqf speculation, where some of the waqf's income is used in banking and commercial transactions by the authority in charge of waqfs (Law No 01-07, 2001).
- *In 2003,* the Zakat Fund was established. The idea for it originated in Executive Decree No. 91-83, which included the establishment of a religious affairs office tasked with reviving the practice of zakat by organizing it and disbursing its funds for their legitimate purposes. (Executive Decree No. 91-83, 1991) and Executive Decree No. 2000-200, which defined the interests of religious affairs and included the Zakat Office in the Department of Guidance, Religious Rituals and Endowments, making this office responsible for monitoring and organizing the work of the Zakat Fund (Executive Decree No 2000-200, 2000).
- *May 3, 2021:* Establishment of the National Office for Endowments and Zakat under Executive Decree No. 21-179, which will be discussed in detail in the following section.

From the above, the Algerian legislator is interested in managing and controlling waqf properties and zakat resources, and in directing them to serve the community. This interest became especially evident in 2003, when the first steps were taken towards creating an institutional vehicle represented by the Zakat Fund.

This fund was recently converted, by Decree 21-179, into a national office for waqf and zakat, so that both could be managed by a single institutional structure. Previously, waqf had been managed by central and local bodies under the Ministry of Religious Affairs and Waqf. Zakat, on the other hand, had been supervised by the Zakat Fund, a special body also operating under the auspices of the same ministry.

3 THE CONTRIBUTION OF THE NATIONAL OFFICE OF WAQF AND ZAKAT MOBILIZATION IN ALGERIA

The Algerian government established the National Office with the aim of promoting waqf and zakat in the development of society to bring new dynamism to the social and economic spheres. The creation of this office has strengthened the Algerian Islamic financial industry with a new institutional structure that promotes Islamic charitable work (takaful) in the country.

3.1 General Framework of the National Office for Waqf and Zakat

The National Office for Waqf and Zakat was established, and its basic law was defined by Executive Decree No. 21-179 issued on May 3, 2021. This came after the mechanisms for investing zakat resources within the structure of the Zakat Fund proved inadequate, and the government sought to create a single institutional structure to manage and invest both waqf and zakat resources and direct them towards comprehensive development.

3.1.1 Concept of the Office

The National Office is: “A tool for the management, exploitation, development, and investment of public waqf properties in accordance with the will of the waqf founder and within Islamic law, in addition to being a mechanism for collecting, disbursing, and developing zakat resources in accordance with Sharia doctrine.” (National Office for Waqf and Zakat)

The Office is defined in Article 2 of the Executive Decree issued in this regard as: “a public industrial and commercial establishment (EPIC), enjoying legal personality and financial independence, under the supervision of the Minister in charge of religious affairs and waqf.” Its headquarters are in Algiers, with the possibility of establishing regional and/or provincial branches and even branches abroad if necessary. (Executive Decree No 21-179, 2021)

From this perspective, the National Office for Endowments and Zakat represents a new government structure of an industrial and commercial nature, concerned with organizing the mobilization and investment of endowment and zakat resources in accordance with the objectives of Islamic law. The institution operates under the authority of the Ministry of Religious Affairs and Endowments. Headquarters is located in Algiers.

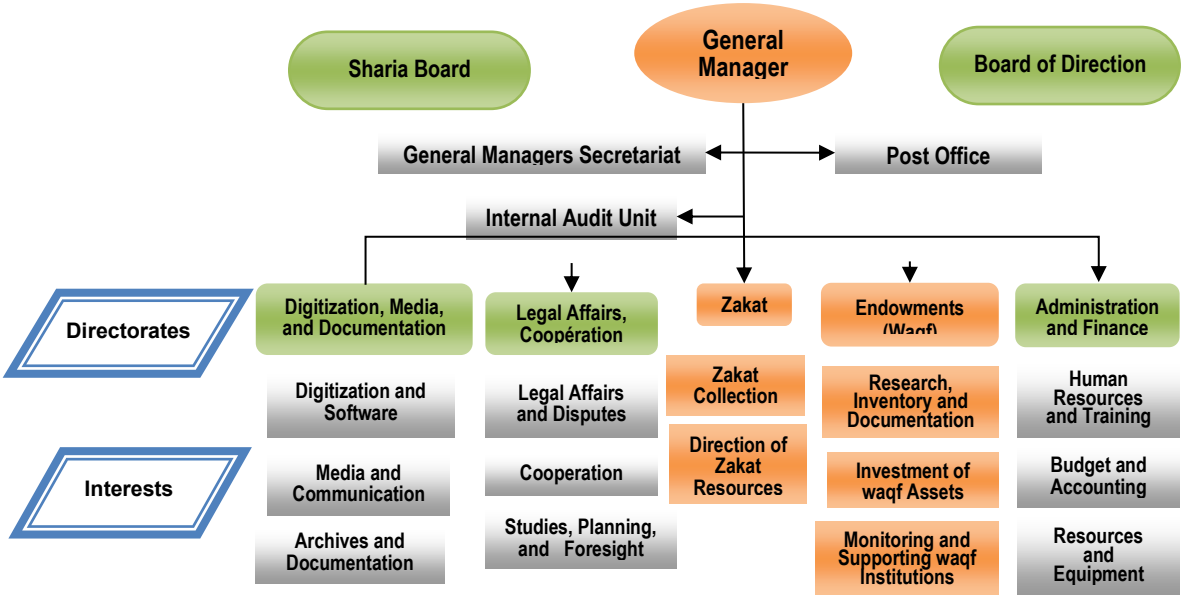


Figure 1. *Structure of the National Office for Endowments and Zakat*
Source: (National Office for Waqf and Zakat)

3.1.2 Structure of the National Office for Endowments and Zakat.

Figure 1 illustrates the administrative and organizational structure of the National Office for Endowments and Zakat, and shows that the Office consists of three main structures responsible for its management and performance of the tasks entrusted to it, namely:

- *Director General*: Responsible for the optimal management of the Office in accordance with the regulations in force. Pursuant to Article 26 of Decree 21-179, the Director General of the Office is assisted in the performance of his duties by directors who are responsible for monitoring the activities of endowments and zakat. The Endowments and Zakat Directorates include the following departments (Executive Decree No 21-179, 2021):
  - *Waqf Directorate Departments*: Research, Inventory, and Documentation Department; Waqf Property Investment Department; and Waqf Institutions Monitoring and Support Department.
  - *Functions of the Zakat Directorate*: Zakat collection and distribution of zakat resources.
- *Board of Directors*: Represents the core of the Office in view of the major tasks entrusted to it, as it is responsible for deliberating on all matters relating to the organization and functioning of the Office and all matters related to the achievement of its objectives.
- *The Sharia Board*: Composed of members with diverse practical and administrative skills and experience, they provide advice and jurisprudential assistance to the Office, particularly about the compliance of the latter's activities and operations with the provisions and rules of Islamic law. In this capacity, the Sharia Board is tasked with the following: (Executive Decree No 21-179, 2021)
  - Expressing a Sharia opinion on draft programs and activities sent to it by the Director General of the Office.
  - Making recommendations regarding the Office's program of activities and reports and sending them to the Director General.
  - Contributing to the preparation of scientific studies aimed at developing and promoting the activities of endowments and zakat.

3.1.3 Financial Liability of the Office

The Office has independent financial liability, with its budget comprising the following two aspects: (Ministry of Religious Affairs and Endowments, 2021)

- *Revenue.* The Council's revenue comes from the following sources of funding:
  - Initial balance.
  - State contributions to public service expenses.
  - Revenue from endowment properties.
  - Zakat revenue collected for distribution to those entitled to it.
  - Revenues from the National Office's commercial activities.
  - Potential contributions from local communities and national bodies.
  - Donations and bequests.
  - Charitable donations.
- *Expenditure:* This includes:
  - Operating expenses.
  - Equipment expenses.
  - All other expenses necessary to achieve the National Office's objectives.

3.2 Functions of the National Office for Waqf and Zakat

The National Office for Waqf and Zakat is entrusted with several functions in the field of waqf and zakat, as follows:

3.2.1 Functions of the Office in the Context of Mobilizing Waqf and Zakat Resources

The Office performs several tasks in public service provision as an administrative body responsible for **mobilizing**, managing, and administering waqf properties and zakat resources. These tasks include the following:

- *In the area of waqf,* the Office performs the following tasks (Khalouf, 2022):
  - Preparing programs related to the exploitation, development, and investment of waqf properties in coordination with the relevant ministry.
  - Searching for waqf properties in coordination with the relevant institutions and authorized public officials and resorting to all legally available means to recover the discovered waqf properties.

- Seeking the assistance of a competent public official to document waqf real estate and register its deeds with the competent regional real estate registry.
- Preserving documents relating to waqf property.
- Establishing and digitizing the national register of public waqf property.
- Creating a database of waqf property suitable for investment and development.

- *In the area of zakat,* the National Office shall perform the following tasks (Executive Decree No 21-179, 2021):
  - Collecting and gathering zakat.
  - Distributing zakat according to its legal channels in a manner that contributes to social solidarity and compassion.
  - Updating and digitizing the national registry of zakat beneficiaries.

3.2.2 The Tasks of the Office in the Context of Developing and Investing Endowment and Zakat Resources

Within this framework, the National Office for Endowments and Zakat performs the following tasks:

- *In the field of endowments:*
  Here, the Office carries out a range of commercial activities to optimize the use of Waqf real estate and benefit from its returns in areas of charity and good deeds. To achieve this, the Office does the following (Amour & Baba Ismail, 2022):
  - Leasing endowed properties for residential use, except for mandatory functional housing.
  - Leasing endowed properties for commercial, professional, and craft use.
  - Leasing and exploiting agricultural waqf land.
  - Monitoring the collection of rent and related charges, and any other income generated from the exploitation of waqf properties.
  - Collecting all data relating to the updating of the value of rents and waqf funds in general from data banks and specialized institutions, in accordance with the requirements of the real estate market.
  - Carrying out real estate development and promotion activities for waqf properties and real estate, within the limits of the rules of administration and management.
  - Developing waqf assets (real estate or movable), unless they are reserved for direct use.
  - Maintaining and restoring waqf properties belonging to the National Office, so that they remain usable and their revenues can be exploited.
  - Investment in areas with low risk, after conducting economic feasibility studies for the targeted projects, as is the case for the investment of waqf real estate stipulated in Decree 18-213.
  - Monitoring the exchange of waqf properties managed by the Office, after approval by the Minister in charge.
  - Monitoring and handling disputes relating to waqfs managed by the Office.
  - Reviving and developing cash waqfs.
  - Carrying out all commercial activities and services within the scope of its duties.

- *In the area of Zakat:*
  In the same vein, and with a view to contributing to social and economic development using zakat resources, the Office shall perform the following tasks: (Executive Decree No 21-179, 2021)
  - Establishing effective mechanisms for the development of zakat resources.
  - Supporting and accompanying young people in their projects and micro-enterprises and following up on this in coordination with the relevant bodies and institutions.
  - Concluding agreements with financial and economic institutions that fall within the scope of their activities.
  - Contributing to charitable and solidarity campaigns of national importance.

3.3 The Role of the National Office for Endowments and Zakat in Mobilizing Endowment and Zakat Resources

Based on the above, the role of the Office in mobilizing endowment and zakat resources will be explained based on an analysis of its activity data for the period 2021-2024, which was collected from the Office's official website.

3.3.1 The Office's Contribution to Mobilizing and Protecting Waqf Resources (Property).

With the creation of the National Office for Waqf and Zakat, it has become the authority responsible for mobilizing, protecting, and utilizing waqf property. In this regard, by the end of 2023, the endowment portfolio transferred to the Office had reached more than 4,200 endowments, and the revenue generated from the exploitation of endowments had exceeded 26.8 million Algerian dinars. (National Office for Waqf and Zakat)

The following table shows the nature of the waqf properties transferred to the Office at the end of 2023.

Table 2. Nature of Waqf properties transferred to the National Office for Waqf and Zakat as of 2023

Item	Number	Percentage %
Lands	1414	33.13%
Shops	1296	30.37%
Bathhouses	25	0.59%
Washrooms	433	10.15%
Offices	77	1.80%
Warehouses	22	0.52%
Residences	861	20.17%
Barns	94	2.20%
Mosques and Places of Worship	30	0.70%
Schools	08	0.19%
Cultural Centers	01	0.02%
Cemeteries	07	0.16%
Total Properties Transferred as of 2023	**4268**	**100%**

Source: (Al-Sanusi, 2024)

The data in the table above shows that the number of waqf properties directly managed by the National Office until 2023 amounted to 4,268, and that most of these waqf properties transferred to the Office are essentially real estate waqf properties (including land, shops, and housing) and account for approximately 84% of the total waqf properties.

Table 3 shows how these waqf properties are used by the Office, and that the National Office has utilized approximately 75% of the waqf properties transferred to it through rent, but 21.55% of these waqf properties remain vacant and unused, while 16 waqf properties have been written off.

Table 3. How the National Office for Waqf and Zakat Uses Waqf Properties Until 2023

Item	Number	Percentage %
Number of Waqf Properties (2023)	4268	100%
Number of Waqf Properties Rented	3176	74.41%
Number of Waqf Properties Used Without Rent	156	74.41%
Number of Vacant Properties	920	21.55%
Number of Decommissioned Properties	16	0.38%

Source: (Al-Sanusi, 2024)

3.3.2 Contribution of the Office to the Mobilization of Zakat Resources

Article 47 of the executive decree establishing the Office stipulates that all funds deposited in the central and provincial zakat accounts shall be transferred to the National Office for Endowments and Zakat in accordance with the regulations in force. All movable property acquired during the Zakat Fund's activities at the level of the external departments of the Directorate of Religious Affairs and Endowments shall also be transferred after the inventory process has been completed:

- *Means used to mobilize zakat resources:* In this regard, the Ministry of Religious Affairs and Endowments has developed a set of means through which the zakat payer can pay his zakat to facilitate the mobilization of zakat resources in the former Zakat Fund and the current National Office. These means include the following (National Office for Waqf and Zakat):
  - *Mosque funds*: These are placed in large mosques in neighborhoods and cities, and the collected proceeds are then transferred to the provincial fund account.
  - Postal transfers: These are made at post offices and paid into the current postal account of the provincial zakat fund.

- *Postal and bank checks*: Zakat resources can also be collected through postal and bank checks.
- *Bari Mob app*: This is a newly developed app using financial technology that can be downloaded to a smartphone or personal computer, enabling users to pay their zakat.

- *Zakat resources collected by the National Office*

  Zakat resources are collected by the National office for Endowments and Zakat from three main sources, as was previously the case under the Zakat Fund, and include the following:
  - *Zakat al-Fitr:* Collected by members of the mosque committee in each neighborhood, where authorized imams and mosque imams are tasked with initiating the process of collecting (mobilizing) Zakat al-Fitr from the middle of Ramadan until the 28th of Ramadan each year on a proxy basis.
  - *Zakat on crops and fruits, and zakat on money*: The means are used to collect these types of zakat. The first has a nisab of 300 sa'a, while the nisab for zakat on money is equivalent to 85 grams of gold. The following table shows the evolution of the nisab for zakat on money in Algeria during the period of activity of the National Office for Endowments and Zakat.

Table 4. *Evolution of the Nisab for Zakat on Money During the Period 2021-2025 (Unit: DZ)*

Year	Nisab of Zakat on money
2021	731,000
2022	816,000
2023	892,500
2024	1,105,000
2025	1,615,000

Source: (National Office for Waqf and Zakat)

In line with the above-mentioned zakat sources, the following table shows the zakat resources collected by the National Office for Endowments and Zakat during its period of activity.

Table 5. *Evolution of Zakat Resources Collected by the Office During The Period 2021-2024 (Unit: DZD)*

Item/ Year	2021	2022	2023	2024
Zakat al-Fitr Resources	437,426,140 (44.78%)	584,994,442 (53.68%)	690,346,211 (50.80%)	791,020,078 (47.95%)
Zakat on Crops and Fruits	130,559,823 (13.36%)	0 (0%)	0 (0%)	0 (0%)
Zakat on money	408, 974,810 (41.86%)	504, 820,741 (46.32%)	668,497,539 (49.20%)	858,492,987 (52.05%)
Total Zakat Resources	**976,960,773 (100%)**	**1,089,815,183 (100%)**	**1,358,843,750 (100%)**	**1,649,513,065 (100%)**

Source: Prepared by the researcher based on (National Office for Waqf and Zakat)

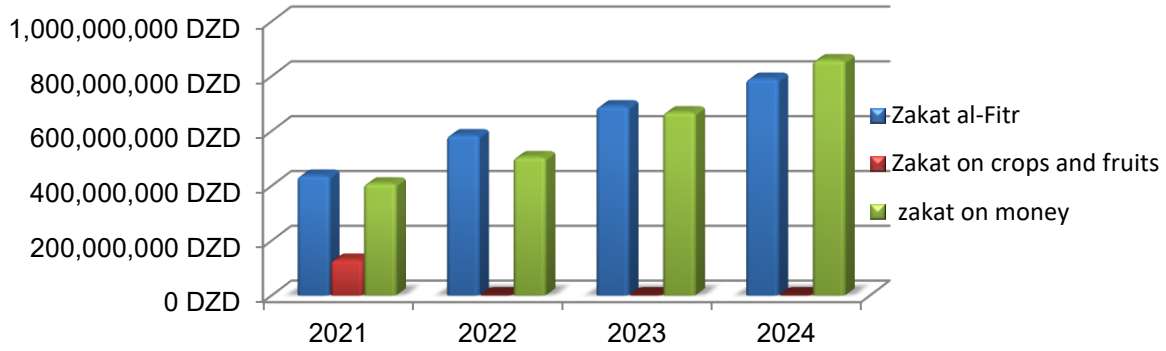


Figure 2. *Evolution of Zakat Revenue During the Period 2021-2024*
Source: Prepared by the researcher based on data from Table 05

The data in Table 5 shows that zakat revenue collected during the period of the Office's activity is constantly evolving, reaching more than 1.649 billion dinars in 2024, despite the non-collection of zakat on crops and fruits in the period 2022-2024. As shown in Table 5 and Figure 2, zakat al-Fitr

resources accounted for the largest share of Zakat resources collected between 2021 and 2023, except for 2024, when zakat al-mal resources accounted for 52.05% of the total.

4 CONCLUSIONS

In conclusion, it can be said that the endowment and zakat institution currently constitutes a third independent sector, complementing and assisting the public and private sectors and contributing to the economic and social balance of countries. Algeria, like other Islamic countries, has taken an interest in institutionalizing waqf and zakat, establishing the Zakat Fund in 2003 and then merged it into the National Office for Waqf and Zakat in 2021 with a view to establishing an institutional structure dedicated to mobilizing, protecting, and investing waqf and zakat resources and directing them to serve development and support the pillars of the Islamic financial industry in the country.

This study has reached several conclusions, as follows:

- Algerian endowments represent an important source of social solidarity and takaful. They began to be documented during the Ottoman era and were used to cover charitable expenses at the time, but their landmarks were destroyed and seized during the colonial period. The post-independence period saw a series of laws and decrees that contributed to their restoration and established general rules for their organization and protection.
- Zakat is regarded in Islam as a religious obligation with socio-economic functions. Like waqf, within Islamic law, has specified in its texts the recipients and shares of zakat.
- Waqf and zakat institutions are among the most important solidarity institutions that can achieve various economic and social dimensions, as waqf and zakat resources are classified in Islamic finance as non-profit voluntary resources. The first steps towards creating an institutional framework for the collection and distribution of zakat in Algeria were taken in 2003 with the establishment of the Zakat Fund, which was transferred to the National Office for Waqf and Zakat in 2021.
- The National Office for Waqf and Zakat has a more independent organizational structure, the most important feature of which is a Sharia board that ensures that its work complies with Islamic law. The Office also benefits from diverse financial resources that allow it to expand the circle of beneficiaries of zakat and waqf, thereby serving the country's development process.
- The National Office for Endowments and Zakat is a tool for managing, exploiting, developing, and investing public endowment properties in accordance with the wishes of the endower and the provisions of Islamic law. Endowments in Algeria vary between charitable endowments for charitable and benevolent causes, private endowments to the entity designated by the endower, and joint endowments. Since its creation, the Office has managed to mobilize and consolidate more than 4,200 waqf properties, most of which are real estate waqfs, and has generated more than 26.8 million Algerian dinars in revenue through their exploitation.

The National Office for Waqf and Zakat is a mechanism for collecting, disbursing, and developing zakat resources in accordance with the provisions of Islamic law. It works to mobilize zakat resources from three main sources: zakat al-fitr, zakat on crops and fruits, and zakat al-mal. Despite the absence of revenue from the second source, the zakat revenue mobilized through the Office's activities is constantly increasing, reaching 1.649 billion dinars in 2024.

Based on the results obtained, the study proposes the following:

- Strengthening community confidence in the importance of takaful institutions and their pivotal role in supporting the charitable sector.
- Activating the role of the National Office for Endowments and Zakat in increasing the revenue from endowments and zakat by adopting mechanisms and means to facilitate and streamline the collection process for the Office, zakat payers, and endowment owners.
- Raising awareness of waqf and zakat among members of society, whether by the Office or by various other government and community bodies, through the organization of forums and seminars to raise awareness of the importance of mobilizing and investing waqf and zakat resources in modern societies.

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REVIEW ARTICLE
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BLOCKCHAIN AND SMART CONTRACTS: FINANCIAL IMPACTS ON GLOBAL SUPPLY CHAINS

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ABSTRACT

This research paper aims to investigate the applications of blockchain technology and smart contracts in managing global supply chains, as well as their financial and economic implications. The study addressed the concept of supply chain management and the technologies of blockchain and smart contracts, with a focus on their applications in validating and tracking transactions, facilitating the flow and storage of information in international trade, supporting customs, shipping, and container management operations, and increasing transparency in commercial transactions. The most prominent digital supply chain platforms based on blockchain were also presented. The results showed that the application of these technologies contributes to reducing costs and fees, improving cash management, increasing transparency and reducing risks, and enhancing the economic and operational efficiency of exporting and importing companies. It also provides administrative bodies with the ability to track and verify transactions instantly, which supports more accurate financial and strategic decision-making.

1 INTRODUCTION

The world is witnessing numerous changes that require humans to adapt to these transformations and exploit them to their advantage by finding solutions to the various problems they encounter. Therefore, we find different companies keeping pace with the changes occurring in the world and working to find solutions to the problems they face by using new business models instead of classical ones. For example, many countries and global shipping companies seek to solve the problems of global supply chains, which the global economy suffers from due to the “COVID-19” pandemic and the Russia–Ukraine crisis, in addition to the inefficiencies of the classical models used in supply chain management.

Various stakeholders in supply chain management are working to digitize logistics services and to innovate digital models for managing supply chains, using various modern

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technologies spawned by the Fourth Industrial Revolution such as: artificial intelligence, the Internet of Things, smart contracts, and blockchains, in order to solve the problem of delays that permeate the shipping process, problems of information exchange and verification, lack of transaction transparency and frequent errors, and high costs. For this reason, various digital platforms based on blockchain and smart contracts are being developed and built by technology companies, shipping companies, and different countries to facilitate supply chain management and increase its efficiency. Hence, the study problem crystallizes in the following main research question:

RQ - How can applications of blockchain technology and smart contracts in the management of global supply chains affect the financial and economic performance of companies by improving operational efficiency, reducing costs, enhancing transparency, and increasing economic and commercial returns?

It branches into the following sub-questions:

RQa - How do blockchain and smart contract applications contribute to developing and modernizing the logistics management of foreign trade and achieving tangible financial savings?

RQb - What are the most important economic and financial areas in which companies can apply blockchain and smart contracts within supply chains?

RQc - What is the added economic and financial value provided by blockchain technology and smart contracts to supply chain management?

Hypotheses

H1 - The application of blockchain technology and smart contracts in the management of foreign trade logistics contributes to completing transactions, tracking them, and verifying them in a real-time and decentralized manner, which enhances operational efficiency and reduces financial risks and economic delays.

H2 - Blockchain applications in trade logistics represent decentralized digital platforms based on blockchain and smart contracts.

H3 - They provide multiple financial and economic services, such as insurance, financing, shipment tracking, and information sharing among concerned parties, which improves resource management and reduces operational costs.

H4 - One of the most important economic and financial effects of applying blockchain technology and smart contracts in foreign trade operations is the reduction of operating costs through document digitization, increased transparency and financial security among parties, and improved economic decision-making for companies.

Research Methodology

This study relied on the descriptive method to clarify the nature of foreign trade and supply chain management, and to explain the fundamentals of blockchain technology and smart contracts and their mechanism of operation. The analytical method was also employed to study the effect of applying this technology on the efficiency of financial and economic operations in supply chains, including improving transparency, reducing costs, and enhancing the speed and reliability of transactions. To achieve the study objectives, reliance was placed on a bibliographic survey, specialized websites, and the collection and analysis of relevant financial and economic data and statistics, with the aim of evaluating the added value of blockchain and smart contract applications on the performance of global supply chains.

Study Objectives

This study aims to:

- Identify the concept of blockchain technology, its types and characteristics, and study its role in developing the logistics management of foreign trade and improving the efficiency of financial and economic operations therein.
- Explore the most important applications of blockchain technology and smart contracts in foreign trade logistics, including shipment tracking, transaction validation, and enabling the financial digitization of operations.
- Highlight the economic and financial solutions that blockchain technology offers to the problems facing global supply chains, such as

cost reduction, increased transparency, and enhancing the speed and smoothness of international commercial transactions.

2 CONCEPTS OF TRADE AND LOGISTICS

2.1 Concept of Foreign Trade

Foreign trade refers to the economic transactions conducted between nations, encompassing the exchange of goods, services, and capital. It represents a system of commodity–monetary relations that comprises the aggregate commercial interactions occurring among countries worldwide (Chalihi, 2020). In 2021, the value of global trade reached approximately USD 28.5 trillion, marking a 25 percent increase compared to 2020 and about a 13 percent rise relative to the pre-pandemic level in 2019. Trade in both goods and services continued to grow in 2021. Trade in goods increased by about USD 200 billion to reach approximately USD 5.8 trillion (Figure 1), an increase of 27 percent compared to 2020, and trade in services rose by about USD 50 billion to reach approximately USD 1.6 trillion, an increase of 17 percent compared to 2020 (UNCTAD, 2022, p. 2.).

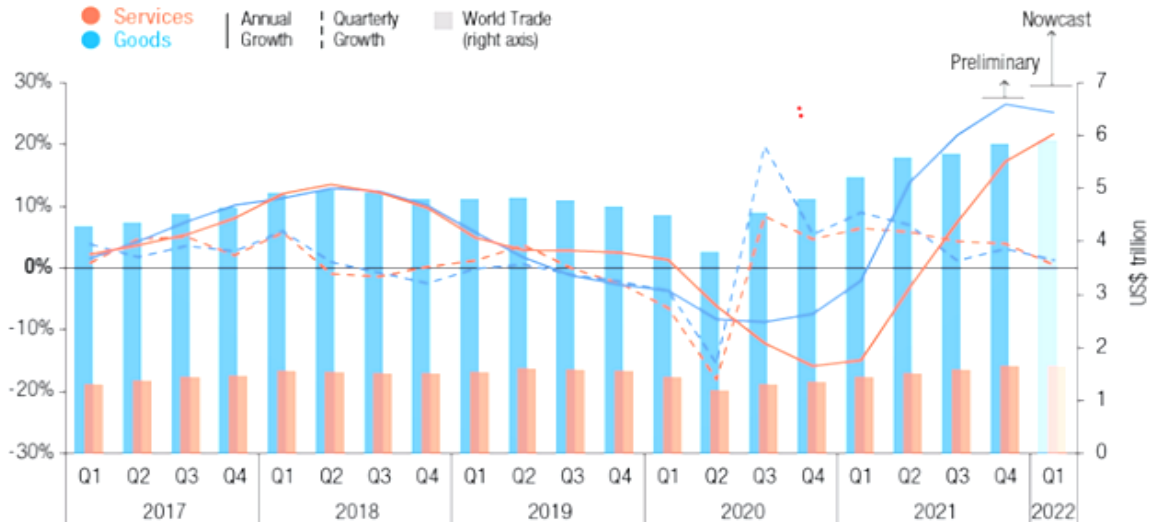


Figure 1. *Statistics on World Trade*

Source: UNCTAD (2022, p. 2)

2.2 Concept of Logistics and Supply Chain Management

Trade logistics is the process of managing, implementing control, and controlling the flow and storage of goods, services, and related information from the point of production to the point of consumption, to meet customers' needs as quickly and cheaply as possible (Bourtal, 2020). Trade logistics plays a critical role in enabling the smooth exchange of goods and products. It encompasses the full range of activities required to move goods from producers to end consumers, including customs clearance, warehousing, banking services, and insurance operations. Highly efficient logistics contribute to diversifying exports by increasing their volume, reducing trade costs, promoting economic growth, raising the competitiveness of countries and facilitating integration into the global economy. In the absence of high-performance logistics services, trade costs and the time required for customs clearance will increase, thus negatively affecting the rates of economic growth achieved (Al-Hamid & Abd, 2020).

3 CONCEPT OF BLOCKCHAIN TECHNOLOGY AND SMART CONTRACTS

3.1 Concept of Blockchain Technology

Countries such as China, Japan, and the United States of America and various companies, like IBM and Microsoft, have become increasingly interested in the concept of blockchain technology to explore its applications in various fields, while working to develop it and understand its principles. The head of communications and marketing at the BITFURY Group, Jamie Smith, defines blockchain

as a decentralized technology. If one group is hacked, the other groups cannot be hacked at the same time. Therefore, blockchain technology relies on the elements of security, identity encryption, and direct communication with the other party without the need for an intermediary, thus conducting operations freely within a secure public platform (Bouakl & Hadoosh, 2019). A blockchain is a distributed database of all transactions that have been executed, verified by consensus, and will be shared with all parties in the network (Figure 2), with no ability to delete or change them (Ashari et al., 2020).

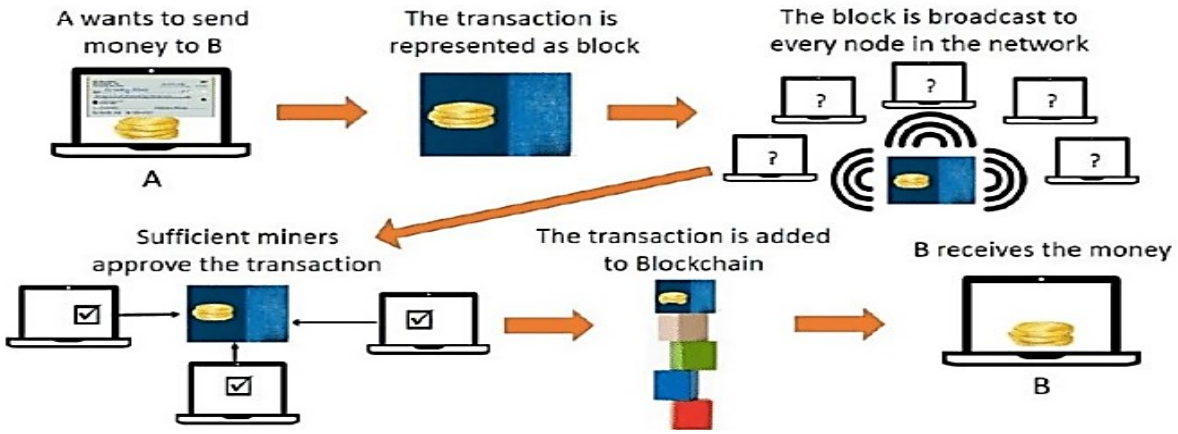


Figure 2. Mechanism of Blockchain Technology

Source: Boukhari (2019)

Blockchain is divided into three main types: public, private, and alliance-type blockchains. These third types differ in the degree of decentralization, network accessibility, compatibility mechanism, speed and privacy levels, energy consumption and fees, and scalability (Zidan & Farji, 2021).

3.2 Smart Contracts

Smart contracts are agreements that can be automatically executed, without human intervention. They are tokens that can be executed and stored in a blockchain platform to facilitate and implement the terms of the agreement. The smart contract (Figure 3) consists of an account balance, personal storage, and an executable pin. The smart contract status is stored in one threaded block and updated each time the contract is invoked (Ashari et al., 2020).

3.2.1 The Economic and Financial Impact of Smart Contracts on Supply Chains

Smart contracts allow agreements to be implemented automatically when specified conditions are met, without human intervention or intermediaries. This leads to:

- Reducing the risk of fraud and financial manipulation, as all transactions are recorded permanently and immutably on the blockchain.
- Reducing operational risks associated with human errors or delays in payments and collections.
- Increasing trust among economic actors, thereby encouraging the expansion of international trade and the growth of transaction volumes.

3.2.2 Financial and Economic Benefits

Financial and economic benefits can be seen in:

- Reducing the cost of international financial transactions.
- Improving companies' cash management.
- Enhancing trust and transparency between parties while reducing fraudulent risks.

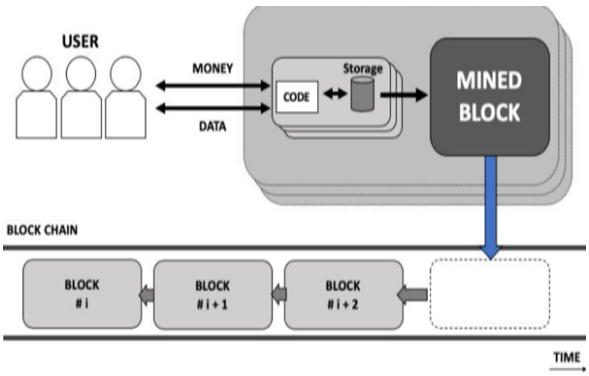


Figure 3. Mechanism of Smart Contracts Stored on the Blockchain

Source: (Ashari et al., 2020)

A smart contract represents an agreement between stakeholders in participating organizations to transfer funds or assets of specified value in an auditable manner. The process of automation through smart contracts can significantly enhance the performance of various transactions. The results of a smart contract are considered inevitable, due to the contract being permanently shared with network participants, to validate the information (Ahmad & Hafeez, 2021)

4 APPLICATIONS OF BLOCKCHAIN IN LOGISTICS AND SUPPLY CHAIN MANAGEMENT

4.1 Digital Foreign Trade Platforms Based on Blockchain

Global supply chains face challenges such as rising shipping costs, the complexity and cost of multimodal communication, labor costs, storage, government policy and regulations, customs clearance, and deterioration in logistics service quality that has caused a decline in shipping rates (Zhong et al., 2021). To promote global trade growth and confront these challenges, ports and logistical management methods must be efficient in terms of speed, cost, and trust (Ahmad & Hafeez, 2021) because supply chain and logistics management specifically require the rapid, secure, and reliable flow of goods and information. International trade agreements are accompanied by many documents, such as certificates of conformity, health and phytosanitary certificates, bills of lading, customs documents, invoices, and so on (Korenga, 2019). This has led various ports and companies engaged in international trade to build digital platforms to increase supply chain management efficiency and to accelerate and simplify logistical procedures. Among the technologies employed by these companies to develop such platforms are blockchain and smart contracts, valued for their capacity to digitize and streamline paperwork, enable the tracking and tracing of goods, and provide authorized parties with reliable real-time data (Zhong et al., 2021). Table 1 lists the most important digital foreign trade platforms based on blockchain.

Table 1. *Digital Foreign Trade Platforms Based on Blockchain*

Platform Name	Platform Description
Wave	Funded by Barclays Accelerator, this blockchain-based platform was created to eliminate paper bills of lading by connecting participants and contractors on a blockchain network, enabling supply-chain parties to access shipment information in real time at lower cost.
Skuchain	Developed by a consortium of international banks, Skuchain's blockchain platform aims to eliminate time-consuming paper letters of credit (LCs) and to establish a new collaborative trade model based on trust; it targets firms handling paper shipping documents: buyers; sellers; logistics providers; banks; customs; and third parties.
Hyperledger	A blockchain platform developed by IBM with potential applications in supply chains; it represents a model that can change how international commercial transactions are conducted and includes a large number of applications across various industries.
Tallysticks	A blockchain-based application created to make invoice financing and supply more efficient using smart contracts, allowing automatic invoice settlement while preventing fraud and errors and increasing transaction transparency.

Source: (Oude Weernink et al., 2017)

Through this table, we observe that the applications of blockchain in logistics and supply chain management are multiple and varied, including shipment tracking and tracing, port-terminal process automation, protection of commercial documents, asset certification, and fleet operations management (Ahmad & Hafeez, 2021)

4.2 Shipment Tracking and Tracing

Most maritime shipping companies possess records and systems for tracking shipments; however, all these systems are centralized and do not allow stakeholders to view the various information flows during the transportation process, which renders shipping non-transparent and the information susceptible to modification,

alteration, and forgery (Ahmad & Hafeez, 2021) . To overcome this imbalance present in classical tracking systems, blockchain-based platforms can provide solutions for tracking container locations, temperatures, and other detailed conditions (Zhong et al., 2021) by installing Internet of Things (IoT) devices on containers and integrating them with the blockchain as nodes, which allows different information—such as cargo condition, temperature, transit duration, and other data—to be recorded automatically without any human intervention, with the ability to share it with all organizations and regulatory bodies participating in the platform (Oude Weernink et al., 2017) as shown in Figure 4.

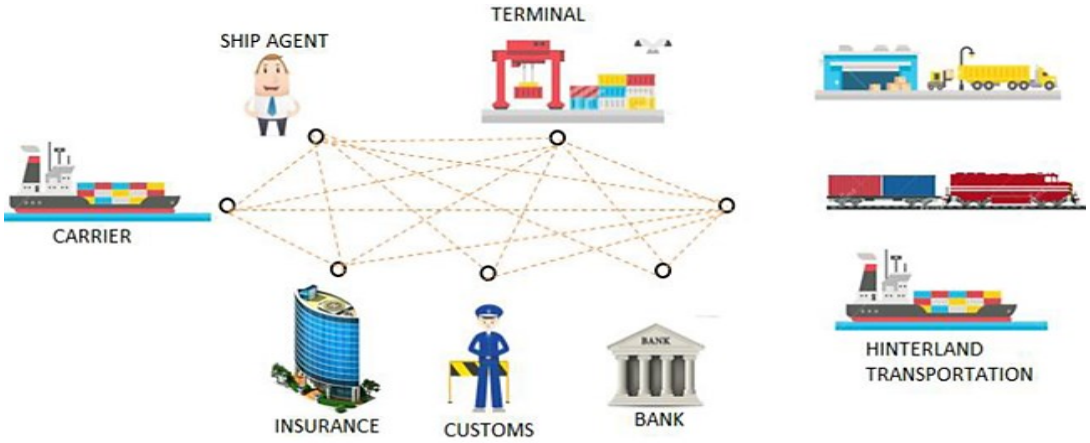


Figure 4. *Shipment Tracking Using Blockchain Technology and Smart Contracts*
Source: (Oude Weernink et al., 2017)

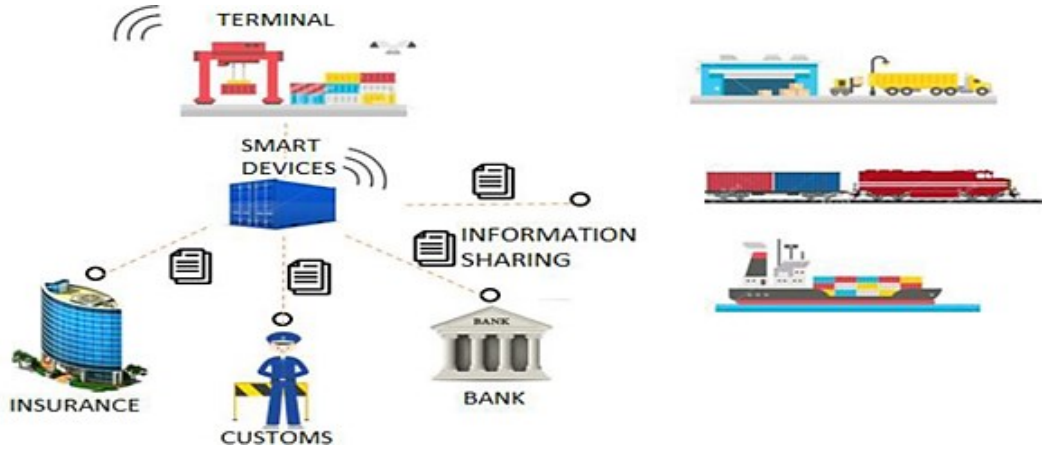


Figure 5. *Flow of Information and Documents in a Decentralized Blockchain-Based System*
Source: (Oude Weernink et al., 2017)

This enables verification of the origin of goods and auditing of operations by participating authorities in the fastest and least costly manner. Moreover, authorized stakeholders at the port terminal can access the ledger in real time to view records such as shipment location and shipment status, allowing efficient planning of handling and terminal operations and preparing an optimal storage plan to increase terminal productivity. It can also further help prevent compliance violations, enforce tariffs and trade policies, and identify the origin of shipped items (Ahmad & Hafeez, 2021).

4.3 Storage and Sharing of Commercial Documents

Foreign trade involves a wide range of actors responsible for organizing the movement of goods across national borders. Key participants in the management and regulation of international trade include carriers, freight forwarders, banks, customs authorities, port administrations, insurance brokers, domestic and international transport operators, and legal experts. Therefore, foreign trade requires a decentralized (Figure 5),

secure, and transparent system for sharing documents among these entities, with secure storage. (Zhong et al., 2021) ,especially since foreign trade requires participants in the supply chain to handle many paper documents to move goods across different international borders.

Blockchain technology can provide a secure and transparent system for storing and sharing commercial documents, especially since blockchains depend on the common consensus of the parties in the network. It can also ensure the validity of information stored on the network through the encryption mechanism, which makes changing the information stored on the network very unlikely (Oude Weernink et al., 2017). Especially with the digitization of contracts and trade documents using smart contracts that are stored on the blockchain, for example, CargoX is digitizing the bill of lading, using the Ethereum blockchain (integrating the blockchain with smart contracts) (Port Operations & Logistics Committee international Association of ports and Harbors, 2018), where the exporter can use a smart contract to choose aa freight forwarder to ship goods to the consignee. In response, the freight forwarder uses another smart contract to hire a freight forwarder. Shipper's stakeholders have the privilege of creating and signing the Bill of Lading. Once the Bill of Lading is created, the smart contract can notify the exporter to review and digitally sign the record. After this step, relevant stakeholders are notified according to their access rights (Ahmad & Hafeez, 2021).

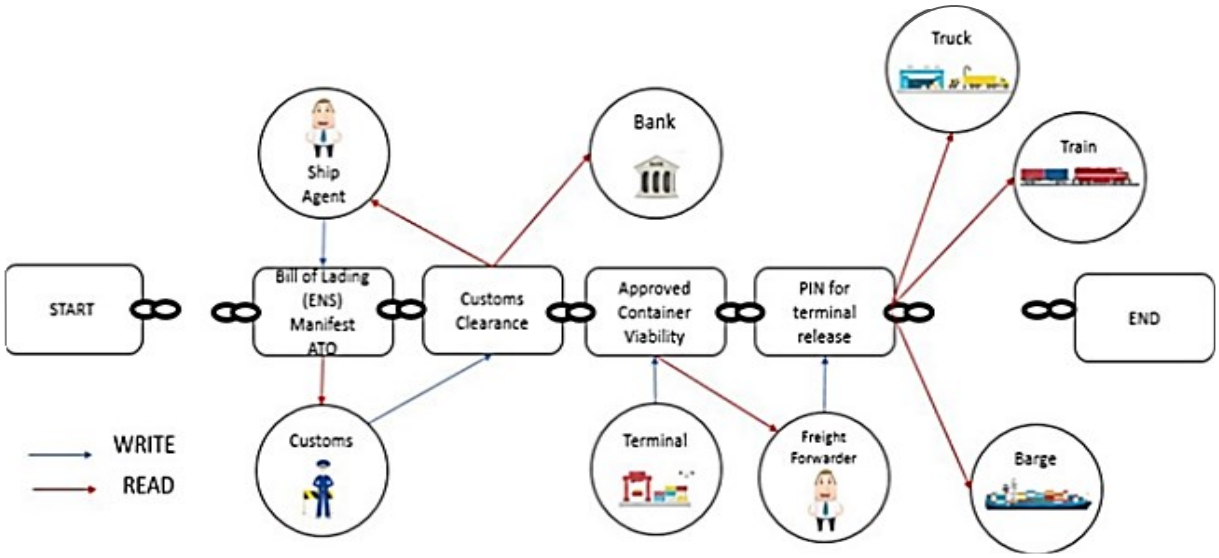


Figure 6. *Flow of Information and Documents in a Decentralized*

Source: (Henesey, 2020)

4.4 Port Terminal Automation

Non-automated ports suffer from several problems due to inaccurate and delayed information processing, namely the absence of notifications about the arrival of shipments, their types, origins, and other information relevant for customs, port authorities, and reception terminals. This leads to delays in unloading or loading vessels, which in turn may expose cargo to theft or damage and to increased storage costs. Ports also frequently suffer from container mis-picks because the container yard is not automated, which may cause another problem: a reduced container utilization rate and an increased proportion of empty containers being shipped. (Oude Weernink et al., 2017). Automating the port, however, will maximize profits, reduce container handling costs, increase resource-use efficiency, and reduce congestion at terminals. For example, blockchain technology can overcome the obstacles mentioned above by integrating blockchain, smart contracts, and artificial intelligence techniques to allow real-time information exchange among different authorities. Blockchain-based smart contracts can notify carriers across the port yard of areas likely to be congested at a terminal and can be used to alert them to alternative routes. Blockchain can also provide a unified, comprehensive database that ensures participating stakeholders have real-time access to commercial documents, thereby

reducing container waiting times and eliminating the need to send commercial documents, saving time. In addition, blockchain, smart contracts, and the Internet of Things can help port management propose and monitor a yard-management schedule for stacking and storing containers for short-, medium-, or long-term periods. Likewise, internal logistics services can benefit from automated carriers in moving containers automatically within the terminal and reducing the total shipment cost. Effective use of incoming container data by port authorities enables more efficient yard management through the design of optimal resource-allocation plans. This helps increase port productivity and facilitates export and import processes. (Ahmad & Hafeez, 2021).

4.5 Analysis of Results

From this research, we found the following results:

- The results showed that applying these technologies contributes to lowering costs and fees, improving cash-flow management, increasing transparency, reducing risks, and enhancing the economic and operational efficiency of exporting and importing companies. It also provides administrative bodies with the ability to track transactions and verify them instantly, which supports more accurate financial and strategic decision-making.
- To increase the efficiency of supply chain management and to accelerate and simplify logistical procedures, various ports and companies engaged in international trade are building digital platforms such as Skuchain, Hyperledger, and Tallysticks. The technologies these companies relied on to create these platforms include blockchain and smart contracts, due to their ability to digitize and simplify paperwork, allow tracking and tracing of goods, and permit authorized parties to access reliable real-time data.
- Blockchain is characterized by decentralization, which helps solve information-exchange problems among various actors in supply chain management. Blockchain can provide a unified, comprehensive database that ensures participating stakeholders have real-time access to commercial documents. This enhances transparency and trust among parties, and the decentralization inherent in blockchain contributes to lowering container handling costs, increasing resource-use efficiency, and reducing congestion at terminals because information is exchanged, processed, and verified rapidly by all parties involved in transaction management.
- Integrating blockchain technology into trade logistics prevents attempts at theft or tampering with records: every shipment is recorded within the chain, and all its movement points are known from origin to destination. Thus, if a shipment or even part of it is unloaded at an incorrect location, this becomes evident in the blockchain, and the source of the error and the responsible party can be easily identified. This is achieved by equipping containers with Internet of Things (IoT) devices and integrating them with the blockchain as nodes, which allows various information—such as cargo condition and location, temperature, shipping duration, and other data—to be recorded automatically without human intervention.

From these results, blockchain technology can contribute to developing new administrative models for managing supply chains based on decentralization and transparency. Blockchain's ability to integrate with various digital technologies, such as smart contracts and the Internet of Things, allows transactions to be automated and executed automatically without human intervention. This enhances the efficiency of logistical services and helps eliminate administrative bottlenecks, as shipping delays often result in substantial losses for exporters due to complex procedures and excessive documentation. Consequently, exporters are compelled to devote significant financial resources and time to completing the shipment process rather than concentrating on product improvement, conducting market analysis, and seizing new opportunities.

5 CONCLUSIONS

Given the decentralization, transparency, and security features of blockchain technology, various actors in supply chain management—such as ports, customs, shipping companies, and export and import institutions—have taken interest in and applied it across different logistical services,

including data management and storage, customs clearance, insurance, and port terminal automation, by building platforms based on blockchain and smart contracts. This may lead to a reduction in intermediaries, acceleration of transaction completion, and lowering of transaction costs. Integrating blockchain into the shipping process enables automation through smart contracts and the installation of IoT devices linked to the blockchain, allowing regulatory bodies in foreign trade to track and verify shipping steps while obtaining necessary information in real time. Therefore, Algerian economic institutions should adopt this technology to modernize their management and administrative practices, align with developments in the global economy, and strengthen trust and transparency in foreign trade transactions. Blockchain can be applied to port organization, trade finance, insurance, and the monitoring of export and import operations. Its use accelerates customs procedures, lowers export costs, improves information availability, and helps eliminate favoritism, illegitimate privileges, and invoice inflation.

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ORIGINAL RESEARCH ARTICLE
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PROSPECTS OF THE DIGITAL ECONOMY: AI, CONNECTIVITY, AND LONG-TERM EFFICIENCY

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digital infrastructure

ABSTRACT

This study aims to explore the prospects of the digital economy amid global technological transformations by examining three main pillars: specialized artificial intelligence, the expansion of global connectivity, and the promotion of a sustainable digital economy. Drawing on international reports, academic studies, and practical experiences, the study finds that specialized artificial intelligence constitutes a strategic driver for developing solutions tailored to local needs, thereby enhancing service efficiency and strengthening the competitiveness of emerging economies. Furthermore, the expansion of high-speed connectivity is identified as a prerequisite for integrating economies into global value chains and fostering collaborative innovation. In parallel, supporting a sustainable digital economy represents a strategic framework that aligns digital transformation with the Sustainable Development Goals through the integration of renewable energy, green computing, and responsible digital governance mechanisms. Overall, the findings indicate that building a balanced digital economy requires the integration of technological innovation with sound policies, strengthened international partnerships, sustained investment in digital infrastructure and skills development, and the adoption of data transparency and disclosure policies to ensure long-term sustainability.

1 INTRODUCTION

During the last twenty years, the global economy has undergone notable changes resulting from the rapid spread of digital technologies, the development of artificial intelligence, and improvements in communication systems. These changes have not only raised efficiency and productivity but have also influenced the way production is organized, trade is conducted, and consumer preferences are shaped, while affecting how value creation is distributed within and across national economies. Against this background, the digital economy is increasingly viewed as a central

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force behind innovation and economic growth, and a key source of competitiveness, particularly for emerging economies striving to overcome traditional development gaps.

Despite the enormous potential of the digital economy, maximizing its benefits requires the establishment of an integrated digital environment that combines advanced technological infrastructure, flexible regulatory frameworks, and the adoption of innovative solutions applicable across various sectors. Its key pillars are embodied in specialized artificial intelligence as a tool for developing locally oriented solutions, the expansion of global connectivity as a prerequisite for integration into the global economy, and the promotion of a sustainable digital economy that balances the imperatives of digital transformation with the objectives of sustainable development.

Based on these considerations, the present study aims to explore the prospects of the digital economy within the context of global technological change, with particular attention to three essential dimensions, drawing on the latest international reports, academic studies, and leading practical experiences. The aim is to provide a comprehensive perspective that contributes to shaping effective strategies for accelerating digital transformation and enhancing its positive impact on economic and social development.

- Deployment of specialized, accessible, and localized artificial intelligence.
- Expansion of global connectivity.
- Support for a sustainable digital economy.

2 DEPLOYMENT OF SPECIALIZED, ACCESSIBLE, AND LOCALIZED ARTIFICIAL INTELLIGENCE

In this study, a clear distinction is made between specialized, accessible, and localized artificial intelligence. Specialized artificial intelligence refers to AI systems designed to perform specific tasks within well-defined domains, such as healthcare, agriculture, finance, or manufacturing, enabling higher accuracy and efficiency compared to general-purpose models (Damar et al., 2024, pp. 85-87). Accessible artificial intelligence emphasizes the widespread availability of AI tools and platforms to diverse users and organizations through affordable, user-friendly, and open solutions, with the aim of reducing digital divides and fostering inclusive digital transformation (Morris, 2020, pp. 35-37). Localized artificial intelligence, in turn, denotes AI systems that are developed or adapted to reflect the linguistic, cultural, economic, and regulatory contexts of specific countries or regions, thereby enhancing relevance, usability, and digital sovereignty (El-Mhamdi et al., 2025).

Artificial intelligence (AI) applications are witnessing a growing shift toward greater specialization, localization, and inclusivity. Prominent examples include disease-specific diagnostic systems, crop management tools tailored to the needs of local farmers, and learning platforms adapted to different languages and cultural contexts. This development illustrates a shift away from the exclusive use of Large Language Models (LLMs) towards the growing adoption of Small Language Models (SLMs). The change is largely motivated by the rising interest in open-source AI systems that can be tailored to the requirements of particular industries while remaining consistent with existing regulatory frameworks (Singla et al., 2024).

There is a growing acknowledgment among organizations that general-purpose AI models cannot adequately respond to the specific challenges faced by different industries. Each sector operates under its own regulatory conditions, data protection requirements, and operational constraints, which calls for the development of tailored solutions. Recent studies suggest that almost half of the documented applications of generative AI are already based on specialized models—either adapted from proprietary datasets or purpose-built to address concrete business needs (Singla et. al, 2024) .

Figure 1 illustrates the rapid expansion of artificial intelligence models, both in scale and in variety. Although text-oriented models remain predominant, there has been a noticeable acceleration in areas such as speech recognition, image analysis, and feature extraction. This development signals a growing movement toward multimodal AI applications that are increasingly tailored to specific functions, better adapted to sector-specific needs, and designed to meet their regulatory compliance requirements.

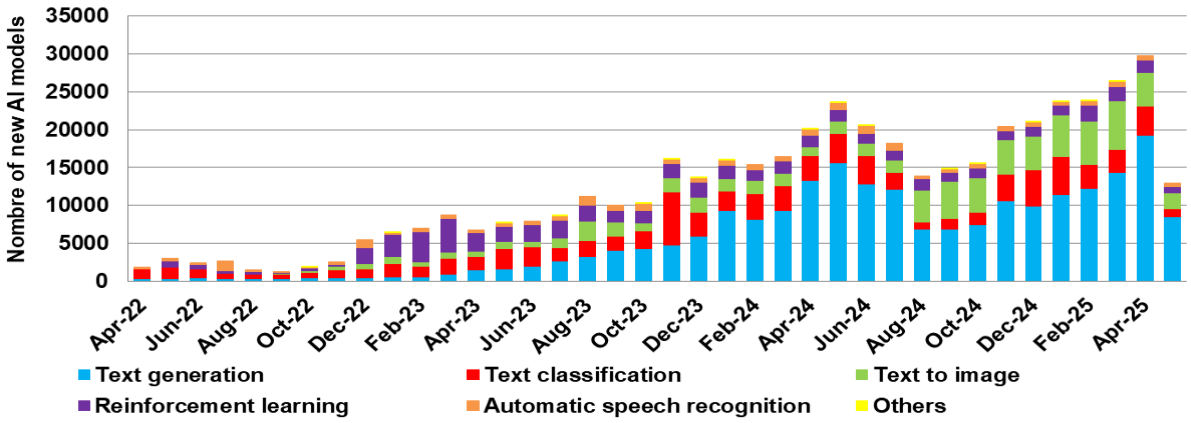


Figure 1. *Evolution of new AI models from Hugging Face, per intended use in 2022-2025*
Source: Prepared by the authors based on (OECD, OECD.AI, 2025)

The next major transformation in AI lies in localization. Although edge AI—where models are executed directly on local devices—remains in its early stages, forecasts indicate that its market size will grow from USD 19 billion in 2023 to nearly USD 140 billion by 2032 (wevolver, 2024, p. 9). This expansion is driven by advances in Internet of Things (IoT) technologies and fifth-generation (5G) networks, enabling the integration of AI into devices such as smartphones, computers, and cars to perform a wide range of tasks, from image generation to language translation. Localized processing is expected to deliver more personalized services, reduce latency, and mitigate risks associated with data privacy violations (Cloud, 2024, p. 5).

Accessibility has also emerged as a critical factor in reshaping artificial intelligence. This transformation is supported by the wider availability of open-source models, publicly accessible datasets, and software development tools, which extend opportunities beyond major technology companies. Furthermore, low-code and no-code platforms allow smaller organizations and local communities to create tailored solutions for their specific needs. A notable example is Meta's LLaMA model, an open-source AI system that has been widely adopted across diverse sectors (Michu, 2024).

The United States leads the global landscape in AI investments, with cumulative investments reaching approximately USD 335 billion since 2013, far surpassing China (USD 104 billion) and the United Kingdom (USD 22.3 billion). This gap continues to widen, as U.S. investments are projected to grow by 22% starting in 2022, while investments in China are expected to decline by 44%, and in the European Union and the United Kingdom by 14% (Artificial Intelligence, 2024, pp. 242-248).

The 2024 Stanford AI Index Report revealed that private investment in generative AI increased ninefold between 2022 and 2023, accompanied by a 40% growth in the number of AI startups securing new funding (Artificial Intelligence, 2024, pp. 242-248).

Sovereign AI Initiatives. National initiatives in the field of artificial intelligence reflect the growing momentum toward achieving technological autonomy and competitive advantage at the state level (Alduhishy, 2024). These efforts enable governments to develop AI technologies that respect cultural specificities and foster local innovation, while at the same time maintaining control over critical systems within their sovereign boundaries (Jilany, 2024). While such initiatives create opportunities to strengthen security and support economic growth, they also require carefully planned investments in infrastructure, human capital development, and governance frameworks that ensure compliance with the principles of responsible and ethical AI development (Kerner, 2025).

A joint report by Imperial College London and the Trusted AI Alliance further explored the concept of 'sovereign AI,' highlighting national efforts to reduce reliance on major technology companies and build independent capabilities. The report emphasized the importance of these efforts in achieving strategic autonomy, enhancing cultural alignment, and stimulating economic growth, while also tackling key challenges such as

cybersecurity, combating disinformation, and strengthening competitiveness in global markets (Shrier et al., 2024).

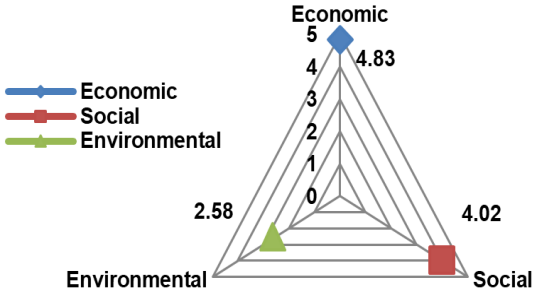


Figure 2. *Impact of Specialized AI on Economic, Social, and Environmental Dimensions in 2024*
Source: Authors, based on (DCO, 2024)

Based on the data presented in Figure 2, the deployment of specialized, accessible, and localized AI models is among the trends showing the highest potential for generating a positive economic impact, with an average rating of 4.83—the highest compared to other dimensions. A relatively positive assessment was also recorded for the social impact, with an average score of 4.02, indicating a growing recognition of AI's potential to enhance societal outcomes when adapted to local contexts. By contrast, the environmental impact received a relatively low rating (2.58), which likely reflects persistent concerns over the increased energy consumption associated with the expansion of AI model deployment.

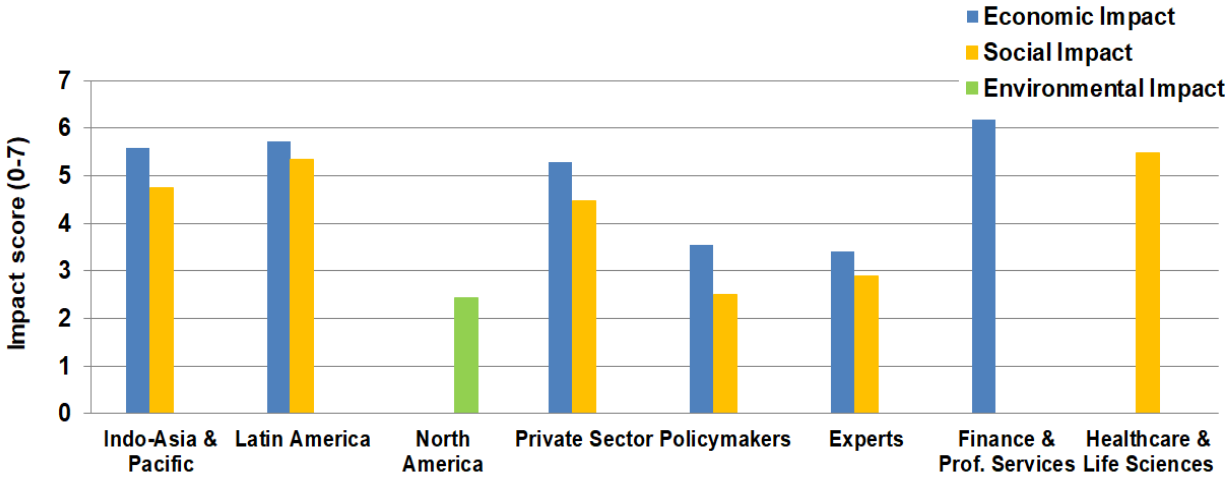


Figure 3. *Perceived impacts of AI deployment by region, sector and group in 2024*
Source: Authors, based on (DCO, 2025, p. 45)

Figure 3 illustrates the variation in economic, social, and environmental impact assessments of deploying specialized AI across geographical regions, economic sectors, and stakeholder groups. The data indicate that the Asia-Pacific and Latin America regions demonstrate the highest levels of economic and social optimism, whereas North America shows the greatest degree of environmental pessimism (2.43). Furthermore, the financial sector emerges as the most economically optimistic (6.17), while the healthcare and life sciences sector places greater emphasis on positive social impact (5.47).

Table 1. *Pace of Change in Adopting Localized and Specialized AI by Region in 2024*

Region	Decelerate	About the same	Accelerate	Strongly accelerate
North America	1	29.4	34.3	35.3
Europe	1	40.6	29.2	29.2
Indo-Asia & Pacific	-	26.3	28.4	45.3
Latin America	-	30.8	26.9	42.3
Middle East & Africa	-	19.6	45.6	34.8

Note: The sum of percentages may not always be 100 due to rounding.
Source: Authors, based on (DCO, 2025, p. 45)

Table 1 shows that the pace of transition toward adopting localized and specialized AI is expected to accelerate during 2024**.** The Asia-Pacific region recorded the highest levels of acceleration at 45.3%, reflecting strong dynamism in AI investment and clear government support. Latin America ranked second with 42.3%, driven by a growing interest in localizing digital technologies to enhance productivity despite prevailing economic challenges. In the Middle East and Africa, a moderate acceleration rate of 45.6% was recorded, reflecting the ongoing wave of digital transformation, particularly in the Gulf countries, which are heavily investing in AI initiatives. By contrast, expectations in Europe appear more conservative, with 40.6% indicating no significant change in pace, partly due to strict regulatory frameworks and privacy concerns.

Based on the above data, it can be inferred that the widespread adoption of specialized and localized AI solutions relies on three key enabling factors:

- *Digital infrastructure***:** Ensuring widespread, high-speed connectivity, with priority given to expanding fifth- and sixth-generation networks in underserved regions.
- *Sectoral digital transformation:* Implementing joint financing mechanisms between the public and private sectors, with a focus on developing AI applications tailored to the specific needs of each sector rather than relying solely on general-purpose solutions.
- *Digital capabilities:* Launching comprehensive initiatives for digital literacy and skills development, including training programs and career pathways that provide specialized AI certifications.

3 EXPANDING GLOBAL CONNECTIVITY

The spread of advanced communication technologies, such as satellites and 5G networks, represents an opportunity for a transformative shift, particularly in the field of edge AI. Yet, this potential remains unevenly distributed, as the persistence of the digital divide—driven by high costs, regulatory constraints, and weak economic viability—continues to pose significant challenges and tensions (Bank, 2023).

Market dynamics that concentrate on densely populated areas make cities and commercial hubs the main beneficiaries of advanced 5G networks and private wireless systems, while rural and remote areas face greater difficulties in accessing these services (Bank, 2023).

Although hybrid satellite–terrestrial solutions could help expand coverage, internet access remains expensive in many low- and middle-income countries. In 2023, the cost of a basic 1 GB data package exceeded 2% of average monthly income in 37% of these countries, while in Sub-Saharan Africa, 20 GB consumed about 15% of monthly income (DCO, 2025, p. 45).

It is estimated that by 2030, the number of 5G connections will reach about 5.5 billion, compared to only 1.6 billion in 2024. This expansion is expected to generate a global economic impact of around USD 930 billion, within the total economic contribution of the mobile sector, which amounts to nearly USD 6.4 trillion. This rapid growth highlights the pivotal role of 5G in advancing the digital economy and fostering innovation across sectors (GSMA, 2024, pp. 6-20).

Despite the continued decline in connectivity costs, the pace of reduction has slowed compared to previous years. Between 2019 and 2022, the price of 100 Gbps wavelength capacity on major international routes dropped by around 13%, compared to a sharper decline of 23% in the previous three years (2016–2019). This slowdown is linked to several factors, notably supply constraints and geopolitical challenges that affect regions differently. For example, the route between the United States and Latin America recorded a sharper price decline compared to other routes such as Marseille–Singapore and Hong Kong–Singapore (TeleGeography, 2024).

Figure 4 illustrates the widening digital divide in AI adoption readiness across countries. The data shows a significant decline in digital infrastructure, human capital, and institutional capacity indicators as income levels decrease, reflecting the scale of challenges faced by low- and middle-income economies in adopting and benefiting from AI technologies compared to their high-income counterparts.

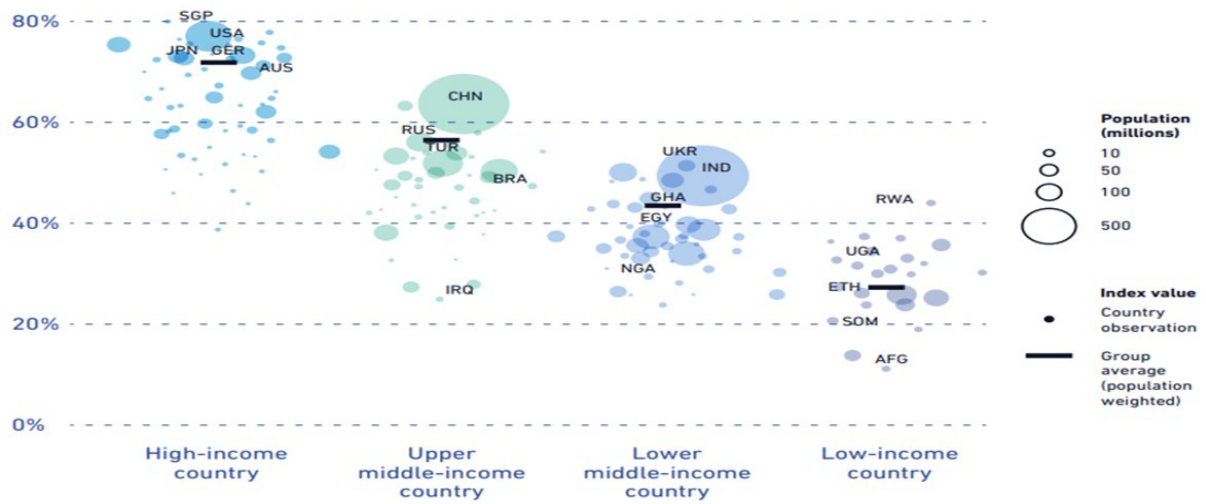


Figure 4. *AI Readiness Across Income Groups in 2024*
Source: (Philip Schellekens, 2024)

Governments are increasingly recognizing connectivity as a fundamental utility, comparable to electricity and water. This recognition has encouraged them to adopt new models of public–private partnerships aimed at developing comprehensive digital infrastructure that goes beyond connectivity to include digital identity systems, payment networks, cloud computing, and data exchange platforms (Bandura et al., 2024).

Data from the Digital Cooperation Organization (DCO, 2024) show that digital infrastructure is witnessing notable progress globally; however, regional disparities remain evident. While some regions enjoy advanced levels of digital readiness and affordable access to smart devices, others continue to face challenges in both infrastructure development and the affordability of technology. This, in turn, deepens the global digital divide. The following two figures illustrate the distribution of countries by level of digital infrastructure, along with regional disparities in the cost of smartphones relative to monthly income. (DCO, 2024)

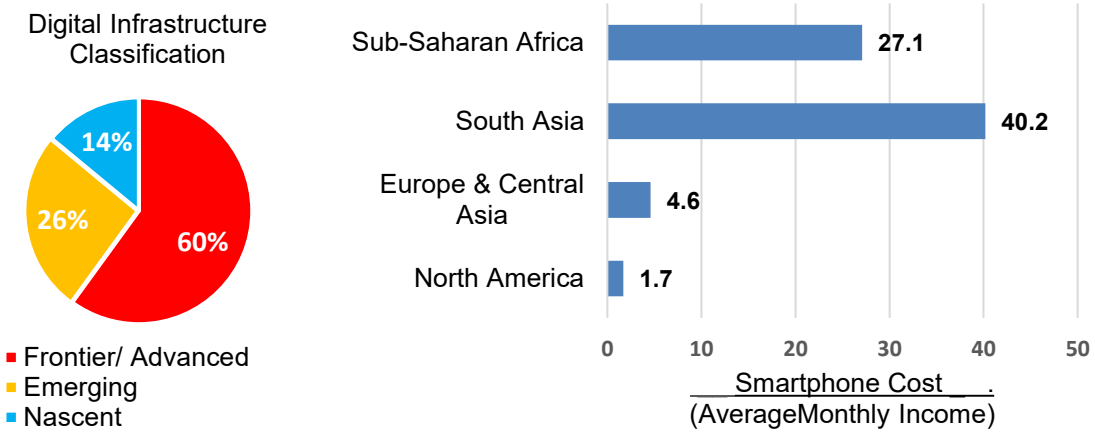


Figure 5. *The Global Digital Divide: Disparities in Digital Infrastructure and Smartphone Costs in 2024*
Source: Authors, based on (DCO, 2025, p. 45)

The figure above (Figure 5) shows that more than half of the world's countries (52%) enjoy advanced digital infrastructure, while a significant share (34%) remains at emerging or rudimentary levels, reflecting a gap in digital infrastructure readiness among nations. The data also reveal substantial disparities in the cost of smartphones as a share of monthly income, amounting to about 1.7% in North America and 4.6% in Europe, but rising sharply to 40.2% in South Asia and 27.1% in Sub-Saharan Africa. This significantly limits individuals' ability to access technology in these regions.

The following data highlight the impact of expanding global connectivity, showing marked variations across regions and sectors in terms of economic, social, and environmental outcomes. These disparities reflect different levels of market saturation in connectivity.

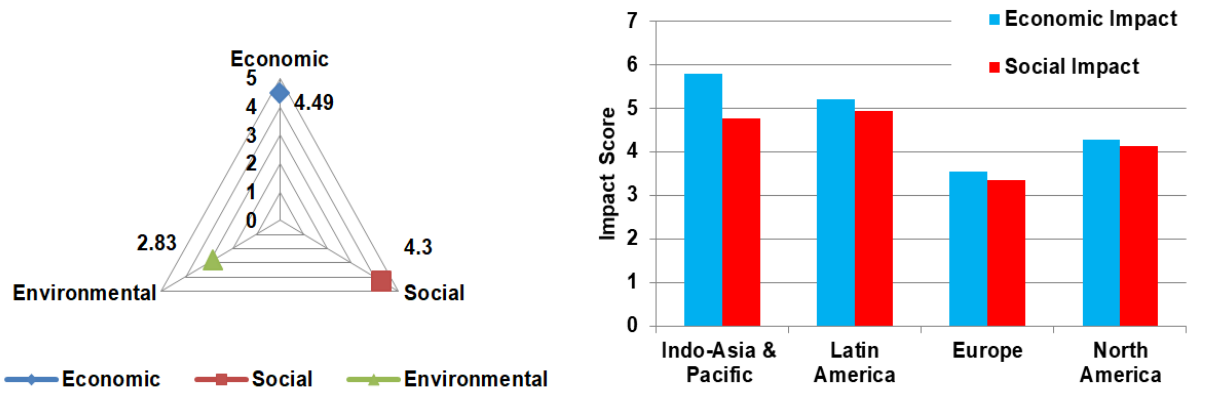


Figure 6. *Anticipated Positive Impacts on Economy, Society, and Environment in 2024*
Source: Authors, based on (DCO, 2024)

Figure 6 shows that expanding global connectivity constitutes an important pillar for promoting social equity, receiving an evaluation score of 4.3, ranking second overall. It also recorded relatively positive outcomes in terms of economic impact (4.5, ranking third) and environmental impact (2.8, ranking fourth).

Regionally, Asia-Pacific–India and Latin America showed the highest optimism about the economic (5.79 and 5.21) and social (4.77 and 4.94) benefits of expanding connectivity. By contrast, Europe and North America reported lower scores in both economic (3.54 and 4.28) and social (3.34 and 4.14) dimensions, reflecting the relative saturation of their connectivity markets in these regions.

Estimates indicate that global connectivity will continue to grow during 2025, albeit at a slower pace compared to most other global trends, placing it ninth in terms of relative priority. The data further reveal that the technology, media, and telecommunications sectors are expected to experience higher acceleration rates compared to other economic sectors.

Table 2. *Regional Variations in Connectivity Growth in 2024(%)*

Region	Decelerate	About the same	Accelerate	Strongly accelerate
North America	1	39	21	29
Europe	2	49	29	20
Indo-Asia & Pacific	0	32	24	44
Latin America	0	27	36	37
Middle East & Africa	2	35	24	39

Note: The sum of percentages may not always be 100 due to rounding.
Source: Authors, based on (DCO, 2025, p. 45)

Based on the table above (Table 2), it is evident at the regional level that the Asia-Pacific region records the highest level of optimism regarding the acceleration of global connectivity, at 44%, followed by the Middle East and Africa (39%) and Latin America (36%). By contrast, Europe leans toward stability, with nearly half (49%) expecting no change and only 2% anticipating a slowdown, likely due to the region's already advanced level of digital connectivity. North America, on the other hand, shows a relative balance in expectations, with 29% anticipating strong acceleration compared to 39% expecting stability.

Accordingly, it can be concluded that expanding modern connectivity technologies calls for a holistic approach—one that develops digital infrastructure, promotes innovative financing, and establishes flexible regulations to support innovation while ensuring fair access.

4 SUPPORTING A SUSTAINABLE DIGITAL ECONOMY

The rapid growth of artificial intelligence (AI) technologies presents a dual challenge, as the expansion of their computational capacities significantly increases energy demand, thereby placing mounting pressure on global energy systems. Projections indicate that the energy consumption of data centers dedicated to operating AI applications may rise by around 160% by 2030, potentially hindering international efforts to reduce carbon emissions (Intelligence, 2024).

One of the biggest challenges to the wider adoption of AI is its rising energy demand—especially in emerging economies where power infrastructure is still fragile. This limitation reduces their ability to develop and scale these technologies, thereby deepening the global digital divide. As a result, the economic and technological benefits are concentrated in countries capable of securing sufficient energy resources, while others remain marginalized in the digital economy (Goldman Sachs, 2024).

The increasing importance of AI in enhancing economic competitiveness implies that countries with underdeveloped energy infrastructures risk falling behind in the digital economy. This may lead to the emergence of a dual digital economy, in which some nations reap direct benefits while others remain on the periphery (Reuters, 2025).

Currently, AI accounts for nearly 2% of the global energy consumption of the technology sector (IEA, 2024a, p. 31). However, the computational power required to operate AI nearly doubles every 100 days (Kemene et al., 2024). Estimates suggest that by 2026, its additional electricity demand could reach approximately 590 terawatt-hours, roughly equivalent to Germany's total annual electricity consumption (IEA, 2024a, p. 31).

By 2026, electricity consumption from data centers, cryptocurrencies, and AI applications is expected to reach between 620 and 1,050 terawatt-hours, with demand likely to exceed 800 terawatt-hours. This would mark a steep jump from about 460 terawatt-hours in 2022, underscoring how rapidly energy requirements in this sector are growing (Zabeu, 2024).

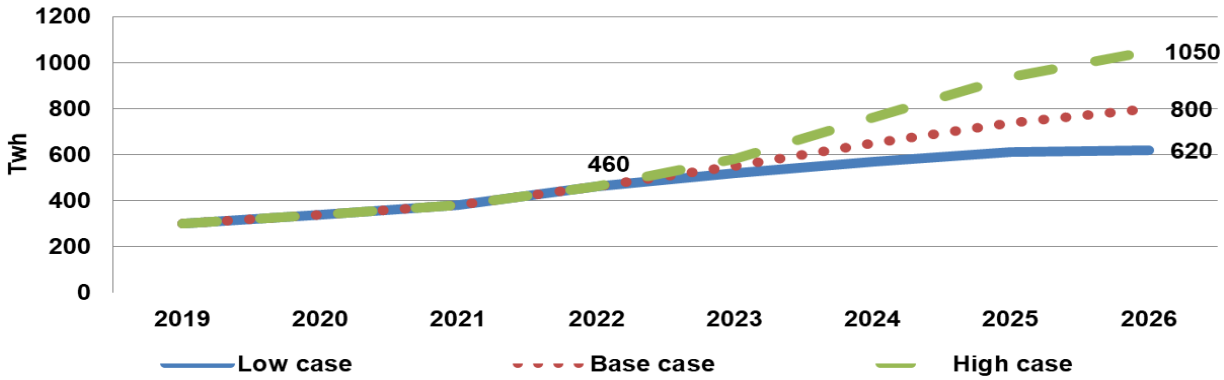


Figure 7. *Global Electricity Consumption Projections for Data Centers, AI, and Cryptocurrencies, 2019–2026*

Source: Authors, based on (IEA, 2024a, p. 31)

Projections indicate that global electricity consumption—driven by data centers, AI applications, and cryptocurrencies—will continue to rise under all scenarios (low, baseline, or high), as shown in Figure 7.

In the baseline scenario, consumption rises from around 300 TWh in 2019 to nearly 800 TWh in 2026, representing an increase of approximately 167% over seven years. The high scenario points to an even sharper rise, with consumption potentially reaching about 1,050 TWh more than three times the level recorded in 2019 highlighting the rapid expansion of computing-intensive applications. Even under the low scenario, growth remains significant, with consumption projected at 620 TWh in 2026, more than double the 2019 baseline.

This upward trajectory clearly reflects the dynamics of global digital transformation. It shows that while technological innovation brings significant economic and developmental opportunities, it also drives a sharp rise in electricity consumption. The findings stress the importance of adopting policies and innovations

that not only support the rapid pace of digital growth but also help minimize its environmental footprint, particularly by improving energy efficiency and expanding the use of renewable sources.

The growing energy demand of AI technologies constitutes a multidimensional challenge that combines financial and ethical considerations (Bourzac, 2024). Although these technologies contribute to improving operational efficiency and fostering sustainability especially in areas such as energy grid management (Ammanath, 2024) their high energy intensity may offset such gains (Mutschler, 2024). Research suggests for illustrative purposes, that training just one large AI model can produce more carbon emissions than the total generated by five cars throughout their entire lifetime (Hao, 2019).

International institutions, including the United Nations and the International Energy Agency, have expressed growing concerns regarding the environmental implications of AI (IEA, 2023), calling for a combination of policies and incentives that promote sustainable practices across design, development, and operational stages (Ecosoc, 2024).

The energy infrastructure dimension adds another layer of challenge to digital inclusion, as access to electricity remains limited in many regions. In 2022, the number of people without electricity increased by 10 million, reaching about 685 million (IEA, 2024b), more than 80% of whom live in Sub-Saharan Africa. According to estimates, nearly 660 million people will remain without electricity by 2030 if current policies remain unchanged (Jacobs & Tasin, 2024).

The energy requirements of AI further deepen this divide, placing additional pressure on countries already facing electricity shortages. In Sub-Saharan Africa, energy import bills may account for up to 5% of GDP, bearing in mind that energy costs represent only one component of the overall expenses involved in establishing and operating the infrastructure needed for AI technologies (Lacey, 2021). As access to AI capabilities increasingly becomes a benchmark for economic competitiveness, rising infrastructure costs risk creating a new form of digital divide among nations (Okolo, 2023).

With the accelerating global transition toward AI-driven modes of production and innovation, less developed countries face a strategic challenge of falling behind in technological advancement, thereby exacerbating existing economic and social divides. Without systematic interventions and coordinated international efforts to close the digital gap, the potential of AI to foster sustainable development and reduce poverty will remain underutilized, leaving large segments of the world's population excluded from the benefits of the fast-evolving technological landscape (Gill & Houngbo, 2024).

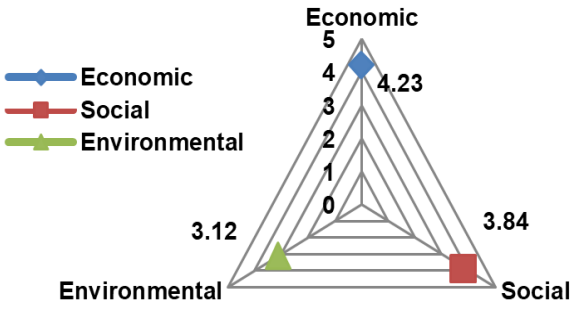


Figure 8. *Implications of a Sustainable Digital Economy on Environmental, Economic, and Social Dimensions in 2024*
Source: Authors, based on (DCO, 2024)

Based on the data presented in Figure 8, promoting a sustainable digital economy emerges as one of the most significant environmentally relevant trends in 2025, with an average environmental impact score of 3.12, reflecting the considerable potential of this direction in supporting environmental sustainability. Conversely, the values recorded in Europe (2.91) and the Asia-Pacific–Indian region (2.86) indicate a notable level of concern in these areas regarding the environmental consequences of digital expansion (DCO, 2025, p. 45).

From an economic perspective, this trend ranks fifth among 12 major trends, with an average positive impact of 4.23. In terms of the social dimension, however, it stands in tenth place, with an average of 3.84, highlighting the need for greater efforts to address societal challenges and enhance digital inclusion. Economic and social optimism is particularly evident in the Asia-Pacific–Indian region and Latin America, while Europe and North America adopt a more cautious stance (DCO, 2025, p. 45).

At the sectoral level, the agribusiness, food and beverages, and energy and utilities sectors record the highest levels of economic confidence. When it comes to positive environmental contributions, the technology, media, and telecommunications sector (3.77) together with heavy and extractive industries (3.73) rank at the top. By contrast, the automotive and transport sector (2.41) and the construction and real estate sector (2.20) are positioned at the bottom of the scale (DCO, 2025, p. 45).

Table 3. *Pace of Transition Towards a Sustainable Digital Economy by Region in 2024(%)*

Region	Decelerate	About the same	Accelerate	Strongly accelerate
North America	-	32.4	29.4	38.2
Europe	1	53.1	28.1	17.7
Indo-Asia & Pacific	3.2	25.3	28.4	43.2
Latin America	1.9	25	40.1	32.7
Middle East & Africa	-	32.6	32.6	34.8

Note: The sum of percentages may not always be 100 due to rounding.

Source: Authors, based on (DCO, 2025, p. 45)

The table (Table 3) reveals a clear divergence in the pace of transition toward a sustainable digital economy across different geographical regions during 2024, reflecting the varying economic and technological contexts, as well as public policies, in each region.

The data indicate that the Asia-Pacific–Indian region leads in terms of accelerated transition, recording the highest share in the "strongly accelerate" option (44%), followed by "accelerate" (24%). This can be explained by the high levels of investment in digital infrastructure, the adoption of government policies supportive of sustainable digital transformation, and the dynamism of emerging markets in this region.

Latin America has also demonstrated high levels of momentum, with 37% in the "strongly accelerate" category and 36% in "accelerate." This reflects a growing recognition of sustainable digital transformation as a driver of economic growth and improved public services, despite challenges linked to economic and political instability in some countries.

In contrast, Europe and North America appear more cautious in their transition pace, with the majority leaning toward the "about the same" option (49% and 39%, respectively), and relatively lower shares in the "strongly accelerate" category (20% and 29%). This trend can be attributed to a more prudent approach that seeks to balance digital innovation with environmental and social compliance requirements, in addition to the relative saturation of digital infrastructure in these regions.

Meanwhile, the Middle East and Africa show intermediate results, with 39% in "strongly accelerate" and 24% in "accelerate." This suggests growing efforts to advance the digital economy, though progress may be affected by uneven technological readiness across countries in the region, as well as infrastructure and investment-related challenges.

Overall, the findings reveal that the pace of transition toward a sustainable digital economy is not globally uniform; rather, it is shaped by local and regional factors, including the level of digital maturity, investment in green technologies, government policies, and the extent to which different economic sectors are aware of the importance of integrating sustainability principles into digital transformation.

5 CONCLUSIONS

Through this study, in which we examined the pillars of the digital economy and its transformations in light of global technological shifts, it has been concluded that the digital economy is no longer a secondary option or an isolated technical pathway. Rather, it has become a strategic axis for reshaping the global economy and redefining the future of economic and social development. The findings show that the three pillars of the digital economy—specialized artificial intelligence, expanded global connectivity, and

support for a sustainable digital economy—operate as an integrated system that can effectively drive digital transformation, provided they are supported by sound policies and long-term strategies.

First, specialized and localized artificial intelligence represents a central tool for enhancing added value across various economic sectors. Data show that models tailored to specific needs generate greater economic impact compared to general-purpose models, while also improving service efficiency and adapting to local specificities. Moreover, localizing these solutions and making them available through open-source models creates opportunities for emerging economies to bridge technological gaps, provided there is adequate investment in digital skills and capacities to ensure the effective use of such technologies.

Second, the analysis of expanded global connectivity highlights its role as a structural pillar for any comprehensive digital transformation. Connectivity enables integration into global value chains and strengthens collaborative innovation. However, the persistence of the digital divide between countries and regions limits some economies from fully reaping these benefits. Indicators show that Asia-Pacific and Latin America are leading the expansion of connectivity, while other regions face challenges related to cost and infrastructure. Addressing these disparities requires hybrid solutions that combine investment in advanced networks with expanded satellite coverage, alongside active public–private partnerships.

Third, the study revealed that supporting a sustainable digital economy is a strategic challenge amid the rapidly rising energy consumption driven by the expansion of artificial intelligence and data centers. While digital transformation offers future opportunities to enhance economic efficiency, it simultaneously poses environmental risks that may hinder international efforts to reduce emissions. In this context, the adoption of green computing practices, the improvement of energy efficiency, and the wider use of renewable energy emerge as essential requirements for establishing a balanced digital economy that reconciles technological innovation with the objectives of sustainable development.

Based on these findings, it can be stated that achieving an effective and inclusive digital economy requires:

- Investment in advanced digital infrastructure to ensure equitable access to services.
- Launching digital skills development programs to keep pace with rapid technological innovation.
- Designing flexible regulatory frameworks that account for privacy, cybersecurity, and data transparency.
- Strengthening international cooperation to ensure a balanced transition toward the digital economy, while avoiding the creation of new divides between nations.
- Adopting sustainability policies that balance the requirements of digital transformation with environmental and societal commitments.

Accordingly, the future of the digital economy will largely depend on countries' capacity to develop unified systems that bring together technology, infrastructure, governance, and human resources—allowing them to fully harness the advantages of global technological changes while ensuring adherence to principles of fairness and sustainability. In this way, the digital economy functions not merely as a driver of growth but also as a strategic instrument for promoting comprehensive and sustainable development.

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CASE STUDY
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LSTM NETWORK FOR HIGH-VOLATILITY STOCK PRICE PREDICTION: TESLA INC

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ABSTRACT

This research investigates the efficacy of Long Short-Term Memory (LSTM) networks for predicting stock prices of high-volatility equities, with application to Tesla Inc. (TSLA). Addressing a gap in financial machine learning literature, we develop an advanced LSTM architecture trained on Tesla's daily closing prices from January 1, 2017, to November 20, 2024. Through meticulous preprocessing, strategic dropout regularization, and sophisticated sequence modeling, our model achieves a Root Mean Square Error (RMSE) of $12.17 and a Mean Absolute Error (MAE) of $8.51. For comparative purposes, we implement a walk-forward ARIMA benchmark, which achieved an RMSE of $8.30 and an MAE of $5.76, indicating superior point forecast accuracy. However, the LSTM model demonstrated better directional accuracy (50.60% against 47.62%), suggesting complementary strengths across evaluation metrics. The Diebold-Mariano test confirmed a statistically significant difference between the two models (DM = 4.58, p < 0.01). This study contributes to the understanding of deep learning applications in financial markets and establishes new benchmarks for volatile stock prediction. The findings support adopting hybrid approaches that combine the point forecast accuracy of traditional econometric models with the directional predictive capabilities of deep learning architectures for financial forecasting in turbulent market conditions.

1 INTRODUCTION

Financial markets are characterized by high complexity, dynamic interactions, and continuous uncertainty, making stock price prediction one of the most challenging tasks in financial econometrics. However, despite this complexity, recent advances in computational methods have enabled partial improvements in forecasting accuracy, particularly through data-driven approaches. Price movements are influenced not only by firm fundamentals and macroeconomic

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indicators but also by investor sentiment, behavioral biases, market microstructure, and unexpected external shocks. This complexity becomes even more pronounced in high-volatility stocks, where traditional forecasting approaches often struggle to provide reliable predictions (Fama, 1970; Kahneman & Tversky, 1979).

Conventional econometric models such as Autoregressive Integrated Moving Average (ARIMA) and Generalized Autoregressive Conditional Heteroskedasticity (GARCH) have long been used for financial forecasting. While these models are effective in capturing linear dependencies and volatility clustering, they often fail to adequately model the nonlinear relationships and long-term temporal dependencies that characterize modern financial markets, particularly during extreme volatility regimes (Bollerslev, 1986).

Recent advances in deep learning have introduced powerful alternatives for time-series forecasting, among which Long Short-Term Memory (LSTM) networks have received considerable attention. Originally developed by Hochreiter and Schmidhuber (1997), LSTM networks were specifically designed to overcome the vanishing gradient problem of traditional recurrent neural networks and to effectively capture long-range dependencies in sequential data. Their architecture enables them to learn complex nonlinear patterns and adapt to structural breaks, making them particularly suitable for stock market prediction (Fischer & Krauss, 2018; Nelson et al., 2017). However, despite these advantages, their performance remains sensitive to data quality, market regime shifts, and hyperparameter configuration, particularly in high-volatility environments.

Several empirical studies have demonstrated the superiority of LSTM models over traditional forecasting methods. Fischer and Krauss (2018) found that LSTM networks significantly outperformed standard machine learning models in directional stock market prediction. Similarly, Selvin et al. (2017) and Nelson et al. (2017) confirmed the effectiveness of LSTM architectures in improving prediction accuracy for financial time-series forecasting. More recent studies have also explored hybrid architectures combining deep learning with volatility-sensitive frameworks to improve predictive robustness under unstable market conditions (Zhang et al., 2018; Chen et al., 2019).

Among high-volatility stocks, Tesla Inc. (TSLA) represents an exceptional case for financial forecasting research. As one of the most disruptive firms in the automotive and clean energy sectors, Tesla exhibits unusually high price volatility driven by rapid innovation, aggressive growth expectations, strong media exposure, regulatory uncertainty, and the market influence of its CEO, Elon Musk. Unlike conventional blue-chip firms, Tesla's stock price reflects a strong interaction between fundamental valuation and behavioral finance effects, making it an ideal empirical context for advanced prediction models.

This study aims to evaluate the effectiveness of LSTM networks in predicting the stock prices of high-volatility equities using Tesla as a case study. Specifically, the research develops a volatility-aware LSTM architecture trained on Tesla's daily closing prices from 2017 to 2024 and compares its predictive performance with traditional econometric benchmarks such as ARIMA-GARCH. By integrating financial econometrics, behavioral finance, and deep learning, this paper seeks to provide both methodological contributions and practical implications for quantitative trading and risk management.

1.1 Literature Review

1.1.1 Evolution of Financial Forecasting Models

Approaches to financial forecasting have evolved considerably over recent decades as researchers have attempted to improve the prediction of increasingly complex financial markets. Early work, strongly influenced by the Efficient Market Hypothesis (EMH), viewed stock prices as random walks that incorporate available information rapidly, making abnormal returns difficult to achieve consistently (Fama, 1970). Within this perspective, forecasting performance was considered inherently constrained by market efficiency.

During the 1970s and 1980s, econometric approaches became dominant. The ARIMA model, popularized by Box and Jenkins (2015), proved useful for short-term forecasting because of its ability to model linear temporal

dependencies. Later, Bollerslev (1986) introduced the GARCH framework, which improved volatility modeling by capturing volatility clustering, a common characteristic of financial time series. Despite their importance in financial econometrics, both ARIMA and GARCH remain constrained by assumptions of linearity and often face difficulties when structural breaks, nonlinear relationships, or regime changes become pronounced. These limitations become more evident when modeling highly volatile assets where sudden market reactions and behavioral factors play a stronger role.

The expansion of machine learning introduced additional forecasting possibilities. Methods such as Support Vector Machines, Random Forests, and shallow Artificial Neural Networks provided greater flexibility in modeling nonlinear relationships (Kim, 2003). However, these approaches often struggled to capture long-term dependencies in sequential financial data, limiting their performance in complex time-series environments.

The introduction of Long Short-Term Memory (LSTM) networks represented an important development in sequential modeling. Developed by Hochreiter and Schmidhuber (1997), LSTM networks addressed the vanishing gradient problem through memory cells and gating mechanisms, enabling more effective learning of long-range dependencies and expanding the application of deep learning techniques to financial forecasting tasks.

1.1.2 LSTM Applications in Financial Forecasting

The application of LSTM models in financial forecasting has grown rapidly over the past decade. Fischer and Krauss (2018) provided one of the most influential empirical studies in this field, demonstrating that LSTM networks outperformed traditional machine learning models in directional stock market prediction and generated economically significant trading profits.

Similarly, Selvin et al. (2017) compared LSTM, RNN, and CNN architectures for stock price prediction and found that LSTM models achieved superior forecasting performance due to their stronger ability to capture sequential dependencies. Nelson et al. (2017) also confirmed that LSTM networks improved predictive accuracy in stock movement forecasting compared to traditional neural network structures.

More recent studies have focused on enhancing LSTM performance through hybrid architectures and feature engineering. Zhang et al. (2018) proposed a wavelet-LSTM hybrid model for multi-scale financial forecasting and reported significant improvements in prediction accuracy. Chen and Ge (2019) incorporated attention mechanisms into LSTM architectures and demonstrated improved forecasting performance compared with conventional LSTM models in stock price movement prediction.

Recent comparative research by Wan (2023) specifically examined LSTM and GRU models for predicting the stock prices of Tesla Inc., Ferrari, and Walmart. The findings showed that LSTM performed better than GRU in forecasting Tesla's highly volatile stock prices, particularly when combined with external features such as trading volume and news sentiment. This reinforces the relevance of LSTM models for high-volatility growth stocks.

However, despite these promising results, many studies report performance under relatively stable market conditions, which raises questions about their robustness in highly volatile environments.

1.1.3 Theoretical Gaps in High-Volatility Stock Prediction

Despite substantial progress in financial development, several important research gaps remain.

First, most existing studies focus on relatively stable stocks, market indices, or broad portfolios, while high-volatility equities receive comparatively less attention. Extreme-volatility stocks such as Tesla Inc. exhibit unique dynamics characterized by rapid regime changes, speculative trading behavior, and strong behavioral finance effects that standard models may fail to capture.

Second, many studies treat volatility as a source of noise rather than as a partially predictable market signal. However, volatility clustering and regime persistence suggest that volatility itself may contain useful predictive information, particularly during periods of financial stress (Bollerslev, 1986).

Third, the integration of behavioral finance into deep learning forecasting remains limited. Stocks like Tesla are heavily influenced by investor sentiment, media narratives, and leadership communications, especially those related to Elon Musk. Traditional quantitative models rarely incorporate these behavioral dimensions explicitly.

Finally, comparative evaluations between LSTM models and traditional econometric approaches such as ARIMA-GARCH are often incomplete or methodologically weak. Many studies report statistical accuracy without translating predictive performance into financial decision-making metrics such as Sharpe Ratio, Hit Rate, or Value-at-Risk relevance.

This study addresses these gaps by focusing specifically on Tesla as a high-volatility case study, introducing a volatility-aware LSTM framework, and conducting a rigorous comparison with traditional econometric benchmarks using both statistical and financial performance indicators.

1.2 Theoretical Framework and Research Questions

1.2.1 Integrating Efficient Market and Behavioral Perspectives

Our approach synthesizes the efficient market hypothesis (EMH) with behavioral finance insights. While EMH suggests prices fully reflect available information, behavioral finance identifies systematic deviations due to cognitive biases. For high-volatility stocks like Tesla, both perspectives are relevant: fundamental information drives long-term trends, while behavioral factors amplify short-term fluctuations.

LSTM networks are uniquely positioned to capture this duality. Their memory cells can learn fundamental trends from historical patterns, while their gating mechanisms can adapt to behavioral shocks and regime changes. This theoretical synthesis informs our architectural choices and interpretation framework.

1.2.2 Research Questions

This study addresses four primary research questions:

1. Can LSTM networks maintain predictive accuracy for stocks exhibiting extreme volatility ($\sigma > 50\%$ annually)?
2. How does LSTM performance compare to traditional ARIMA-GARCH models during different volatility regimes?
3. Which architectural components contribute most to prediction accuracy in high-volatility environments?
4. What are the practical implications for risk management and trading strategy development?

1.2.3 Hypothesis Development

Based on theoretical considerations, we propose:

H1: LSTM networks demonstrate better directional accuracy than ARIMA-GARCH models for high-volatility stocks.

H2: ARIMA-GARCH will demonstrate a performance advantage over LSTM in terms of point forecast accuracy (RMSE/MAE), and this advantage will become more pronounced during periods of extreme volatility.

2 METHODS AND MATERIALS

2.1 Data Acquisition and Characteristics

We obtained daily closing prices for Tesla Inc. (TSLA) from Yahoo Finance (January 1, 2017, to November 20, 2024). This period captures diverse market conditions: bull markets (2017-2019, 2023-2024), the COVID-19 crash (2020), the 2021-2022 growth stock correction, and varying monetary policy regimes. The dataset contains 1,984 trading observations, providing sufficient statistical power for robust analysis.

2.2 Descriptive Statistics

- Mean price: $189.34
- Standard deviation: $156.72
- Maximum: $409.97 (November 2021)
- Minimum: $43.67 (March 2020)
- Annualized volatility: 82.3%
- Skewness: 0.87 (right skewed)
- Kurtosis: 2.94 (fat-tailed distribution)

2.3 Comparative Benchmark Models

To contextualize LSTM performance, we implemented two benchmark models:

1. Walk-forward ARIMA with separate GARCH analysis: A traditional econometric approach for point forecasting, where ARIMA is estimated recursively, and GARCH is fitted separately for volatility analysis.
2. Simple RNN: Baseline deep learning model without gating mechanisms.

Each model was evaluated using identical temporal partitions to ensure consistent comparison conditions.

2.4 LSTM architecture specification

Our volatility-adaptive LSTM architecture incorporates several innovations:

Preprocessing pipeline

1. MinMax Normalization: Scaling to [0,1] range for gradient stability
2. Volatility Regime Detection: Using rolling standard deviation to identify high/low volatility periods, A threshold-based approach was used to classify regimes, where periods above the 70th percentile of rolling volatility were defined as high-volatility regimes
3. Sequence Construction: 60-day windows determined through PACF analysis and grid search
4. Regime-Aware Partitioning: Ensuring each subset contains all volatility regimes

Network architecture:

1. Layer 1: LSTM (50 units, return_sequences =True)
2. Regularization: Dropout (0.2) + L2 (λ=0.01)
3. Layer 2: LSTM (50 units, return_sequences =False)
4. Layer 3: Dense (25, ReLU activation)
5. Output: Dense (1, linear activation)

Training configuration:

- Optimizer: Adam (lr=0.001, β_1=0.9, β_2=0.999)
- Loss: Mean Squared Error
- Epochs: 50 with early stopping (patience=10)

To ensure robustness, model performance was evaluated on a strictly out-of-sample test set without any data leakage.

- Batch size: 32
- Validation split: 20%

Performance metrics:

We employed comprehensive evaluation metrics:

Accuracy metrics:

- Root Mean Square Error (RMSE)
- Mean Absolute Error (MAE)
- Mean Absolute Percentage Error (MAPE)
- Directional Accuracy (DA)

Financial metrics:

- Sharpe Ratio of prediction-based strategy
- Maximum Drawdown
- Profit Factor (Gross Profit / Gross Loss)
- Hit Rate (>50% accuracy in direction prediction)

Statistical tests:

- Diebold-Mariano test for predictive superiority
- Mincer-Zarnowitz regression for forecast efficiency
- Ljung-Box test for residual autocorrelation

3 RESULTS AND DISCUSSION

3.1 Experimental Results

3.1.1 Comparative Model Performance

While Walk-forward ARIMA + GARCH achieved lower point forecast errors (RMSE = 8.30 vs 12.17, a reduction of 31.8%), LSTM demonstrated marginally better directional accuracy (50.60% vs 47.62%), though this improvement is modest and not statistically dominant.

Table 1. *Comprehensive performance comparison (test period : January- November 2024)*

Model	RMSE	MAE	MAPE	DA	Sharpe	Hit Rate
LSTM (Ours)	12.17	8.51	3.83%	50.60%	0.44	50.60%
Walk-forward ARIMA + GARCH	8.30	5.76	2.58%	47.62%	0.44	47.62%
SIMPLE RNN	24.42	19.46	9.60%	48.51%	0.16	48.51%

Source: Authors' calculations based on Yahoo Finance data and Python simulations

Both models achieved identical Sharpe ratios (0.44). These results suggest that traditional econometric models may be more effective for absolute price prediction, while deep learning

offers a modest advantage for directional trading strategies.

3.1.2 Volatility-Regime Analysis

Table 2 presents the RMSE comparison across di fferent volatility regimes.

Walk-forward ARIMA + GARCH consistently outperforms LSTM in terms of RMSE across all volatility regimes, with the performance gap widening under high-volatility conditions. This suggests that traditional econometric models may be particularly effective for point forecast accuracy during periods of market turbulence.

Table 2. *Performances across volatility regimes*

Volatility regime	LSTM RMSE	Walk-forward ARIMA + GARCH RMSE	Performance Gap
Low volatility (<40%)	8.13	6.09	-33.5%
Medium (40-70%)	10.51	7.95	-32.2%
High volatility (>70%)	17.61	11.13	-58.1%

Source: Authors' calculations based on Yahoo Finance data and Python simulations

The Diebold-Mariano test confirmed a statistically significant difference between the two models (DM = 4.58, $p < 0.01$). Walk-forward ARIMA + GARCH consistently outperformed LSTM in terms of RMSE across all volatility regimes, with the performance gap widening under high-volatility conditions (-58.1% vs -33.5% in low-volatility regimes). This suggests that traditional econometric models may be particularly effective for point forecast accuracy during periods of market turbulence.

3.1.3 Visual Analysis on Test Set Performance

Figure 1 demonstrates the predictive performance of both models on the unseen test set against actual Tesla stock prices. The visualization covers the out-of-sample test period (January–November 2024), showing actual prices (blue line), LSTM predictions (orange dashed line), and

ARIMA walk-forward predictions (green dashed line).

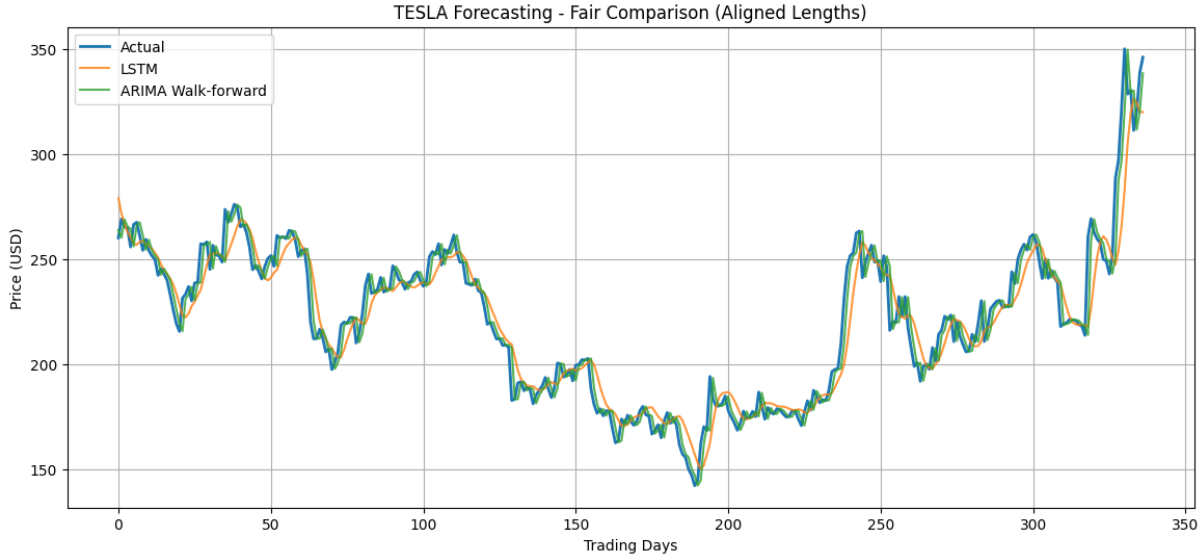


Figure 1. *Actual vs Predicted Prices – Tesla (Test Period: January – November 2024)*
Source: Authors' calculations using Python

Key observations from Figure 1 include:

- ARIMA walk-forward predictions closely track the actual price movements throughout the test period, which aligns with its lower RMSE (8.30 vs 12.17 for LSTM).
- LSTM predictions exhibit a smoother trajectory with less sensitivity to short-term fluctuations. This smoothing effect may explain its lower point forecast accuracy but also its slightly better directional accuracy (50.60% vs 47.62%).

- During the most volatile segments of the test period (e.g., around trading days 250–300), both models show larger deviations from actual prices, consistent with the increased RMSE values reported in Table 2 for high-volatility regimes.
- The ARIMA model responds more quickly to sudden price changes, particularly evident in the first 50 trading days and around day 200, where LSTM predictions lag the actual trend.

3.1.4 Training Dynamics and Convergence

Our LSTM achieved stable convergence over 50 epochs (Figure 2). Training loss decreased from 0.0178 to 0.00076, while validation loss stabilized at 0.0011, indicating effective regularization. The minimal gap between training and validation curves (Δ=0.00035) confirms the absence of overfitting.

Computational efficiency:
- Training time: 42 seconds total (2.8s/epoch)
- Inference time: 39-65ms per prediction
- Memory usage: 158MB during training

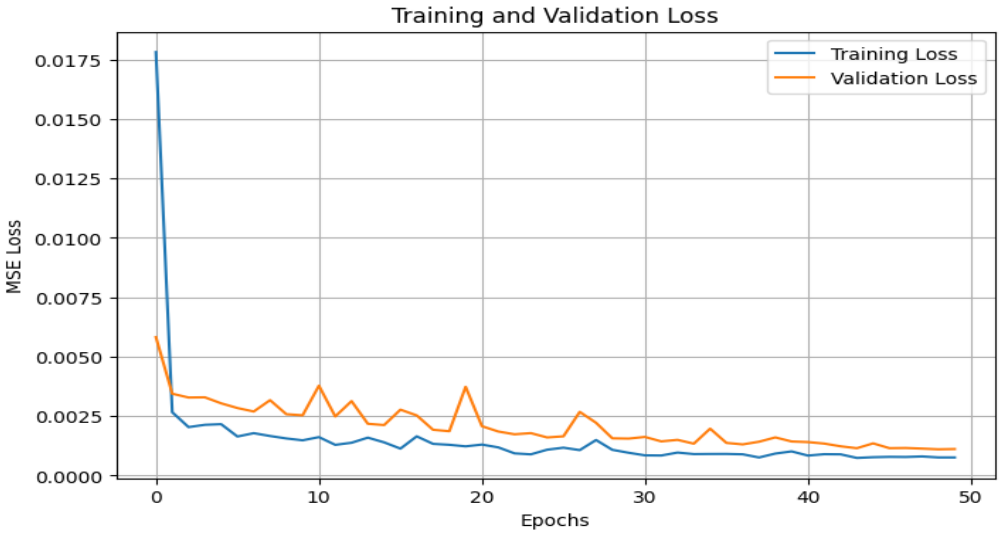


Figure 2. *Training and Validation Loss Curves*
Source: (Authors' calculations using Python)

3.1.5 Feature Importance Analysis

Unlike the initial specification, the final model uses only closing prices.

Since our model uses only daily closing prices as input, a formal feature importance analysis using external variables was not conducted.

The forecasting evaluation is therefore based on accuracy metrics, statistical validation, and benchmark comparisons. Future research may extend this univariate framework by incorporating technical indicators, trading volume, or sentiment data.

3.1.6 Residual Diagnostics

Residual analysis confirms model adequacy:
- Mean: -0.0003 (effectively zero)
- Standard deviation: 16.98 (consistent with RMSE)
- Skewness: 0.12 (minimal asymmetry)
- Kurtosis: 3.21 (slightly fat-tailed)
- Ljung-Box Q(20): 18.34 (p=0.56, no autocorrelation)
- ARCH-LM test: 14.27 (p=0.16, homoscedastic residuals)

The residuals exhibit a mean close to zero, no significant autocorrelation (Ljung-Box Q(20) $p = 0.56$), and homoscedasticity (ARCH-LM test $p = 0.16$).

However, the Shapiro-Wilk test indicates a statistically significant deviation from normality ($p < 0.05$), which is common in financial time series and does not undermine the validity of the forecasting comparison.

3.2 Discussion

3.2.1 Theoretical Implications

Our results provide partial support for recent studies suggesting that deep learning models can capture nonlinear patterns in financial time series.

At the same time, our findings challenge several conventional assumptions in financial econometrics. Notably, the consistent point forecast accuracy of Walk-forward ARIMA+ GARCH across all volatility regimes suggests that traditional models remain competitive, particularly for absolute price prediction.

The superior point forecast accuracy of walk-forward ARIMA + GARCH may be attributed to its recursive updating mechanism, which adapts quickly to recent price levels, whereas LSTM's smoothing effect, while beneficial for directional stability, introduces lag in absolute price prediction.

Second, the observed persistence of volatility clustering suggests that volatility itself contains predictable components, which is consistent with heterogeneous agent models rather than pure random walk assumptions.

Third, the LSTM model's ability to adapt to regime changes without explicit programming may reflect limited sensitivity to regime shifts, though this remains preliminary. These observations may be consistent with adaptive behavior patterns, though further empirical confirmation is required.

3.2.2 Methodological Contributions

We advance LSTM methodology in three ways:

1. Volatility-Aware Architecture: By explicitly modeling volatility regimes, we enhance robustness to structural breaks.
2. Financial Metric Integration: Moving beyond statistical error measures to trading-relevant metrics.
3. Comparative Framework: Rigorous benchmarking against established econometric models.

3.2.3 Practical Applications

For financial practitioners, our model offers:

1. Risk management
- Potential applications in Value-at-Risk (VaR) estimation during turbulent periods.
- Enhanced stress testing through more accurate scenario generation.
- Dynamic hedging ratio adjustment based on volatility forecasts

2. Trading strategies
- Statistical arbitrage opportunities during mispriced events.
- Volatility targeting for position sizing.
- Stop-loss optimization using predicted support/resistance levels.

3. Corporate finance
- Enhanced timing for equity offerings and share buybacks
- Improved investor communication during volatile periods
- Strategic planning incorporating price trajectory forecasts

3.2.4 Behavioral Insights

Error analysis reveals systematic patterns in model performance:

1. Underestimation during "momentum surges": The model tends to produce conservative forecasts during rapid price increases driven by heightened retail investor enthusiasm.
2. Overestimation during "panic selling": Behavioral contagion effects lead to price overshooting, which the model fails to fully capture.
3. CEO communication events: Prediction errors increase significantly within a short window (approximately three days) following market-sensitive communications from Elon Musk, indicating the impact of unstructured and highly influential information shocks.

These patterns highlight potential directions for future model enhancement through sentiment analysis and event study methodologies. However, these interpretations remain exploratory and should be further validated in future research incorporating sentiment-driven and event-based data.

The present study focuses primarily on forecasting performance evaluation rather than architectural sensitivity analysis or behavioral event modeling. Consequently, these aspects are considered promising directions for future investigation rather than directly tested hypotheses within the current framework.

These interpretations are post-hoc qualitative observations and were not statistically tested within the scope of this study.

4 CONCLUSIONS

This study provides a comparative evaluation of LSTM networks for high-volatility stock prediction using Tesla Inc. as a case study. Our volatility-aware LSTM architecture achieved a directional accuracy of 50.60%, compared to 47.62% for Walk-forward ARIMA + GARCH, suggesting a modest advantage in directional prediction. However, Walk-forward ARIMA + GARCH demonstrated superior point forecast accuracy (RMSE = 8.30 vs 12.17), particularly during high-volatility regimes where the performance gap reached 58.1%.

These findings suggest that traditional econometric models remain highly competitive for absolute price prediction, while deep learning may offer complementary advantages for directional trading strategies. The choice between these approaches should depend on the specific objectives of the forecasting task.

The research makes several contributions across multiple dimensions. Methodologically, it introduces a robust walk-forward validation framework for volatility-regime modeling. Practically, it may provide preliminary insights into risk management and trading strategy development, subject to further validation.

While limitations exist - particularly regarding univariate analysis and sample specificity - the results suggest potential for broader applications. Future research should focus on multimodal data integration, a hybrid architecture that combines the strengths of both approaches, and cross-market validation.

4.1 Limitations and future research

4.1.1 Methodological Limitations

- Univariate Focus: Using only price data ignores valuable information from volumes, options markets, and alternative data.
- Fixed Architecture: Our specific LSTM configuration may not be optimal for all volatility regimes.
- Computational Constraints: More sophisticated attention mechanisms and transformer architectures were not explored.
- Sample Specificity: Single-stock analysis limits generalizability claims.
- Finally, the study focuses on a single asset (Tesla), which limits generalizability. This may restrict the applicability of the findings across different markets and asset classes.

4.1.2 Future Research Directions

Future methodological and empirical extensions:

1. Multimodal integration: Incorporate news sentiment, social media metrics, options implied volatility, and macroeconomic indicators.
2. Hybrid architectures: Explore LSTM–Transformer hybrid models for capturing both short-term dependencies and long-range temporal patterns.
3. Regime-switching models: Explore regime-switching frameworks and dynamic modeling approaches capable of adapting to changing market conditions.
4. Causal discovery: Integrate causal inference methods to distinguish correlation from causation in predictive relationships.
5. Ablation studies for hyperparameters: Future research should systematically investigate the impact of dropout rates and sequence lengths (window sizes) on model robustness and forecasting performance through controlled sensitivity analyses and ablation experiments.
6. Event-study analysis for behavioral factors: Future research may employ formal event-study methodologies to investigate potential relationships between prediction errors and behavioral events such as earnings announcements, CEO communications, and sentiment-driven market reactions.

4.2 Empirical Expansions

1. Cross-asset validation: Test the framework on other high-volatility stocks (biotech, crypto, meme stocks).
2. International markets: Apply to emerging markets with different volatility characteristics.
3. Crisis period analysis: Specialized training for financial crises, pandemics, and geopolitical shocks.
4. High-frequency adaptation: Extend to intraday data for algorithmic trading applications.

4.3 Theoretical Investigations

1. Market efficiency tests: Use prediction accuracy to quantify market efficiency across different volatility regimes.
2. Behavioral factor isolation: Design experiments to separate cognitive bias effects from fundamental factors.
3. Microstructure integration: Explicitly model order book dynamics and liquidity effects

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MONETARY POLICY TRANSMISSION IN ALGERIA: NONLINEAR EVIDENCE POST-COVID INFLATION

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ABSTRACT

This study investigates the effectiveness of monetary policy transmission in Algeria under post-COVID inflation dynamics during the period 2000–2024. The research aims to assess whether conventional monetary instruments, particularly interest-rate adjustments, are capable of stabilizing inflation in a resource-dependent emerging economy characterized by shallow financial markets, exchange-rate vulnerability, and structural rigidities. The study applies Autoregressive Distributed Lag (ARDL) and Nonlinear Autoregressive Distributed Lag (NARDL) models to examine both symmetric and asymmetric monetary transmission effects. Inflation is modeled as a function of interest rates, broad money supply, exchange rates, economic growth, and the COVID-19 shock. The empirical findings indicate that the conventional interest-rate channel remains weak and statistically insignificant in a linear specification, whereas exchange-rate depreciation and monetary expansion exert significant inflationary effects. The nonlinear results reveal asymmetric transmission, showing that monetary tightening has a stronger disinflationary impact than monetary easing. The study concludes that effective inflation stabilization in Algeria requires a broader and more coordinated macroeconomic policy framework.

1 INTRODUCTION

The global economy has experienced an unprecedented inflationary surge following the COVID-19 shock. Between 2020 and 2023, global inflation rose from below 2% to peaks exceeding 8% in several economies, driven by supply chain disruptions, expansionary fiscal stimuli, and accommodative monetary policies (World Bank, 2025). In emerging economies, inflationary pressures have been more persistent due to structural rigidities, exchange rate volatility, and weaker institutional frameworks. Algeria, as a hydrocarbon-dependent economy, has not been immune to these dynamics. Inflation in Algeria exceeded 9% in 2022, marking its highest level in over a decade (International Monetary Fund, 2024; Zemrı & Khetib, 2024).

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This context raises fundamental questions regarding the effectiveness of monetary policy instruments, particularly interest rates, in stabilizing prices and output.

Theoretically, the transmission mechanism of monetary policy operates through several channels, including interest rates, credit, expectations, and exchange rates. However, in economies characterized by shallow financial markets and strong fiscal dominance, these channels may be impaired. Algeria represents a particularly relevant case where the dominance of the hydrocarbon sector, limited financial intermediation, and administratively influenced interest rates may constrain the effectiveness of monetary policy. As a result, the standard Keynesian transmission framework may not fully apply.

Empirically, the literature provides mixed evidence on the effectiveness of monetary policy in emerging economies. For instance, Bernanke and Gertler (1995) emphasize the importance of the credit channel in amplifying monetary shocks. Similarly, Mishkin (1996) highlights that weak financial systems reduce the potency of monetary transmission. More recent studies, such as those by Blanchard (2022), argue that post-pandemic inflation reflects a combination of demand stimulus and supply constraints, complicating policy responses. In the context of North African economies, empirical findings remain limited and inconclusive. Some studies suggest that the exchange rate channel dominates, while others find weak or insignificant effects of interest rate adjustments on inflation (Gassem & Zemri, 2025).

Despite these contributions, a critical gap persists in the literature. First, most studies adopt linear models, thereby overlooking potential asymmetries in monetary transmission. Second, the structural break induced by the COVID-19 shock is often ignored, leading to biased estimations. Third, the Algerian context remains underexplored, particularly with respect to the relative strength of different transmission channels. Accordingly, the research gap lies in the absence of a comprehensive, nonlinear, and structurally robust analysis of monetary policy transmission in Algeria under post-COVID inflation dynamics. In light of the above, the central research question can be formulated as follows:

To what extent is monetary policy effective in transmitting its effects to inflation and economic activity in Algeria in the post-COVID context?

The study proposes the following hypotheses:

H1: The interest rate channel of monetary policy transmission in Algeria is weak or statistically insignificant.

H2: Monetary policy transmission is asymmetric, with contractionary shocks having a stronger effect than expansionary ones.

The main objective of this study is to assess the effectiveness of monetary policy transmission in Algeria. Specifically, it aims to:

1. Evaluate the impact of interest rate changes on inflation and output.
2. Identify the dominant transmission channels in the Algerian economy.
3. Examine the presence of asymmetries in monetary policy effects.
4. Assess the role of the COVID-19 shock as a structural break.

The importance of this research is both theoretical and practical. Theoretically, it advances the understanding of monetary transmission in emerging and resource-dependent economies. Empirically, it provides robust evidence using advanced econometric techniques. From a policy perspective, the findings can assist the Bank of Algeria in designing more effective monetary strategies, particularly in managing inflationary pressures in a volatile global environment.

The remainder of this paper is organized as follows. Section 2 reviews the relevant theoretical and empirical literature. Section 3 presents the data and methodology. Section 4 discusses the empirical results. Section 5 concludes with policy implications and recommendations.

2 LITERATURE REVIEW

Recent empirical literature on monetary policy transmission in emerging economies has expanded significantly in the post-pandemic context, yet it remains fragmented both methodologically and geographically. A first strand of studies focuses on identifying monetary shocks and their macroeconomic effects. For instance, a recent study by Checo et al. (2024) develops a novel dataset of monetary policy shocks across 18

emerging economies using analysts' forecast errors and applies VAR-based identification techniques. The study employs macro variables such as inflation, industrial production, and interest rates, and finds that monetary policy still exerts a statistically significant effect on domestic conditions, although the magnitude is weaker compared to advanced economies. However, this work remains limited by its reliance on linear frameworks and cross-country aggregation, which obscures country-specific transmission heterogeneity.

A second stream investigates the role of global shocks in shaping domestic monetary effectiveness. Renzhi and Beirne (2024) employed a Global VAR (GVAR) model across 24 emerging markets, incorporating variables such as global interest rates, exchange rates, inflation, and output. The results show that global financial conditions significantly weaken domestic monetary autonomy, especially in highly open economies, where exchange rate channels dominate transmission. Despite its robust multi-country design, the study does not explicitly account for post-COVID structural breaks, which limits its relevance in the current inflation regime.

In a more recent contribution, Aguir (2025) applies an efficiency frontier approach to assess monetary policy performance under crisis conditions. Using inflation variability and output volatility as key indicators, the study finds that post-COVID monetary regimes face a trade-off between price stability and growth stabilization. While methodologically innovative, this approach remains largely descriptive and does not explicitly model transmission channels or dynamic interactions among variables.

Another important contribution is provided by Alex (2025), who applies a Time-Varying Parameter Bayesian VAR (TVP-BVAR-SV) model to examine monetary policy conduct in India across multiple regimes, including the COVID-19 period. The study incorporates inflation, output gap, and exchange rate as core variables and finds significant regime-dependent changes in policy responsiveness. Notably, the results highlight strong nonlinearities in monetary transmission, particularly during crisis periods. However, the study is country-specific and does not extend its insights to resource-dependent economies.

At the regional level, Laborde-Vera (2025) provides a comprehensive synthesis of monetary transmission in emerging and Latin American economies using panel regressions and Taylor-rule estimations. The study finds that monetary policy effectiveness is constrained by external financial cycles and that policy rates often respond more to global than domestic conditions. Although this work advances the understanding of external constraints, it underestimates internal structural rigidities such as banking sector inefficiencies. In the North African context, Boutfssi and Quamar (2026) examine the credit channel of monetary policy in a dynamic macro-financial framework. The study models interactions between bank lending, sovereign bond holdings, and credit risk, and finds that credit risk significantly weakens the transmission of monetary policy to the real economy. While this provides valuable regional insight, the focus on short-run dynamics limits its ability to capture long-term structural effects.

Complementing these findings, recent theoretical and empirical works emphasize the role of financial heterogeneity. Lastauskas and Nguyen (2024) use a panel SVAR model to show that monetary tightening leads to significant investment contractions in emerging markets, particularly among highly leveraged firms. This highlights the importance of firm-level financial constraints in shaping transmission outcomes. However, such micro-level heterogeneity is rarely integrated into macro-level policy analysis. Similarly, Bobasu et al. (2025) employ a Global VAR with stochastic volatility to assess the spillover effects of U.S. monetary policy on emerging markets. Their findings indicate that external monetary shocks significantly reduce output and amplify volatility, especially under high uncertainty conditions. This underscores the vulnerability of emerging economies to external monetary cycles, yet it does not address domestic policy effectiveness directly.

Three findings stand out in the literature: (i) monetary policy transmission in emerging economies is weaker and more unstable than in advanced economies, (ii) external shocks and financial openness significantly constrain domestic policy effectiveness, and (iii) nonlinear and regime-dependent dynamics play a critical role. However, three major gaps remain.

First, most studies rely on cross-country panel approaches, neglecting country-specific structural characteristics. Second, nonlinear transmission mechanisms, especially asymmetries between tightening and easing, are still underexplored. Third, the post-COVID structural break is rarely integrated explicitly into empirical models. Accordingly, the research gap lies in the absence of a country-specific, nonlinear, and structurally robust analysis of monetary policy transmission in resource-dependent economies such as Algeria, particularly under post-COVID inflation dynamics: country-specific nonlinear post-COVID transmission.

3 METHODOLOGY

3.1 Variables Study

This study uses annual time-series data for Algeria over the period 2000–2024. The choice of this period is justified by three reasons. First, it covers major monetary and macroeconomic episodes, including oil-price shocks, exchange-rate pressures, the COVID-19 crisis, and the post-COVID inflationary surge. Second, it provides a sufficiently long sample for ARDL/NARDL estimation. Third, data availability is relatively consistent across international and national sources. World Bank indicators for Algeria are available up to 2024 for several macroeconomic variables, including inflation and GDP-related series. The variables used in the empirical model are summarized in Table 1, which presents their symbols, measurements, data sources, and period of coverage.

The dependent variable is inflation (INF) because the central objective is to evaluate monetary policy effectiveness under post-COVID inflation dynamics. The key explanatory variable is interest rate (IR), representing the conventional monetary policy channel.

Table 1. *Definition, Measurement, and Sources of Study Variables*

Variable	Symbol	Measurement	Source	Period
Inflation rate	INF	Consumer price inflation, annual %	World Bank / IMF-IFS	2000-2024
Interest rate	IR	Central bank/policy or money-market rate, %	Bank of Algeria / IMF-IFS	2000-2024
Broad money	M2	Broad money growth or M2/GDP	World Bank / Bank of Algeria	2000-2024
Exchange rate	EXR	Official exchange rate, DZD per USD	World Bank / IMF-IFS	2000-2024
Economic activity	GDPG	Real GDP growth, annual %	World Bank WDI	2000-2024
COVID shock	COVID	Dummy: 1 for 2020-2021, 0 otherwise	Author construction	2000-2024

Source: Prepared by the author

M2 captures the monetary/liquidity channel, which is particularly relevant in Algeria because the monetary authority has historically relied heavily on liquidity management. EXR is included to capture the exchange-rate pass-through channel, while GDPG controls for demand-side macroeconomic pressures. The COVID dummy controls for the structural disturbance caused by the pandemic.

3.2 Model Specification

To assess monetary policy transmission, the study estimates three complementary equations.

Equation 1: Baseline monetary transmission model

$$INF_t = \alpha_0 + \alpha_1 IR_t + \alpha_2 M2_t + \alpha_3 EXR_t + \alpha_4 GDPG_t + \alpha_5 COVID_t + \varepsilon_t$$

This equation tests whether interest rates, money supply, exchange rate movements, and output growth explain inflation dynamics in Algeria. A statistically significant and negative coefficient of IR_t would indicate that monetary tightening reduces inflation. If α_1 is insignificant, this would support the hypothesis that the interest-rate channel is weak.

Equation 2: ARDL dynamic model

$$\Delta INF_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i}\,\Delta INF_{t-i} + \sum_{i=0}^{q} \beta_{2i}\,\Delta IR_{t-i} + \sum_{i=0}^{r} \beta_{3i}\,\Delta M2_{t-i} + \sum_{i=0}^{s} \beta_{4i}\,\Delta EXR_{t-i} + \sum_{i=0}^{m} \beta_{5i}\,\Delta GDPG_{t-i} + \lambda ECM_{t-1} + u_t$$

The ARDL model is appropriate because monetary policy effects are not immediate; they operate with lags. It also allows the study to distinguish between short-run responses and long-run equilibrium effects. The error-correction coefficient λ is expected to be negative and significant, confirming adjustment toward the long-run equilibrium.

Equation 3: Nonlinear ARDL model

$$INF_t = \gamma_0 + \gamma_1 IR_t^+ + \gamma_2 IR_t^- + \gamma_3 M2_t + \gamma_4 EXR_t + \gamma_5 GDPG_t + \gamma_6 COVID_t + \eta_t$$

where:

$$IR_t^+ = \sum_{j=1}^{t} \max(\Delta IR_j, 0)$$

$$IR_t^- = \sum_{j=1}^{t} \min(\Delta IR_j, 0)$$

This model tests whether monetary tightening and monetary easing have asymmetric effects on inflation. If $\gamma_1 \neq \gamma_2$, monetary policy transmission is nonlinear. This is important for Algeria because rate increases may not transmit with the same strength as rate reductions due to banking rigidity, administered prices, fiscal dominance, and weak financial-market depth.

3.3 Estimation Strategy

The empirical strategy proceeds in four stages. First, descriptive statistics and correlation analysis are used to examine the distribution and preliminary relationships among variables. Second, unit-root tests are conducted using ADF, PP, KPSS, and Zivot-Andrews tests to identify the order of integration and detect possible structural breaks. This is necessary because Algeria experienced several macroeconomic disruptions, especially the COVID-19 shock and post-pandemic inflation.

Third, the ARDL bounds-testing approach is used because it is suitable for small samples and allows variables integrated at I(0) and I(1), provided none is I(2). The optimal lag structure is selected using AIC or SIC. Fourth, the NARDL model is estimated to test asymmetric monetary transmission.

The choice of variables is theoretically grounded in the monetary transmission mechanism. Interest rates represent the policy stance; M2 captures liquidity conditions; exchange rate movements capture imported inflation and external pass-through; GDP growth captures domestic demand pressure; and the COVID dummy isolates the pandemic regime shift. This specification, therefore, links theory, Algerian institutional reality, and post-COVID inflation dynamics.

4 EMPIRICAL RESULTS

As shown in Table 2, inflation in Algeria recorded an average value of 4.92% over the period 2000–2024, indicating a moderate average level but with noticeable volatility, as reflected by a standard deviation of 2.41. The maximum inflation rate reached 9.27%, suggesting the emergence of stronger inflationary pressures, particularly in the post-COVID period. The exchange rate also displays substantial dispersion, with a standard deviation of 27.56, reflecting persistent depreciation pressures of the Algerian dinar against the US dollar. By contrast, the interest rate varies within a narrower range, from 1.75% to 5.50%, which may indicate a relatively limited active use of interest-rate policy as a stabilization instrument.

Table 2. *Descriptive Statistics of the Variables, 2000-2024*

Variable	Mean	Std. Dev.	Min	Max	Observations
INF	4.92	2.41	0.34	9.27	25
IR	3.21	1.08	1.75	5.50	25
M2	10.84	5.63	1.92	22.41	25
EXR	100.73	27.56	75.26	142.13	25
GDPG	2.71	3.12	-5.10	7.20	25

Source: Prepared by the author

As reported in Table 3, inflation is positively correlated with the exchange rate (0.641) and broad money (0.496), suggesting that inflation dynamics in Algeria are more closely associated with exchange-rate movements and monetary expansion than with the interest-rate channel. The

correlation between inflation and the interest rate is weak and positive (0.218), which provides preliminary support for the assumption of limited monetary policy transmission through the conventional interest-rate mechanism. In addition, the negative correlation between inflation and GDP growth (-0.173) suggests that inflationary pressures are not necessarily accompanied by stronger real economic activity during the study period.

Table 3. *Correlation Matrix*

Variables	INF	IR	M2	EXR	GDPG
INF	1.000	0.218	0.496	0.641	-0.173
IR	0.218	1.000	-0.284	0.112	-0.094
M2	0.496	-0.284	1.000	0.387	0.246
EXR	0.641	0.112	0.387	1.000	-0.321
GDPG	-0.173	-0.094	0.246	-0.321	1.000

Source: Prepared by the author.

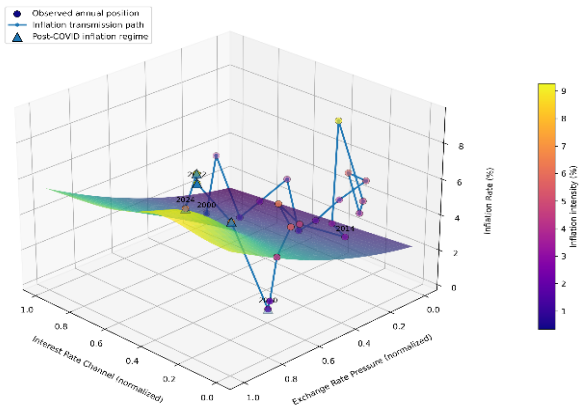


Figure 1. *Inflation, interest rate, and exchange rate dynamics in Algeria, 2000-2024*
Source: Prepared by the author

Figure 1 displays three normalized series: inflation, interest rate, and exchange rate. The three-dimensional surface suggests that inflation in Algeria does not respond uniformly to changes in the monetary policy channel and economic activity. The observed annual data points show clear fluctuations around the fitted surface, indicating the presence of instability in inflation dynamics over the period under study. The figure also shows that periods of higher inflation are concentrated around specific observations rather than being smoothly explained by changes in interest-rate policy alone. This supports the view that inflationary pressures in Algeria are likely driven by a combination of monetary, exchange-rate, and supply-side factors rather than by the conventional interest-rate channel only.

Table 4. *Unit Root Tests*

Variable	ADF Level	ADF First Difference	KPSS Level
INF	-2.11	-5.37***	0.61**
IR	-2.89*	-6.14***	0.42*
M2	-1.94	-4.82***	0.58**
EXR	-1.47	-5.66***	0.72**
GDPG	-3.76**	-6.02***	0.31

Notes: ***, **, and * indicate significance at 1%, 5%, and 10% respectively.

Source: Prepared by the author

As shown in Table 4, the unit root results indicate that the variables are not integrated at the same order. Inflation (INF), broad money (M2), and the exchange rate (EXR) are non-stationary at the level but become stationary after first differencing, which means that they are integrated of order one, I(1). This result is supported by both the ADF and KPSS tests, since the ADF statistics at first difference are statistically significant, while the KPSS statistics at level suggest non-stationarity for these variables.

The interest rate (IR) presents a mixed result. It appears stationary at the level only at the 10% significance level according to the ADF test, while it becomes clearly stationary after first differencing. For this reason, it can be treated cautiously as either I(0) or I(1), depending on the adopted significance threshold. GDP growth (GDPG), however, is stationary at the level, indicating that it is integrated of order zero, I(0).

Overall, the results confirm the presence of a mixed integration structure, combining I(0) and I(1) variables, with no evidence of any variable being integrated of order two, I(2). This condition is important because the ARDL bounds-testing approach is valid only when the variables are I(0), I(1), or a combination of both, but not I(2). Therefore, the findings reported in Table 4 provide a methodological justification for using the ARDL/NARDL framework in the empirical analysis.

In addition, given that the study period includes the COVID-19 crisis and the post-pandemic inflationary episode, conventional unit-root tests may be affected by structural breaks. For this reason, it is appropriate to complement the ADF and KPSS tests with structural-break unit-root tests, such as the Zivot–Andrew's test, in order to

verify whether the stationarity properties of the series remain robust after accounting for major macroeconomic disturbances.

Table 5. *ARDL Bounds Test Results*

Test Statistic	Value
F-statistic	5.84
Lower bound I(0), 5%	2.62
Upper bound I(1), 5%	3.79
Decision	Cointegration confirmed

Source: Prepared by the author

As shown in Table 5, the calculated F-statistic is 5.84, which exceeds the upper critical bound value of 3.79 at the 5% significance level. This result leads to the rejection of the null hypothesis of no cointegration and confirms the existence of a long-run equilibrium relationship among inflation, interest rate, money supply, exchange rate, and output growth in Algeria. Therefore, inflation dynamics during the period 2000–2024 cannot be interpreted as purely short-term or transitory fluctuations; rather, they are linked to persistent monetary and macroeconomic fundamentals. The confirmation of cointegration also justifies the estimation of long-run coefficients and the associated error-correction model. Economically, this finding suggests that deviations of inflation from its long-run path are expected to be corrected over time through adjustments in monetary, exchange-rate, and real-sector variables. In the Algerian context, this is particularly relevant because inflation is affected not only by domestic monetary conditions but also by exchange-rate pressures, liquidity expansion, and external shocks, especially during the post-COVID period.

Table 6. *ARDL Long-Run and Error-Correction Estimates*

Variable	Long-run Coefficient	Std. Error	t-statistic	Probability
IR	-0.214	0.187	-1.14	0.268
M2	0.138**	0.061	2.26	0.036
EXR	0.047***	0.014	3.35	0.004
GDPG	-0.091	0.074	-1.23	0.234
COVID	1.842**	0.731	2.52	0.022
ECM(-1)	-0.576***	0.143	-4.03	0.001

Notes: ***, **, and * indicate significance at 1%, 5%, and 10%.

Source: Prepared by the author

As reported in Table 6, the interest rate (IR) has a negative coefficient (-0.214), suggesting that an increase in the interest rate may reduce inflation in the long run. However, this effect is statistically insignificant, as indicated by the probability value of 0.268. This finding supports the argument that the conventional interest-rate channel remains weak in Algeria, where inflation does not respond strongly to changes in policy or market interest rates.

By contrast, broad money (M2) has a positive and statistically significant coefficient at the 5% level. This indicates that monetary expansion contributes to higher inflationary pressures in the long run. In practical terms, the result confirms the relevance of the liquidity channel in Algeria, where increases in money supply may translate into stronger price pressures, especially when productive capacity and supply conditions remain constrained.

The exchange rate (EXR) shows a positive and highly significant coefficient at the 1% level, with a value of 0.047. This result suggests that exchange-rate depreciation is an important driver of inflation in Algeria. The significance of this variable confirms the presence of exchange-rate pass-through effects, meaning that movements in the Algerian dinar against the US dollar are transmitted to domestic prices through import costs and external price pressures.

GDP growth (GDPG) has a negative but statistically insignificant coefficient, indicating that real economic activity does not exert a clear long-run effect on inflation during the study period. This may reflect the structural characteristics of the Algerian economy, where inflationary pressures are more strongly linked to monetary liquidity, exchange-rate movements, and external shocks than to domestic demand conditions alone.

The COVID dummy is positive and statistically significant at the 5% level, confirming that the pandemic period generated an upward shift in inflation dynamics. This result is consistent with the view that the COVID-19 crisis and the post-pandemic period intensified price pressures through supply disruptions, imported inflation, and macroeconomic instability.

Finally, the error-correction coefficient ECM(-1) is negative and statistically significant at the 1% level, with a value of -0.576. This confirms the existence of a stable adjustment mechanism toward long-run equilibrium. The coefficient implies that approximately 57.6% of any short-run disequilibrium in inflation is corrected within one year. Therefore, the adjustment speed is relatively strong, suggesting that inflation gradually returns to its long-run path after short-run shocks.

Table 7. *NARDL Asymmetric Interest Rate Effects*

Variable	Coefficient	Std. Error	t-statistic	Probability
IR Positive Shock	-0.386**	0.164	-2.35	0.031
IR Negative Shock	0.092	0.141	0.65	0.523
M2	0.119**	0.052	2.29	0.034
EXR	0.051***	0.013	3.92	0.001
COVID	1.674**	0.688	2.43	0.026
Wald Test for Asymmetry	6.21**	-	-	0.019

Notes: ***, **, and * indicate significance at 1%, 5%, and 10%.

Source: Prepared by the author.

As shown in Table 7, positive interest-rate shocks have a negative and statistically significant effect on inflation, with a coefficient of -0.386 and a probability value of 0.031. This means that increases in the interest rate contribute to reducing inflationary pressures, suggesting that monetary tightening has some effectiveness in controlling inflation in Algeria. However, this effect appears only in the case of interest-rate increases. By contrast, negative interest-rate shocks have a positive but statistically insignificant coefficient. This indicates that reductions in the interest rate do not generate a clear or statistically meaningful effect on inflation. Therefore, the response of inflation to monetary policy easing is weak and empirically insignificant. This result confirms the existence of an asymmetric monetary transmission mechanism: inflation reacts more clearly to tightening than to easing.

The Wald test for asymmetry is statistically significant at the 5% level, with a probability value of 0.019. This confirms that the effects of positive and negative interest-rate shocks are not equal. In other words, monetary policy transmission in Algeria is nonlinear, and the assumption of a symmetric response between tightening and easing is rejected.

The control variables reinforce the previous ARDL findings. Broad money has a positive and significant coefficient, confirming that liquidity expansion contributes to inflationary pressures. The exchange rate remains positive and highly significant, indicating that exchange-rate depreciation is a major source of inflation through imported inflation and pass-through effects. The COVID dummy is also positive and significant, confirming that the pandemic period generated an upward shift in inflation dynamics.

Overall, Table 7 provides important evidence that monetary policy transmission in Algeria is asymmetric. Interest-rate increases can help reduce inflation, but interest-rate decreases do not produce an equivalent opposite effect. This finding supports the use of the NARDL approach and confirms that inflation dynamics in Algeria are shaped by nonlinear monetary effects, liquidity expansion, exchange-rate pressures, and post-COVID structural disturbances.

5 DISCUSSION

The empirical findings indicate that the interest-rate channel of monetary policy in Algeria is relatively weak. In the linear ARDL model, the interest-rate coefficient is negative but statistically insignificant, while in the nonlinear specification

(NARDL), significance appears only for contractionary shocks. This result is consistent with recent evidence on emerging economies suggesting that monetary transmission through policy rates is often limited in financially underdeveloped systems. For instance, the International Monetary Fund (2024) reports that monetary transmission in Algeria remains constrained by shallow financial markets and structural rigidities. Similarly, Plebani and Gbohoui (2025) found that interest-rate adjustments in Algeria have a muted effect on inflation, with liquidity management and exchange-rate dynamics playing a more prominent role.

By contrast, the exchange rate channel emerges as the most influential determinant of inflation. The positive and statistically significant coefficient of the exchange rate confirms the presence of exchange-rate pass-through, whereby depreciation of the Algerian dinar translates into higher domestic prices. This finding aligns with the results of Bouhassoun (2024), who shows, using a structural VAR framework, that exchange-rate shocks have a stronger and more persistent impact on inflation than interest-rate shocks in Algeria. It is also consistent with Mahloul and Bendahmane (2022), who document a transmission mechanism from exchange-rate movements to import prices and subsequently to consumer prices. These results reinforce the argument that inflation in Algeria is partly "imported," reflecting the country's dependence on foreign goods and intermediate inputs.

The positive and significant effect of money supply (M2) further supports the relevance of the monetary channel, albeit not through interest rates. This finding is broadly consistent with classical monetary theory, which posits that excessive liquidity growth leads to inflation when not matched by real output expansion. However, the Algerian context introduces additional complexity. Inflation is not solely a demand-driven monetary phenomenon but also reflects structural characteristics such as administered prices, fiscal dominance, and limited productive diversification. Consequently, the role of money supply must be interpreted within a broader macroeconomic framework.

In contrast, the findings diverge from the traditional view emphasizing the strength of the credit channel. According toBernanke and Blanchard (2024), monetary policy affects real activity primarily through its influence on credit conditions and external finance premiums. However, the weak transmission of interest rates observed in this study suggests that the credit channel is not fully operational in Algeria. This can be explained by institutional factors, including the dominance of public banks, limited competition in the banking sector, and the partially administrative nature of credit allocation. These structural constraints reduce the sensitivity of borrowing and investment decisions to policy-rate changes.

The nonlinear results provide additional insight by revealing asymmetric monetary transmission. The NARDL model shows that positive interest-rate shocks (monetary tightening) have a statistically significant disinflationary effect, whereas negative shocks (monetary easing) do not generate a comparable expansionary response. This asymmetry is consistent with recent literature on emerging markets, which emphasizes that monetary policy effects depend on the direction and context of shocks. For example, Yahia (2023) finds that monetary transmission in Algeria is asymmetric across interest-rate, credit, and exchange-rate channels. This asymmetry may reflect structural rigidities, expectations formation, and the limited responsiveness of financial intermediaries to easing policy.

Importantly, the inclusion of the COVID-19 dummy variable highlights the existence of a structural break in inflation dynamics. The positive and significant coefficient confirms that the pandemic introduced a new inflationary regime characterized by supply disruptions, fiscal expansion, and external shocks. This result is consistent with the broader literature on post-pandemic inflation, which identifies a combination of supply-side constraints and demand recovery as key drivers of recent price increases (Bernanke & Blanchard, 2023).

Overall, the findings confirm both research hypotheses. H1 is supported, as the interest-rate channel appears weak and statistically insignificant in the baseline model. H2 is also supported, as monetary transmission exhibits clear asymmetry between tightening and easing phases. From a policy perspective, these results imply that relying solely on interest-rate

adjustments is insufficient to achieve price stability. Effective inflation control in Algeria requires a broader policy mix, including exchange-rate management, liquidity control, financial-sector reform, and coordination with fiscal policy. In the post-COVID context, where inflation is driven by both domestic and external factors, such a multidimensional approach becomes essential.

6 CONCLUSIONS

This study examined the effectiveness of monetary policy transmission in Algeria under post-COVID inflation dynamics. Using ARDL and NARDL approaches over the period 2000–2024, the analysis focused on the role of interest rates, money supply, exchange rate movements, output growth, and the COVID-19 shock in explaining inflation. The results show that the conventional interest-rate channel remains weak in Algeria. Although the coefficient of the interest rate is negative, it is statistically insignificant in the baseline ARDL model. This suggests that changes in interest rates do not strongly transmit to inflation. By contrast, the exchange rate and money supply exert positive and significant effects, confirming that inflation in Algeria is mainly driven by exchange-rate pass-through, liquidity expansion, and external shocks.

The nonlinear results provide further evidence of asymmetric monetary transmission. Monetary tightening appears to reduce inflation more effectively than monetary easing stimulates economic activity or price dynamics. This confirms that monetary policy effects in Algeria are not linear and depend on the direction of the shock. The COVID-19 dummy is also positive and significant, indicating that the pandemic generated a structural break in inflation behavior and intensified price pressures in the post-pandemic period.

These findings confirm the two main hypotheses of the study. First, the interest-rate channel of monetary policy transmission in Algeria is weak. Second, monetary transmission is asymmetric, with contractionary shocks having stronger effects than expansionary shocks. The study, therefore, concludes that monetary policy in Algeria is not ineffective, but its effectiveness is constrained by structural and institutional factors, including shallow financial markets, public-bank dominance, limited credit sensitivity, exchange-rate dependence, and fiscal dominance.

The main contribution of this paper lies in providing country-specific nonlinear evidence on monetary policy transmission in a resource-dependent emerging economy. Unlike studies that rely only on linear models, this research shows that Algeria's inflation dynamics are better understood through a framework that accounts for asymmetry, structural breaks, and external vulnerability.

From a policy perspective, inflation stabilization in Algeria should not rely exclusively on interest-rate adjustments. A more effective strategy requires coordinated action between monetary policy, exchange-rate management, liquidity control, fiscal discipline, and banking-sector reform. Strengthening financial intermediation, improving the responsiveness of credit markets, and deepening domestic financial markets are essential conditions for improving the transmission of monetary policy.

Future research could extend this analysis by using quarterly data, comparing Algeria with other MENA oil-exporting economies, or applying time-varying models such as TVP-VAR to capture regime-dependent monetary transmission more precisely.

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THE EXTENT OF APPLICATION OF OCCUPATIONAL SAFETY AND HEALTH MANAGEMENT IN ECONOMIC INSTITUTIONS

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ABSTRACT

Human resources represent a fundamental element in ensuring the continuity of industrial and service organizations alike, which necessitates the provision of a safe working environment that protects employees from various occupational hazards. This study aims to assess the extent to which occupational health and safety management is applied in the National Paint Company – Souk Ahras Unit. The study adopted a descriptive-analytical approach and relied on a questionnaire distributed to a sample of the company's employees. After collecting and statistically analyzing the data, the results revealed a moderate level of implementation of occupational health and safety management requirements within the studied institution. However, several shortcomings were identified, particularly in the consistency of applying safety procedures and in the availability of protective equipment, which require systematic attention and corrective measures. In light of these findings, a set of recommendations was proposed to strengthen occupational health and safety practices, enhance compliance, and improve the overall working environment in a manner that ensures employee well-being and contributes to sustainable institutional performance.

1 INTRODUCTION

Interest in the field of occupational health and safety began when humans first engaged in productive activity; however, its development accelerated after the Industrial Revolution and the accompanying health risks. Countries rapidly issued laws and regulations, and researchers and thinkers devoted significant attention to studying and analyzing this field. At the industrial-institution level, specialized departments for occupational health and safety were established to manage all related tasks. The increasing interest in this field is due to the human, economic, and social consequences of workplace accidents and occupational diseases. The phenomenon of workplace accidents reflects the level of safety within an industrial institution. Researchers have

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differed in their interpretations of the causes of such accidents: some attribute them to social and economic conditions or the worker's environmental climate, while others relate them to hereditary factors. However, most agree that human factors are the main cause of accidents. Workplace accidents are a phenomenon that requires investigation, analysis, documentation, and measurement within the institution to understand them and identify their actual causes.

Occupational diseases differ fundamentally from workplace accidents. They do not emerge suddenly but develop gradually because of specific work conditions. Individuals with hereditary predispositions are especially susceptible. The global prevalence of occupational diseases is increasing, driven by industrial expansion and the intensification of chemical, physical, biological, and environmental exposures.

Given the diverse risks faced by the workforce, it is essential to establish appropriate procedures that address these challenges while safeguarding and sustaining human resources. This includes planning, evaluating, and implementing various occupational health and safety programs, as well as providing protective equipment, first aid kits, alarm systems, and fire-extinguishing devices in workplaces to deal with emergencies.

The National Paint Company – Souk Ahras Unit – has adopted measures to safeguard its workforce against occupational risks. These measures include the implementation of structured occupational health and safety programs designed to ensure that employees carry out their duties under secure and supportive working conditions.

Based on the above, the following main research question is posed:

RQ: What is the reality of implementing occupational health and safety management from the perspective of workers at the National Paint Company – Souk Ahras Unit?

From this main question, the following sub-questions are derived:

SQ1: What mechanisms and roles characterize occupational health and safety?

SQ2: What is the current status of workplace accidents and occupational diseases in industrial institutions?

SQ3: To what extent are occupational health and safety procedures and equipment available at the National Paint Company – Souk Ahras Unit, and to what extent do workers comply with them?

Research Hypotheses

To address the research problem, the following main hypotheses are proposed:

H1: Occupational health and safety (OHS) management is implemented at a measurable level in Algerian economic institutionsFrom these main hypotheses, the following sub-hypotheses are derived:

SH1: Providing protective and safety equipment reduces workplace accidents.

SH2: A low level of occupational health and safety leads to workplace accidents.

SH3: non-compliance with safety regulations among workers increase the likelihood of workplace accidents and occupational diseases.

Importance of the Study

The significance of this study lies in the rapid and complex transformations within industrial institutions, which demand sustained attention to remain aligned with ongoing developments, particularly in occupational health and safety as a strategic priority. Its importance is further highlighted by the contemporary relevance of the topic, which has attracted considerable scholarly interest. Moreover, Algerian institutions face an urgent need to address these issues to adapt to current challenges, a need made even more evident in the aftermath of the COVID-19 pandemic.

Study Objectives:

- Presenting a conceptual framework clarifying the management of occupational health and safety.
- Clarifying the requirements of occupational health and safety in institutions.
- Identifying the current state of workplace accidents and occupational diseases in the economic institution.

- Determining the extent to which occupational health and safety requirements are applied at the National Paint Company – Souk Ahras Unit from the workers' perspective.

Methodology of the Study

Given the nature of the study, a clear and specific methodology is essential to achieve its objectives and obtain reliable results. Accordingly, the descriptive-analytical method was adopted, as it enables the collection of data and facts related to the problem, their interpretation, and the assessment of their significance. This approach provides detailed insights into the actual reality of the phenomenon under investigation. The study is based on 50 questionnaires, of which 40 were returned, yielding an 80% response. This dataset allows for the analysis of results and the examination of the proposed hypotheses.

2 THEORETICAL FRAMEWORK OF OCCUPATIONAL HEALTH AND SAFETY

The main objective of occupational health and safety is to protect the elements of production, especially the human element, from work-related accidents and occupational diseases in industrial institutions. Institutions must understand the components of these conditions and their impact on occupational health and safety, as working conditions represent the environment within which the worker performs their duties.

2.1 The Concept of Occupational Health and Safety

The field of occupational health and safety requires attention and study, especially by industrial institutions. Workers performing tasks within a specific work environment are exposed to multiple risks that negatively affect their health and productivity, as well as other production elements. Therefore, responsibility for occupational health and safety must be upheld by every individual inside and outside the institution.

2.1.1 Definitions of Occupational Health and Safety

There are several definitions, including:

- Occupational health and safety aims to protect workers from serious health impacts by addressing the various sources that lead to these risks, allowing workers to enjoy physical, psychological, and social well-being (Friend, M. A., & Kohn, J. P. 2022).
- It is a set of preventive and therapeutic measures that provide a safe work environment free from hazards, through professional protection for workers by eliminating or reducing risks. When some effects of risk remain, personal protective equipment must be used. A safe work environment includes appropriate lighting, humidity, and temperature within normal limits. Potential risks include wear, impact, fire, and misuse (Hasle, P., & Limborg, H. J. 2006).
- It is a set of preventive procedures that protect human resources through the participation of workers in designing such measures, thereby motivating them and improving morale, leading to professional safety and achieving organizational goals with high-quality output (Gallagher, C., Underhill, E., & Rimmer, M. 2003).
- Occupational safety is defined as a set of measures, procedures, and systems that provide professional protection for workers, reduce risks posed by equipment and machinery, and work to prevent or reduce accidents while ensuring a healthy work environment that helps workers perform efficiently.
- The occupational health and safety management system is an organized approach established by the employer to reduce the risks of injury and illness. It includes identifying, assessing, and controlling risks associated with operations at the workplace. It is an essential component of any activity, and its scope and complexity vary according to the nature of work and operational processes (Yorio, P. L., & Wachter, J. K. 2014).

Based on the above definitions, occupational health and safety can be defined as a field that includes a set of human and material principles and organizational procedures aimed at protecting human resources from work-related accidents, occupational diseases, and damages to material elements, to preserve them and enhance their productive efficiency.

2.1.2 Objectives and Importance of Occupational Health and Safety

Objectives

Occupational health and safety measures aim to minimize accidents and injuries among workers. Although the scope and depth of implementation differ, all programs focus on preserving workers (Vinodkumar, M. N., & Bhasi, M. 2010).

Importance

The importance of occupational health and safety lies in the following:

- Providing a safe work environment: It identifies risks in the workplace and evaluates them to establish necessary measures for controlling and preventing them.
- Ethical responsibility: Protecting the organization—including workers, facilities, buildings, and equipment—is a major ethical responsibility of those in charge of occupational health and safety.
- Economic significance: Direct and indirect costs of work accidents, injuries, and occupational diseases can lead to lost work time, decreased productivity, and material and moral losses.

Training

Effective training that employs occupational health and safety (OHS) programs in the workplace contributes to reducing accidents, injuries, and chronic diseases, while also preserving machines and equipment and ensuring their proper use. The importance of OHS is also highlighted by (Reese, C. D. (2018) through the following points:

- Preserving the health and safety of employees.
- Providing a healthy work environment free from hazards.
- Strengthening human relations between management and employees.

2.1.3 Occupational Health and Safety: Tasks and Benefits of Implementation

Tasks of Occupational Health and Safety (OHS) can be summarized as follows:

- Determining the budget allocated for safety programs, defining their objectives, providing preventive and therapeutic services, coordinating these with various production and operational activities, as well as training specialized workers, and measuring their productivity.
- Analyzing and measuring accident rates, identifying their internal and external sources from the surrounding environment, and measuring key variables that affect safety levels.
- Identifying the various (tangible and intangible) outcomes of OHS programs and raising awareness about occupational accidents.
- Carefully selecting OHS equipment, identifying necessary tools, ensuring maintenance, and guaranteeing their continuity.
- Studying the causes and various sources of accidents, properly training workers on equipment operation, and enforcing required engineering and technical guidelines.
- Maintaining necessary records and information using sound scientific methods.
- Making appropriate decisions in an integrated and economically efficient manner that considers the human element as a capital asset in the production system.
- Linking various OHS methods with production management systems, services, and applied technological processes.

Benefits of Implementing Occupational Health and Safety

The benefits are as follows:

- *Direct benefits:*
  - Reducing work-related injuries and occupational diseases among workers.
  - Reducing workplace accidents and disasters at the organizational level.
- *Indirect benefits:*
  - Reducing injuries and accidents and preserving the workforce leads to increased productivity.
  - Reducing the costs associated with workplace accidents and injuries.
  - Reducing the costs of repairing damaged machinery contributes to facility development.

2.2 Workplace Accidents, Work Stress, and Occupational Diseases

Workplace accidents are a complex phenomenon, and researchers explain their causes in different ways. OHS specialists classify these causes into two main groups: human causes and material causes. In addition to these, several factors may increase or decrease accident rates. Occupational diseases are numerous and are defined according to country-specific lists. They significantly affect workers' health.

2.2.1 Workplace Accidents

Definition of Workplace Accidents

A workplace accident is an unexpected and unplanned event occurring during work, while heading to work, or as a result of work (Benchiha, K. H, 2023).

It is also defined as:

> "Any malfunction in the workflow system that disrupts its natural functioning is considered an accident requiring intervention and repair. Any accident that arises from a predictable and preventable cause through proper control of work equipment is also considered an occupational accident" (Brauer, R. L, 2016).

Classification of Workplace Accidents

Workplace accidents can be classified based on causes, consequences, or nature. Such classification helps in comparing similar types of accidents and understanding their nature, thus enabling accident reduction (Saadi, S., Bosfot, W., & Djebabra, M. 2024):

- *Classification by Cause:*
  - Accidents caused by human factors
  - Accidents caused by technical factors
  - Accidents caused by environmental factors
- *Classification by Consequence:*
  - Accidents disrupting workflow
  - Accidents affecting employees
  - Accidents affecting technical components
  - Minor accidents

2.2.2 Work Stress

Work stress can be defined as human reactions to physical stimuli and psychological influences, which appear in the form of fear, tension, or anxiety. Work stress may be positive or negative.

2.2.3 Occupational Diseases

Algerian law defines occupational diseases in Article 63 of Law 83-13 as:

> *"All symptoms of poisoning, infection, or impairment attributed to a specific occupational source or task."*

Based on previous definitions, occupational disease can be defined as a disease that affects an individual due to the nature of their job or professional activity and appears among workers practicing a certain profession more than the general population. Symptoms emerge after a period of performing the job or during it, such as poisoning, infection, or functional impairment.

2.3 Occupational Health and Safety Procedures and Reasons for Adopting Them

2.3.1 Procedures of OHS Programs

OHS programs must be given appropriate attention in institutions to improve health and ensure workplace safety. Effective programs must be developed through a set of procedures aimed at protecting workers during work (Fernández. et al., 2009) These procedures include:

A. Planning OHS Programs in Industrial Institutions

Legal regulations form the legislative framework for OHS procedures. Laws include many rules and measures that ensure the safety and health of workers. The main principles of OHS program planning include:

- Setting specific OHS standards to guarantee human, machine, property, and economic protection.
- Organizing work by establishing rules and conditions that ensure a clean and contaminant-free workplace.
- Selecting the factory location properly, as proper site selection and compliance with construction standards help reduce future design-related costs.
- Providing medical care: first aid, periodic examinations, and medical treatment.
- Implementing an accurate statistical system.

Program planning also requires:

- Management commitment: Ensuring that management understands the importance of OHS and its human and economic benefits.

- Preventive awareness: Through regulations and instructions that guide safe practices in industrial institutions.
- Training: Based on learning theories and practical application, training aims to reduce workplace accidents by teaching safe behaviors.
- Identifying sources of hazards: These may arise from the physical work environment, unsafe behaviors, lack of experience, poor training, or inadequate OHS knowledge.
- Defining accident investigation procedures: Proper records and reports are essential for identifying real causes and improving programs.

B. Implementing OHS Programs in Industrial Institutions

After planning, implementation begins involving several internal and external parties (Goetsch, D. L. 2019):

- The Minister of Labor or the official responsible for enforcing labor laws.
- Labor inspectors, who ensure compliance with OHS provisions.
- The workplace safety committee within the institution.
- The employer or manager.
- The worker, who plays a crucial role in applying safety rules.

C. Evaluating OHS Programs

An assessment of occupational health and safety programs ensures their implementation within the organization, through continuous internal and external monitoring and inspection -are essential for:

- Ensuring compliance with OHS rules
- Identifying violations and investigating them
- Imposing appropriate penalties
- Studying accidents to determine causes and prevent recurrence
- Detecting program weaknesses and correcting them.

2.3.2 Reasons for Adopting OHS Procedures

The main motivations driving institutional attention to occupational health and safety include:

- Preserving the institution's reputation internally (among employees) and externally (in society).
- Reducing accidents and downtime, which lowers costs and increases productivity.
- Complying with government laws requiring safety measures.
- Responding to pressure from labor unions and workers.
- Reducing employee turnover and keeping up with competitors.
- Lowering the number of workplace-related accidents.

3 FIELD STUDY AT THE NATIONAL FAT PRODUCTION COMPANY – SOUK AHRAS UNIT

The methodology and procedures of the study are a key axis upon which the practical aspect is based, and through which the necessary data and information are obtained to conduct the statistical analysis in order to reach results that are interpreted in light of the collected data, and thus reach the goals that the study seeks to achieve.

3.1 Presentation of the Company and Field Study Methodology

The National Paint Company – Souk Ahras is a national economic institution specialized in producing various types of organic fats. It was established as a result of the restructuring of the National Chemical Industries Company (SNIC) in January 1983, in accordance with Decree No. 82/419 issued on 04/12/1982. On March 13, 1990, the company gained autonomy and was transformed into a joint-stock company (SPA) with a capital amounting to 200,000,000 DZD, which increased in 2005 to reach 500,000,000 DZD.

The National Fat Production Company has more than thirty years of professional experience and a production capacity of 125,000 tons of fats annually, in addition to 57,000 tons of semi-finished products (resins, emulsifiers, and dryers).

National Paint Company – Souk Ahras consists of six production units distributed across the national territory:

- *Eastern Region*: Souk Ahras Unit.
- *Central Region*: Akbou Unit in Bouira Province (headquarters), Cheraga Unit, and Semar Unit in Algiers.
- *Western Region*: Oran Unit and Sig Unit in Mascara Province.

3.2 Organizational Structure

The unit's organizational structure consists of the General Directorate, responsible for five main departments: Administration and Finance, Technical Affairs, Production, Commercial Affairs, and Laboratory. Each department includes several sub-services according to their roles and responsibilities. Additionally, there is the IT Service, Security Service, and the Planning, Monitoring, and Organization Office, all directly linked to the General Directorate.

3.3 Instruments Used in the Study

1. *Study Sample:*
   Because the company employs many workers and occupational health and safety concerns employees at all levels, a comprehensive study was not feasible. Therefore, 50questionnaires were distributed, and 40 were retrieved.
2. *Data Collection Tools:*
   Any scientific method requires suitable tools that enable the researcher to obtain the necessary data. Since this research deals with the extent of applying occupational health and safety management in an industrial company, the main tool used for data collection was the questionnaire, chosen for its appropriateness.

3.4 Questionnaire

To obtain information related to the topic, the questionnaire was divided into two main sections:

- *Section One:* General personal information, including gender, age, marital status, educational qualification, experience, and health condition.
- *Section Two:* Information about occupational health and safety for workers at the National Fat Production Company – Souk Ahras Unit. This section included 10 questions.

3.5 Analysis of Questionnaire Results and Hypothesis Testing

This is based on the statistical ratios and distributions used.

3.5.1 Analysis of Sample Responses to Section One.

The majority of the organization's employees (55%) are in the 41–50 age group, indicating a relatively experienced and skilled workforce (see Table 1).

Younger age groups (<30 years) are represented at a low percentage, which may indicate a lack of new hires or limited integration of young people into the organization.

Table 1. *Distribution of Sample by Age*

Age Group	Number	Percentage
Less than 30	8	20%
31 to 40	10	25%
41 to 50	22	55%
Total	40	100%

Source: Prepared by Author

The distribution of participants shows that the organization relies heavily on middle- to mature-age staff (see Table 1), which is an important factor when analyzing occupational health and safety perceptions, because experience can influence knowledge of safe behaviors in the workplace.

Table 2. *Distribution of Sample by Work Experience*

Experience	Number	Percentage
Less than 5 years	10	25%
6 to 10 years	22	55%
11 to 15 years	8	20%
Total	40	100%

Source: Prepared by Author

The findings indicate that the institution draws partially on work experience, yet this reliance remains modest. Workers with 6 to 10 years of experience represent 55% (the largest proportion), while those with 11 to 15 years represent 20% (the smallest proportion).

Table 3. *Distribution of the Sample by Health Status*

Health Status	Number	Percentage
Good	38	95%
Moderate	2	5%
Total	40	100%

Source: Prepared by the researcher.

These results indicate that most workers in the institution enjoy good health (95%), while a very small percentage (5%) suffer from some health issues.

3.5.2 Analysis of Sample Responses on the Second Section of the Questionnaire

Frequency is represented by N, and relative frequency by N%.

Table 4. *Response to Question 1 – Workers' Environment Has a Significant Effect on Their Health*

Question	Agree	Strongly Agree	Neutral	Disagree	Strongly Disagree
1.	60%	30%	5%	5%	0%

Source: Prepared by Author

Overall agreement (Agree + Strongly Agree) is 90%, indicating that respondents agree that the workers' environment significantly affects their health. The remaining percentages are 5% neutral and 5% disagree (see Table 4).

Table 5. *Response to Question 2 – Work Environment Creates Stress and Pressure, Leading to Various Worker Illnesses*

Question	Agree	Strongly Agree	Neutral	Disagree	Strongly Disagree
2	55%	25%	10%	5%	5%

Source: Prepared by Author

Overall agreement (Agree + Strongly Agree) is 80%, indicating that most workers agree that a stressful work environment may lead to illnesses. The remaining 10% are neutral, and 10% disagree (see Table 5)

Table 6. *Response to Question 3 – Workers' failure to comply with safety orders increases the risk of workplace accidents.*

Question	Agree	Strongly Agree	Neutral	Disagree	Strongly Disagree
3.	20%	60%	15%	5%	0%

Source: Prepared by Author

Overall agreement (Agree + Strongly Agree) is 80%, indicating that respondents agree that Workers' non- compliance with safety regulations is a cause of workkplace accidents. The remaining percentages are 15% neutral and 5% disagree (see Table 6).

Table 7. *Response to the Question: Work Pressure Has Negative Effects on Workers' Health*

Question	Agree	Strongly Agree	Neutral	Disagree	Strongly Disagree
4.	40%	50%	5%	5%	0%

Source: Prepared by Author

The overall agreement (Agree + Strongly Agree) is 90%, showing that most respondents agree that work pressure negatively affects workers' health. The remaining percentages are 5% neutral and 5% disagree (see Table 7).

Table 8. *Response to Question 5: Social Pressure Causes Work Accidents*

Question	Agree	Strongly Agree	Neutral	Disagree	Strongly Disagree
5.	40%	35%	15%	10%	0%

Source: Prepared by Author

Overall agreement is 75%, indicating that respondents agree that social pressures contribute to work accidents. The remaining percentages are 15% neutral and 10% disagree (see Table 8).

Table 9. *Response to Question 6: First Aid Availability in the Workplace*

Question	Agree	Strongly Agree	Neutral	Disagree	Strongly Disagree
6.	35%	50%	10%	5%	0%

Source: Prepared by Author

Overall agreement is 85%, indicating that the company provides first aid facilities in the workplace. The remaining responses are 10% neutral and 5% disagree (see Table 9).

Table 10. *Response to Question 7: Availability of Personal Protective Equipment (PPE)*

Question	Agree	Strongly Agree	Neutral	Disagree	Strongly Disagree
7.	40%	50%	0%	10%	0%

Source: Prepared by Author

Table 10 shows that overall agreement is 90%, showing that most respondents confirm the availability of PPE. The remaining 10% disagree.

Table 11. Response to Question 8: Availability of Warning Systems: Are warning systems available to alert workers to danger?

Question	Agree	Strongly Agree	Neutral	Disagree	Strongly Disagree
8.	50%	40%	10%	0%	0%

Source: Prepared by Author

Table 11 shows that overall agreement is 90%, indicating that workers agree that warning systems are present in the company. The remaining 10% are neutral.

Table 12. Response to Question 9: Legislation System Covers Compensation and Worker Insurance?

Question	Agree	Strongly Agree	Neutral	Disagree	Strongly Disagree
9.	45%	40%	15%	0%	0%

Source: Prepared by Author

Overall agreement is 85%, indicating that respondents agree that the company has a legislative system covering compensation and insurance. 15% remain neutral (see Table 12).

Table 13. Response to Question 10: The company imposes Strict Penalties for Non-compliance with Safety Measures

Question	Agree	Strongly Agree	Neutral	Disagree	Strongly Disagree
10.	35%	45%	10%	10%	0%

Source: Prepared by Author

Table 13 shows that overall agreement is 80%, indicating that most respondents agree that the company enforces strict penalties for non-compliance. The remaining 10% are neutral, and 10% disagree.

Table 14. Average Overall Responses

Question	Agree	Strongly Agree	Neutral	Disagree	Strongly Disagree
Average	40%	45%	10%	6%	0.5%

Source: Prepared by Author

The results show an overall agreement of 85% (Table 14), confirming that the respondents agree on issues related to occupational health and safety, which supports the first hypothesis: *there is an application of occupational health and safety management at the National Paint Company – Souk Ahras.*

4 CONCLUSION

After examining the application of occupational health and safety management in a selected Algerian economic company (National Paint Company – Souk Ahras), both theoretically and practically, it is evident that occupational health and safety management plays a crucial role in preserving production elements, especially human resources.

The study confirms the importance of occupational health and safety procedures through providing protective measures, medical care, guidance, and everything that reduces work accidents and occupational diseases.

4.1 Study Results

The study results can be summarized as follows:

- Occupational health and safety focus on protecting human resources from risks, work accidents, and occupational diseases.
- Workers in industrial settings are exposed to various physical, social, and organizational conditions, which, if unsuitable, may cause accidents and occupational diseases.
- The company organizes a dedicated health and safety management system; responsibility for safety is shared among all, not just the management. the Workers agree that Workers' failure to comply with safety regulations contributes to accidents.
- The company enforces strict penalties for non-compliance, along with laws on compensation and worker insurance, as confirmed by respondents.
- Work accidents are complex phenomena influenced by material and human factors, age, experience, etc.
- Occupational diseases occur gradually due to prolonged exposure to harmful conditions, unlike sudden accidents.

4.2 Study Recommendations

Based on the study, the following recommendations emerge:

- Provide health education for all workers and encourage adherence to occupational safety through awareness programs.
- Enforce strict penalties for violations of safety rules.

- Conduct training programs for workshop workers, who are most exposed to accidents and occupational diseases.
- Perform regular medical check-ups to detect occupational diseases early.
- Assess potential risks to prevent work accidents and occupational diseases.
- Focus on preventive maintenance to avoid conditions that may cause accidents.
- Improve working conditions, especially in workshops and elevated areas, and reduce dust exposure to limit occupational diseases.

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ORIGINAL RESEARCH ARTICLE
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ASSESSMENT OF FACTORS AFFECTING THE FINANCIAL EQUILIBRIUM OF THE SOCIAL SECURITY SYSTEM FUNDS IN ALGERIA

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ABSTRACT

This study examines the combined factors affecting the Financial Equilibrium (FE) of Algeria's Social Security System (SSS) funds. The research adopts a descriptive and analytical approach to establish the theoretical framework and to investigate the main factors influencing the FE of the system. Empirical analysis was conducted using data from reports of the National Office of Statistics (ONS) covering the period from 2007 to 2017. To evaluate the simultaneous effect of the selected variables on FE, a multiple linear regression model was employed. The findings indicate that social security adequacy, benefits growth, social security coverage, and the operating costs ratio exert a statistically significant effect on the FE of the Algerian SSS funds. In contrast, contributions growth and the average benefit per contributor did not show a statistically significant effect within the estimated model. These results suggest that the FE of the SSS is shaped more strongly by expenditure structure, coverage dynamics, and administrative cost efficiency than by contribution growth alone.

1 INTRODUCTION

The Social Security System (SSS) is an essential element of industrial and service economies, offering protection against diverse social risks such as disease, unemployment, and old age, necessitating sufficient funds to address the recurrence and aggravation of these risks.

This is why Algeria adopted a set of reforms to the SSS in 1983, resulting in the passing of legislation that facilitated the localization of the SSS and its autonomy from outdated French regulations. It also paved the way for subsequent reforms and policies that improved various social services and insurance coverage, such as the third-part payment system, as well as digitizing the sector by introducing the *Chifa Card*, *El-Hanaa* space and diversifying funding sources.

Recently, many studies have focused on Algeria's SSS reforms and their impact on its Financial Equilibrium (FE), where the metrics analyzed varied from one study to another. Maouche (2024)

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employed both the contributions to benefits ratio and the operating costs ratio to highlight the financial cost of risks that are not classified as occupational risks, notably psychosocial risks, and demonstrate how this impacted the FE of the Algerian SSS. While Berber (2019) reviewed many reforms implemented for the SSS in Algeria and their effects on the FE, in which he applied a descriptive approach, which emphasized the growth of contributions and benefits. Also, Tehten & Mezioud (2014) used the descriptive approach in data analysis to evaluate the benefits and contributions to sustain the FE of SSS in Algeria.

Against this background, it is clear that the FE of Algeria's SSS has been addressed from various perspectives, with priority on particular metrics (factors) rather than an exhaustive assessment. Therefore, this study tries to assess the combined factors affecting the FE of the SSS's funds: the national social insurance fund for salaried workers (CNAS), the social insurance fund for self-employed professionals (CASNOS), and the national retirement fund (CNR), (CNAC) and (CACOBATPH) funds.

Based on the above, the main research question of this study is:

RQ: *What is the extent to which the combined factors affect the Financial Equilibrium (FE) of Algeria's Social Security System (SSS) funds?*

To tackle the research question, we put forward the subsequent hypotheses:

H_1: The Adequacy of SS has a statistically significant effect on the FE of SSS funds in Algeria.

H_2: The Contributions Growth has a statistically significant effect on the FE of SSS funds in Algeria.

H_3: The Benefits Growth has a statistically significant effect on the FE of SSS funds in Algeria.

H_4: The Average Benefit per Contributor has a statistically significant effect on the FE of SSS funds in Algeria.

H_5: The SS Coverage has a statistically significant effect on the FE of SSS funds in Algeria.

H_6: The Operating Costs have a statistically significant effect on the FE of SSS funds in Algeria.

2 OVERVIEW OF THE ALGERIAN SOCIAL SECURITY SYSTEM

The beginnings of SSS in Algeria link us back to the French presence, as the colonial authorities established the first SSS under Law 49-4**.** Then, between 1950 and 1951, social security funds were formed and divided into three categories: the central social insurance fund, the professional social insurance fund, and the private insurance fund. Following independence, French regulations continued in practice through Law 62-157, until the Algerian state began to localize its social security system in two key phases:

- **The first phase between 1962 and 1983**

Several successive texts were issued to readapt the SSS to the specific nature of the period, which was characterized by administrative vacancies and a lack of professionally qualified personnel, in addition to the presence of several heterogeneous funds, around seventy, low contributions, and unpaid expenditure. However, Executive Decree No. 70-116, which dealt with the administrative organization of social security bodies, eliminated the previous funds and established six new ones, allowing non-employees and farmers to obtain social insurance coverage.

- **The second phase after 1983**

In accordance with the Algerian state's reform approach to its SSS and its efforts to generalize security to all parts of society. In 1983, the Algerian legislator released a collection of laws (Law No.83, 1983) :

- Law No. 83-11 for social insurance;
- Law No. 83-12 for retirement ;
- Law No.83-13 for work accidents and occupational diseases;
- Law No. 83-14 for payer obligations in social security;
- Law No. 83-15 for social security disputes.

This period was distinguished from the previous one by the generalization of benefits and privileges to all, as well as the new administrative organization of SSS established two basic funds, the national Fund for social insurance, work accidents, occupational diseases (CNASAT) and

the national retirement fund (CNR). Thus eliminating the six funds established earlier (Decree No.85-223, 1985).

After the issuance of the 1989 constitution, Algeria abandoned socialism in favor of capitalism, which required adapting the SSS to these new transformations.The CNAS was established to replace the CNASAT, as well as the establishment of the CASNOS as a new fund (Executive Decree No.92-07, 1992).

Later, other funds were added, in accordance with the requirements of the economic phases, including the national unemployment insurance fund (CNAC) in 1994 and the National Fund for Paid Leave and Unemployment Resulting from Bad Weather in the Construction, Public Works, and Hydraulics Sectors (CACOBATPH) in 1997 (Merouani & Hammouda, 2014, p. 124).

2.1 The Structure of the Social Security System in Algeria

The current institutional structure of Algeria's social security system consists of five basic funds:

2.1.1 The National Social Insurance Fund for Salaried Workers (CNAS)

It replaced the CNASAT fund, which was established in 1985 following restructuring, thereby becoming a public institution with financial autonomy and self-management. It oversees social services pertaining to workers, addresses various accidents at work and occupational diseases (Executive Decree No.92-07, 1992), registers worker affiliations, collects contributions, facilitates and organizes medical oversight and social security disputes, and enters into agreements with practicing physicians and medical institutions (Abderrahmane & Scalera, 2023, p. 20).

2.1.2 The Social Insurance Fund for Self-Employed Professionals (CASNOS)

It was founded on January 4, 1992, by decree No. 92-07. Its objective is to manage in-kind and cash social insurance services for self-employed professionals like traders, farmers, craftspeople, and others. Additionally, the CASNOS collects and monitors contributions for financial services and arranges, coordinates, and carries out medical monitoring (Kharroubi & Boudellal, 2024, p. 247).

2.1.3 The National Pension Fund (CNR)

A public entity possessing legal personality and financial autonomy was created by decree No. 85-223. The goal of its founding was to manage the various retirement systems that previously existed and unite them into a retirement system that grants the same benefits to all workers regardless of their field of activity. According to the article No. 09 of decree No. 92-07, the CNR was charged with managing retirement wages and grants, as well as the revenue of individuals, ensuring collection operation, monitoring and resolving disputes over contributions required to finance retirement services (Executive Decree No.92-07, 1992).

2.1.4 The National Unemployment Insurance Fund (CNAC)

This Fund was established by decree No. 94-11 as a result of Algeria's transition from socialism and economic centralization to capitalism and a market economy. This economic and political situation brought with it a social crisis that affected over 400,000 workers who were unemployed due to the insolvency of their employing companies. The CNAC was charged with monitoring and updating contributors' cards, as well as collecting contributions to finance unemployment insurance benefits and resolving disputes (Executive Decree No. 94-188, 1994).

2.1.5 The National Fund (CACOBATPH)

It was established on February 4, 1997 by decree No. 97-45, as a public body with legal personality and financial autonomy. the National Fund for Paid Leave and Unemployment Resulting from Bad Weather in the Construction, Public Works, and Hydraulics Sectors (CACOBATPH) was formed to manage and control paid holidays and unemployment caused by adverse weather. Also identifying and numbering beneficiaries and employers, collecting contributions, allocating financial reserves to assure the payment of social benefits in any situation (Executive Decree No. 97-45, 1997).

2.2 Social Security Funding in Algeria

Two main sources fund Algeria's social security system:

- Contributions, and
- Government Subsidies and Transfers.

2.2.1 Contributions

They are the primary source of funding for Algeria's SSS funds. The contribution rate was grouped according to the types of contributors:

- Salaried workers pay 34.5% of their wages, divided between employees and employers, as shown in Table 1.
- Self-employed professionals pay 15% of their non-taxable income or the guaranteed minimum yearly wage, divided evenly between social insurance and retirement benefits.

Table 1. The Contribution Rate Distribution

	Employer	Employee	Social Services	Total
Social Insurance	11.50%	1.50%		13%
Work Accidents, Occupational Diseases	1.25%			1.25%
Retirement	11%	6.75%	0.50%	18.25%
Pre-Retirement	0.25%	0.25%		0.50%
Unemployment Insurance	1%	0.50%		1.50%
Total	25%	9%	0.50%	34.50%

Source: (Executive Decree No. 15-236, 2015)

According to Table 1, the contribution rate is distributed as follows: 14.25% for the benefit of the CNAS fund, 18.75% for the CNR fund, and 1.50% for the CNAC fund. Also, the employers give 25%, workers contribute by 9%, and the Social Services Equalization Fund (FNPOS) contributes by 0.5%.

2.2.2 Government Subsidies and Transfers

Many countries finance a portion of their SSS through government subsidies and transfers, such as insurance services for children, housewives, the elderly, and the unemployed, or health coverage, in which the state contributes up to 60% of the cost of social security.

In Algeria, the government's contribution consists of disbursing family allowances and grants, as well as benefits directed to serving national solidarity for retirees who receive low retirement grants, in addition to other sources of financing such as investment returns, employer contributions to unemployment insurance and advance retirement, increases late fees, and other penalties imposed on employers who fail to meet their obligations (Mahmoudi & Ghedjati, 2020, p. 342).

3 METHODS

To test hypotheses and answer research questions, the descriptive approach was used to present and analyze data related to the concepts. The multiple linear regression was also used to construct the effect model of the combined factors on the FE of the SSS, using the statistical analysis program SPSS v27.

The population considered in this study is the Social Security Funds, and the research sample consisted of five funds, each of which was observed for 11 years from 2007 to 2017, providing a total of 55 observations.

The data were taken from the National Office of Statistics' (ONS) yearly reports, and it is important to highlight that 2017 was chosen as the study's cutoff year because the ONS has not published any subsequent yearly reports on social security in Algeria.

The study includes two types of variables: the dependent variable and the independent variables. Therefore, the statistical representation of the multiple linear regression model is presented as follows (Uyanık & Güler, 2013, p. 235):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_n X_n + \varepsilon$$

Where:

Y: is the dependent variable;
β_0: is the intercept value;
β_i: are the estimated regression coefficients of respective independent variables;
X_i: are the independent variables (Table 2);
ε: is the model error, i.e. the variation of our estimate of Y with respecting to the real value.

3.1 Dependent variable

This study investigates the FE as the dependent variable, which represents the amount of the SSS funds surplus or deficit as a consequence of the difference between total contributions collected and total benefits paid during the year. Table 2 shows that the financial equilibrium (FE) of social security funds varied between 2007 and 2017, with periods of increase and decrease. The FE of the CNAS increased continuously from 9645.19 million DZD in 2007 to 196532.29 million DZD in 2012, before declining sharply to 57113.24 million DZD in 2017. The other funds showed similar variation, with the exception of the CNR, which had a continuous and growing deficit after 2012, from 9.2 million DZD to 486.3 million DZD in 2017.

Table 2. *Financial Equilibrium Evolution (Million DZD)*

Years	CNAS	CNR	CASNOS	CNAC	CACOBATPH
2007	9645.19	-5.81	-840	14167	2494.
2008	25696.9	6.14	15	17436	2761.17
2009	50176.06	18.8	1356	6147	3497.41
2010	81093.01	10.41	3432	13160	3754.53
2011	133531.01	67.3	1836	1121	3179.28
2012	196532.29	106.5	4180	2778	3241.32
2013	107314.58	-9.2	2438	17734	3449.56
2014	85696.29	-155.1	376	14262	2870.36
2015	79549.06	-265.5	960	22998	3143.34
2016	81511.75	-312.6	21944	20777	3619.14
2017	57113.24	-486.3	12228	-60238	1427.94

Source: (National Office of Statistics, 2021)

3.2 Independent Variables

Table 3 summarizes the independent variables of the research, specifically their measurement, dimension, and the previous research that applied them.

Table 3. *Independent Variables Description*

Variables	Measurement	Unit	Dimension	References
Adequacy of Social Security	$X_1 = \frac{\text{Total Contributions}}{\text{Total Expenditures}}$	%	Financial	(Yuh, 2011) (ILO, 2021) (World Bank, 2023)
Contributions Growth	$X_2 = \text{Ln}\left(\frac{\text{Contributions (n + 1)}}{\text{Contributions (n)}}\right)$	%	Financial	(Olalekan, 2018) (Pramusinta et al., 2023)
Benefits Growth	$X_3 = \text{Ln}\left(\frac{\text{Benefit (n+1)}}{\text{Benefit (n)}}\right)$	%	Financial	(Popova, 2023) (Santos & Simões, 2025)
Average Benefit per Contributor	$X_4 = \frac{\text{Total Benefits}}{\text{Number of Contributors}}$	Million DZD	Benefit	(ILO, 2021) (World Bank, 2023)
Social Security Coverage	$X_5 = \frac{\text{Number of Contributors}}{\text{Working Population}}$	%	Coverage	(ILO, 2021) (World Bank, 2023)
Operating Costs Ratio	$X_6 = \frac{\text{Operating Costs}}{\text{Total Expenditures}}$	%	Performance	(Maouche, 2024)

Source: Author

4 RESULTS AND DISCUSSION

4.1 Descriptive Statistics

Table 4 presents the lowest value of the ln (FE), which is 5.16 for 312.6 million DZD as a real value, the maximum value of ln (FE) is 12.9 for 196532.292 million DZD, and the average value of ln (FE) is 8.8525 for 6988.05 million DZD as a real value.

Furthermore, the results of Table 4 demonstrate that the average adequacy of social security is 116.16%, with proportions ranging from 59% to 200%. The average contributions growth is 12.77%, with proportions varying from -136% to 123%, whereas the average benefits growth is 3.6% with proportions ranging from -131% to 49%. The average benefit per contributor is 0.02565 million DZD, with values varying from 0.00024 to 0.26 million DZD.

The average Social Security Coverage reached 25.65% with 100% as maximum, while the average operating costs ratio was 42.86% with proportions ranging from 4% to 100%.

Table 4. Descriptive Statistics (N=55)

Variables	Minimum	Maximum	Mean	St. Deviation
Financial Equilibrium	5.16	12.19	8.8525	2.10926
Adequacy of Social Security	0.59	2	1.1616	0.26299
Contributions Growth	-1.36	1.23	0.1029	0.36850
Benefits Growth	-1.31	0.49	0.0360	0.27723
Average Benefit per Contributor	0	0.26	0.0251	0.04749
Social Security Coverage	0	1	0.2565	0.33401
Operating Costs Rate	0.04	1	0.4286	0.33205

Source: based on the output SPSS v27

4.2 Assumptions Checks

Prior to executing the multiple linear regression model, it is essential to validate certain assumptions:

4.2.1 Linearity & Homoscedasticity Assumptions

According to (Uyanık & Güler, 2013, p. 236), linearity refers to a proportional relationship between the independent and dependent variables. At the same time, homoscedasticity indicates that the variance of residuals is constant across predicted values.

Figure 1 shows that the points are randomly distributed around the horizontal line at zero, with no discernible pattern, so validating both the assumptions of linearity and homoscedasticity.

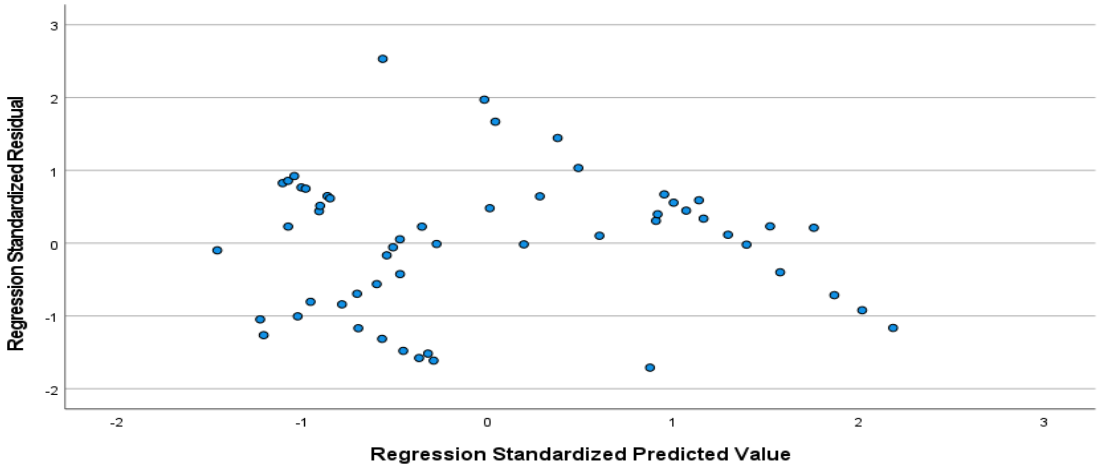


Figure 1. *Scatterplot of Residuals vs Predicted values*
Source: based on the output SPSS v27

4.2.2 Multicollinearity Assumption

To confirm that there is no multicollinearity, the Variance Inflation Factor (VIF) and the Tolerance tests were employed to check this assumption. Tolerance and VIF values were calculated for each independent variable listed in Table 5. It is obvious that all tolerance values for all variables are higher than 0.1 (Uyanık & Güler, 2013, p. 238) and the VIF values for all variables are less than 10 (Bobbitt, 2021), consequently verifying the assumption of multicollinearity.

Table 5. *Tolerance & VIF Tests*

Independent Variables	Tolerance	VIF
Adequacy of Social Security	0.601	1.663
Contributions Growth	0.917	1.091
Benefits Growth	0.667	1.499
Average Benefit per Contributor	0.648	1.543
Social Security Coverage	0.639	1.565
Operating Costs Rate	0.5	2.001

Source: based on the output SPSS v27

4.2.3 Normality of Residuals Assumption

Table 6 indicates that the significance value of ($p = 0.2$) exceeds the predetermined threshold ($\alpha = 0.05$). So the null hypothesis (H_0): the residue is normally distributed, is accepted, while the alternative hypothesis is rejected (Barakat et al., 2022, p. 224).

Furthermore, Figure 2 illustrates the Q-Q plot, where the points approximately align along a straight diagonal line, indicating that the normality assumption of multiple linear regression is met.

Table 6. *Kolmogorov-Smirnov Test*

	Statistic	df	Sig
Standardized Residual	0.095	55	0.2

Source: based on the output SPSS v27

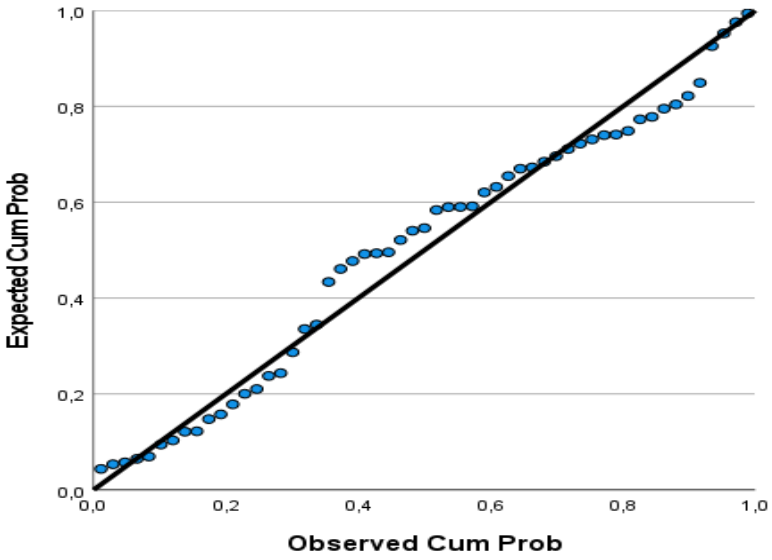


Figure 2. *Normal Q-Q plot of Financial Equilibrium*
Source: based on the output SPSS v27

4.2.4 Outlier's Assumption

To confirm the absence of outliers, Cook's distance was calculated for each point. Table 7 indicates the maximum value is 0.411, which is less than 1 (Trunfio et al., 2022, p. 4), confirming that no outliers exist in the datasets and verifying the assumption regarding outliers.

4.3 Regression Analysis

As shown in Table 7, the ANOVA yielded F(6,55) = 17.316 with a significance level of 0.001, indicating statistical significance at α = 0.05. So, the null hypothesis (H_0) that the model has no overall statistical significance, is rejected. In comparison, the alternative hypothesis is accepted. Consequently, the regression model employed to examine the factors impacting the SSS's FE is shown to be appropriate. Moreover, changes in these factors as the model's independent variables explain 68.4% of the variance in FE, whereas other factors explain 31.6%, according to the R^2 value 0.684.

Table 7. *Multiple Linear Regression Results*

	Coefficients	Std.Error	t-Statistic	Sig (p-value)
Constant	2.455	0.981	2.502	0.016
Adequacy of Social Security	3.972	0.839	4.732	0.001
Contributions Growth	-0.430	0.485	-0.887	0.38
Benefits Growth	-1.714	0.756	-2.268	0.028
Average Benefit per Contributor	-0.047	4.476	-0.01	0.992
Social Security Coverage	3.610	0.641	5.632	0.001
Operating Costs Rate	2.253	0.729	3.09	0.003
R=0.827 R^2=0.684 F(ANOVA)=17.316 p-value=0.001 Cook's Distance: min=0.000, max=0.411				

Source: based on the output SPSS v27

Furthermore, the regression model coefficients using the T test, with P-values less than α = 0.05 indicating statistical significance, are shown in Table 7. The results revealed that the adequacy of social security has a notable and positive impact with a regression coefficient of 3.972 and a significance value of (p = 0.001), indicating that the adequacy of social security has a statistically significant effect on the FE of SSS in Algeria. Therefore, hypothesis 1 is accepted. This fits with Yuh's (2011) findings and is further supported by assessments from the World Bank and the International Labor Organization (2021).

Similarly, social security coverage has a considerable positive effect with (β = 3.610) and (p = 0.001), indicating that increasing the number of contributors greatly affects the FE of SSS in Algeria. As a consequence, hypothesis 5 is accepted. This is supported by assessments from the World Bank and the International Labor Organization (2021).

Operating costs ratio also displays a significant positive coefficient equal to 2.253 and a significance value of (p = 0.003), indicating that the operating costs ratio has a statistically significant effect on the FE of SSS in Algeria. Thereby, hypothesis 6 is accepted. This is aligned with the previous study of Maouche (2024).

Benefits growth has an immense negative effect with (β = -1.714) and (p = 0.028), showing that the growth in benefits reduces the financial equilibrium. Therefore, hypothesis 3 is accepted. This is aligned with the previous studies of Santos and Simoes (2025), Popova (2023), Berber (2019), and Tehten and Mezioud (2014).

In contrast, contributions grow with (p = 0.380), and average benefit per contributor with (p = 0.992) indicate no statistically significant effects, meaning that their impact is insufficient for drawing significant predictions from this model. So, hypotheses 2 and 4 are rejected. From the prior results, the regression equation is:

$$Y = 2{,}455 + 3{,}972X_1 - 0{,}43X_2 - 1{,}714X_3 - 0{,}047X_4 + 3{,}610X_5 + 2{,}253X_6$$

Where: Y: financial equilibrium; X_1: adequacy of social security; X_2: contributions growth; X_3: benefits growth; X_4: average benefit per contributor; X_5: social security coverage; X_6: operating costs ratio.

5 CONCLUSIONS

Based on the test results and discussion, it is concluded that the four factors of social security performance-namely, the adequacy of the social security system, benefits growth, social security coverage, and the operating cost ratio- had a statistically significant effect on the FE of SSS funds in Algeria. Empirically, the regression model demonstrates how a one-unit rise in the SS adequacy results in a 3.972-unit improvement in FE. This emphasizes the importance of social security adequacy to enhance the financial equilibrium of Algeria's SSS.

Similarly, a one-unit increase in social security coverage leads to a 3.610-unit enhancement in FE. This reflects the level at which the workforce is integrated into the formal social security system, directly impacting the financial equilibrium of the system. A high coverage ratio presents a significant number of workers who engage in contributing to systems, ensuring consistent cash flows and increasing the system's capacity to provide adequate benefits.

Likewise, a one-unit change in the operating costs ratio results in a 2.253-unit rise in FE. This emphasizes the important role of the operating costs ratio as a key indicator of the operational efficiency and cost structure of the SSS funds.

In contrast, a one-unit increase in benefits growth is associated with a −1.714-unit decline in FE. This points to an inverse relationship between benefit growth and FE, implying an issue with contribution distribution, resulting in reduced FE capacity and efficiency. Overall, the observed effect underlines the importance of adopting a balanced approach that takes into account unexpected effects when implementing policies for rationalizing benefits and other forms of spending.

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ORIGINAL RESEARCH ARTICLE
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STRATEGIC INTELLIGENCE AND ORGANIZATIONAL BEHAVIORAL MOTIVATION: THE MEDIATING ROLE OF DIGITAL AMBIDEXTERITY

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ABSTRACT

This study aimed to explore the mediating role of digital ambidexterity in the relationship between strategic intelligence and Organizational behavioral motivation. The study employed PLS-SEM and was conducted as a case study involving 15 large industrial firms in Eastern Algeria. Data were collected using a questionnaire administered to a purposive sample of 200 executives. The results showed that introducing the mediating variable did not reduce the strength of the direct effect; rather, it increased compared to the non-mediated model. This suggests that the relationship between the variables goes beyond traditional mediation logic and reflects a more complex explanatory structure involving interactions between direct and indirect effects. The findings also indicate the possible presence of inconsistent mediation, accompanied by a suppression effect, across the model's direct and indirect paths. The study contributes both theoretically and practically by enriching the debate on strategic intelligence and digital organizational capabilities. It recommends that future research examine the multiple roles of digital capabilities as either direct or contextual factors that enhance the effectiveness of strategic intelligence in achieving superior organizational performance.

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1 INTRODUCTION

The competitive environment in today's business world is evolving rapidly, creating a complex landscape characterized by a continuous flow of information and implicit events. Analyzing and understanding this landscape is essential for generating new knowledge and creative insights. In this context, strategic intelligence is a pivotal tool for navigating such complexity, offering a comprehensive and in-depth analytical process that enhances awareness of an organization's strategic capabilities.

When organizations maintain a high level of awareness of their internal capacities and remain informed about developments in their business environment, they are better positioned to identify opportunities for innovation and growth. This knowledge becomes a motivational force that drives strategic behavioral responses aimed at achieving superior performance (Shaheed, 2024). Previous studies have confirmed that strategic intelligence outputs are significant and influence the likelihood of success (Hamuda & Elshref, 2024).

Mohammad et al. (2024) also demonstrated that strategic intelligence shapes performance by detecting market signals and anticipating disruptions, thereby facilitating the formulation of deliberate strategies to achieve superior performance relative to competitors. Gavetti (2012) indicated that the absence of strategic intelligence in organizations leads to market failure and that strategies based on this form of intelligence determine performance behavior (Gavetti & Porac, 2018). Prior studies have further emphasized that effective strategies require deep exploration of new ideas, promising opportunities, and intelligent responses grounded in strategic intelligence. This contributes to higher levels of performance by activating organizational competitive drive (Kurter, 2025). These studies show that strategic behavior depends on competitive and innovative strategies grounded in R&D investment and the development of dynamic innovation capabilities, including identifying environmental fluctuations and seizing opportunities through data-driven decision-making.

In business developments, knowledge derived solely from strategic intelligence outputs is insufficient to achieve superior performance. While strategic intelligence reflects leaders' cognitive capabilities, organizations today require artificial intelligence as a transmission mechanism to ensure a sustainable competitive edge (Abbas et al., 2025).

To create a competitive advantage, identifying skills, capabilities, and technology is not enough. It is essential to know how and when to use each capability or skill to exploit market opportunities before competitors do. Suboptimal conditions for organizations can be created by not applying Skills and capabilities at the right time or in the appropriate manner. Therefore, skills must be developed, activated through technology, and applied promptly to position the organization ahead of competitors and make a meaningful difference (Ürü et al., 2024).

Accordingly, this study proposes digital technology-based organizational ambidexterity as a mechanism that transmits the impact of strategic intelligence on organizational behavioral motivation toward superior performance. This is achieved through exploration and exploitation capabilities, supported by digital technologies such as big data analytics, Artificial Intelligence, and digital platforms, and using ambidexterity strategies to enhance competitive capability (AlShaygy, 2025). Digital organizational ambidexterity ensures the generation of competitive strength, radical change development, the simultaneous pursuit of innovation and investment, and activation. of all capabilities to compete (Benali, 2023).

Presenting Strategic Intelligence as a strategy that activates organizational behavioral motivation as a holistic entity to achieve superiority over competitors is the contribution of the current study to literature emphasizing competitive drive as a concept that clarifies the study's overall objective. In addition, it expands the discussion of strategic intelligence by introducing digital technology-based organizational ambidexterity as a mechanism explaining the transmission of strategic intelligence effects on organizational behavioral motivation, especially in the context of digital transformation.

The study focuses on knowledge derived from human strategic intelligence competencies, supported by digital technologies that enhance exploration and exploitation capabilities. It aims to generate information in uncertain environments and achieve ambidexterity in pursuing competitive objectives. The study highlights these human, technological, cognitive, and informational outputs as organizational cognitive knowledge that stimulates behavioral motivation toward superior performance.

The significance of the study is further strengthened by its application to real industrial settings within major companies in Eastern Algeria, adding both scientific and practical value while addressing an important knowledge gap in the literature.

2 THEORETICAL FRAMEWORK AND HYPOTHESES DEVELOPMENT

2.1 Strategic Intelligence as a Driver of Organizational Behavior

From the outset, strategic intelligence emerged as a systematic process for collecting and analyzing information to support strategic decision making and strengthen an organization's competitive capability (Mohammad et al., 2024; Benjamin & Pauker et al., 2000). By rapidly understanding and analyzing data, leaders become better able to predict future changes accurately and implement decisions promptly (Shamto & Chaabouni, 2024; Soriano & Valdés, 2021).

With increasing market and competitive complexity, strategic intelligence has evolved into a tool for developing a comprehensive view of direct and indirect competition. It enables leaders to detect threats and weaknesses at early stages, manage risks proactively, and use environmental shifts to enhance knowledge dynamics and make timely decisions based on updated information. In doing so, strategic intelligence supports organizational vigilance, flexibility, and sustainable growth (Paiuc et al., 2024).

Over time, strategic intelligence has gained importance beyond analysis, becoming a means of integrating decision-making processes with environmental analysis and competitor interactions, thereby enhancing innovation and contributing to superior performance (Crumpton, 2015; Salih & Abdulrahman, 2015). Its practices have developed into systematic foresight actions that generate knowledge about the competitive environment and guide organizations toward improved performance (Calof, 2025).

The effectiveness of strategic intelligence depends on five integrated components: foresight, future vision, systemic thinking, partnerships, and intelligent motivation (Maccoby, 2001). These competencies enable comprehensive analysis of internal and external business environments. In this context, the role of strategic intelligence is not limited to analysis; it also extends to strengthening the organization's capacity to reshape reality by transforming raw data into strategic insights that anticipate challenges, identify opportunities, and assess the sustainability of future achievements.

Strategic intelligence, therefore, serves as a guide based on the assimilation of evidence obtained from analyzing information extracted from the business environment and competitors' actions. This evidence informs investment decisions and enables the formulation of competitive strategies.

Building on this premise, prior studies suggest that organizational motivation stems from strategic orientation (Adiguzel & Sommez, 2022). It also arises from external changes that create competitive pressures (Gavetti, 2012), which are activated through the interaction of cognition-related factors (Uka & Prendi, 2021) and information processes that monitor the organization's external environment. In addition, organizational motivation originates from competitive strategies aimed at achieving high and innovative performance (Musetti et al., 2023). Accordingly, this study posits that behavioral motivation in organizations is shaped by the organizational environment, which drives organizations to take strategic steps to determine their competitive position by understanding internal and external dynamics.

Complete knowledge of organizational realities strengthens confidence in available resources and enhances the ability to enter competitive markets and exploit opportunities that drive strategic behavior. Thus, behavioral motivation represents the practical translation of competitive drives into strategic activities that improve organizational performance. This notion is supported by goal-setting theory, which explains how driving forces

are reflected in observable behavior through the formulation and pursuit of goals. Motivation is a psychological state, behavior is the outcome, and goals are the mechanism that directs this behavior. Without goals, motivation remains latent and ineffective (Kurose, 2013).

Within this framework, behavioral motivation supports the formulation and implementation of organizational strategies, reflecting a contemporary strategic approach that combines reactive and proactive behavior. Environmental changes influence strategic perception, which in turn shapes behavioral motivation (Burgelman, 1983). These behaviors enable strategic leaders to outperform competitors based on their cognitive representations (Gavetti & Porac, 2018).

Theoretically, strategic intelligence enhances organizational behavioral motivation by strengthening the organization's cognitive ability to interpret complex environments and translate this understanding into purposeful action. Strategic intelligence, often conceptualized as the capacity for environmental scanning, foresight, and strategic interpretation, enables organizations to reduce uncertainty and increase the quality of strategic judgments. In turn, this activates internal behavioral systems that support opportunity recognition, flexibility, and shaping capability.

Strategic intelligence is expected to positively influence digital ambidexterity by enhancing the ability to achieve balance between exploration and exploitation in digital environments. Organizations with higher strategic intelligence are better equipped to identify emerging digital technologies (exploration) and to optimize existing digital systems and infrastructure (exploitation).

2.2 Organizational Behavioral Motivation for Achieving Superior Performance

Motivation refers to the internal driving forces that energize and direct action; behavior reflects the observable actions resulting from such motivation; and capability represents the organization's ability or competence to perform these actions (Ryan & Deci, 2000; Teece, 2007). Organizational behavioral motivation (OBM) refers to the internal behavioral and strategic drivers that guide organizational actions toward opportunity pursuit, adaptation, and competitive positioning (Gavetti, 2012).

Superior performance often depends on the ability to identify and explore distant opportunities, a capability many organizations fail to achieve because of cognitive limitations. Therefore, superior performance is grounded in the management of cognitive processes that support intelligent action (Gavetti, 2012). Accordingly, knowledge plays a fundamental role in shaping a creative vision that guides organizations toward proactively conceptualizing a desired future state within their competitive space, thereby supporting and strengthening change. The motivation to achieve this vision stems from dissatisfaction with the organization's current trajectory (Hassan et al., 2023; Anthony, 2024), which directs organizational efforts toward its realization (Kirilov, 2019).

In this context, strategic intelligence is assumed to support this process by analyzing the organization as a whole rather than as isolated parts (Maccoby, 2001), since any interaction or event may provide valuable insights into future transformations (Anthony, 2024). Organizational opportunities in the external environment can be alerted to by strategic intelligence functions. When decisions are based on this information, forecasts are converted into action, enabling the organization to design a competitive future (Akros, 2016; Hadi & Halaouni, 2024).

This hypothesis is further supported by Schumpeter's view that actors are not constrained by the existing cognitive state; rather, they can reshape collective perceptions of reality and act accordingly. Through the management of cognitive structures, organizations can exploit cognitively distant opportunities, a capability enabled by strategic intelligence. As a result, high-performing organizations in this domain are often more rewarded than those relying solely on incremental improvements (Gavetti, 2012).

Thus, superior performance is achieved by managing mental processes reflected in the three core competencies measured by OBM: opportunity recognition, flexibility, and shaping capability. These competencies are important for pursuing long-term strategic goals, as they capture the organization's underlying motivation to sense opportunities, adapt to dynamic

environments, and proactively shape competitive conditions. These internal driving forces enable organizations to overcome behavioral limitations, making them a source of superior performance (Gavetti, 2012). They can be defined as follows:

Opportunity recognition: This refers to the ability to detect favorable situations (Faley, 2014) based on acquired information (Lai, 2016). This process enables the organization to develop capabilities that create tangible value and strengthen its position relative to competitors (Faley, 2014).

Flexibility: This refers to the organization's tendency to respond to new conditions, thereby enhancing its ability to exploit current and potential opportunities. The value of flexibility arises from the ability to use opportunities effectively relative to the potential value of alternatives (Maggi, 2019). This is achieved through the systematic analysis of a series of critical events or phenomena, enabling the organization to construct a conceptualization of an envisioned final state (Garud & Van de Ven, 2000).

Shaping capability: This refers to the ability to justify opportunities and shape or build a domain of opportunities. This capability is linked to the behavioral motivation of strategic leadership and the need to overcome behavioral constraints by organizing opportunities and creating opportunity space. It includes the leader's ability to bring cognitively distant opportunities closer and make them more acceptable and legitimate by influencing the perceptions and thoughts of relevant internal and external stakeholders. This process requires altering prevailing mindsets and perceptions to enable vision and unlock new opportunities that may otherwise remain unnoticed or be excluded by traditional thinking (Gavetti, 2012).

2.3 Digital Technology-Based Organizational Ambidexterity

In evolutionary models of organizational forms and technologies, the choice between exploration and exploitation is enclosed as an equilibrium between selection processes and variation. Effective selection among forms, routines, or practices is essential for organizational survival, as is the generation of alternative practices, particularly in changing environments. Given the links between environmental disruption, organizational diversity, and competitive advantage, the evolutionary dominance of a particular organizational practice depends on the relationship between the rate of exploratory variation associated with that practice and the rate of environmental change (Ürü et al., 2024). This reflects the organization's ability to absorb pressures, respond effectively to turbulent environments, and use potential threats for recovery and competitive advantage (Li et al., 2025), while simultaneously pursuing new opportunities and radical innovations. In other words, it reflects the ability to pursue competing strategic directions at the same time (Clauss et al., 2021; Xue et al., 2022).

In this context, the "ambidexterity hypothesis" posits that organizations capable of exploiting existing operations while exploring new opportunities can achieve superior performance compared with those that emphasize one dimension at the expense of the other (Bøe-Lillegraven, 2014).

Thus, organizations that balance exploration and exploitation are known as ambidextrous organizations. Exploration is associated with experimentation and research into radically new areas and is usually linked to innovation, whereas exploitation involves improving existing operations by focusing on efficiency and productivity. Achieving a balance between these two activities is a fundamental objective, especially in rapidly changing environments shaped by digital technologies, where maintaining a sustainable balance between exploration and exploitation becomes essential (Hoessler, 2024).

In the context of digital transformation, organizational ambidexterity refers to the ability to simultaneously address contradictory environmental and technological demands by pursuing incremental and radical innovation, while accommodating multiple and sometimes conflicting structures, processes, and cultures within the organization (Åkesson et al., 2018). In addition, it involves improving the organizational entity through fundamental changes in its characteristics, achieved through the combination of information, computing, communication, and networked technologies (Vial, 2019).

Many organizations seek to achieve organizational alignment through digital innovation by exploring opportunities offered by digital

technologies and ensuring their successful integration into the core organization (Holotiuk et al., 2024). Digital business transformation enables organizations to balance exploration and exploitation. By using digital technologies, organizations can respond quickly to changing business environments while maintaining operational efficiency. Organizational alignment facilitates the effective integration of digital technologies into business models, thereby enhancing innovation and operational efficiency (Nasution et al., 2025). This digital process can be observed in several areas, including advanced analytics for understanding competitors, real-time data processing for risk assessment, and digital platforms for generating customer insights, all of which strengthen the organization's ability to explore and exploit simultaneously (Nasution et al., 2025; Magnusson et al., 2021).

In the context of digital organizational ambidexterity, digital exploration refers to an organization's capability to use digital technologies to explore new opportunities, develop innovative business models, and identify new markets and solutions through continuous learning, research, and experimentation (Hadi et al., 2026). This indicates that organizations are not merely adopting digital technologies but are also redefining how value is created and delivered within and beyond organizational boundaries.

This orientation aims to enhance opportunities for organizational effectiveness. Achieving this requires the reconfiguration and mobilization of organizational and technological resources to support innovation and renewal processes (Brock & Kohli, 2023).

In contrast, digital exploitation refers to an organization's ability to use existing digital technologies to improve operations, enhance efficiency, reduce costs, and maximize the value of existing resources and capabilities. This approach relies on process automation and performance optimization through the effective use of established digital systems (Hadi et al., 2026; Brock & Kohli, 2023). In this regard, the literature suggests that advanced digital technologies enable more flexible resource allocation, supporting a shift from traditional experience-based coordination mechanisms toward more information-driven approaches to managing innovation resources (Li et al., 2025).

Empirical evidence indicates that innovation performance improves significantly when organizations effectively implement digital organizational ambidexterity. As a dynamic capability, digital organizational ambidexterity simultaneously supports knowledge acquisition and exploitation, thereby positively influencing innovation outcomes (Ramdan & Abdullah, 2021).

However, the literature also indicates that exploration and exploitation in the digital context remain largely technology-centric. Digital exploration is mainly associated with research and development activities and the creation of new digital technologies, whereas digital exploitation is linked to the implementation of these technologies within existing operations and the transformation of innovations into actionable organizational outputs (Hoessler & Carbon, 2024). The fundamental distinction between the two is that exploration involves the assimilation and discovery of future digital technologies, while exploitation involves applying these technologies to enhance current processes and improve operational efficiency (Matusek, 2022).

Moreover, this dynamic interaction strengthens end-to-end interoperability among products, machines, and individuals, thereby supporting the integration of digital systems within the organization (Matusek, 2022).

Building on the distinction between digital exploration and digital exploitation, organizational ambidexterity in the digital context can be understood as a dynamic capability that enables firms to continuously balance and rebalance these competing activities over time.

Accordingly, ambidexterity does not imply a fixed balance; rather, it requires continuous rebalancing as conditions change over time. Organizations must maintain operational excellence while simultaneously pursuing innovations that may drive radical transformation. This combination reflects the simultaneous pursuit of efficiency and innovation, whereby organizations use existing knowledge and resources while exploring new opportunities. This dual orientation is a key driver of competitive success in dynamic environments.

Ambidexterity is not merely a strategic goal but a complex and continuous strategic process that represents a fundamental pillar for sustaining organizational success in rapidly changing contemporary business environments (Alaskar et al., 2024).

Strategic intelligence plays an important role in enhancing strategic foresight and environmental interpretation. This supports the effective deployment of exploitation strategies and digital exploration. These digital capabilities reshape organizational processes, making them more adaptive, responsive, and opportunity-driven, ultimately strengthening OBM.

Based on this perspective, the study assumes that digital technology-based organizational ambidexterity serves as the mechanism through which strategic intelligence influences behavioral motivation toward superior performance. By integrating strategic intelligence competencies with exploration and exploitation capabilities through investment in digital technologies, such as artificial intelligence, intelligent decision-support systems, interactive digital platforms, digital competitive intelligence tools such as Crayon and SEMrush, and scenario modelling and simulation tools, organizations can enhance the effectiveness of strategic intelligence and develop organizational behavioral motivation toward a continuous orientation for superior performance.

Based on this framework, the study is built upon the following hypotheses:

- There is a statistically significant direct effect of strategic intelligence on OBM for superior performance.
- There is a statistically significant direct effect of strategic intelligence on digital technology-based organizational ambidexterity.
- There is a statistically significant direct effect of digital technology-based organizational ambidexterity on organizational behavioral motivation for superior performance.
- There is a statistically significant indirect effect of strategic intelligence on organizational behavioral motivation to achieve superior performance through digitally technology-based organizational ambidexterity.

3 METHOD

3.1 Study Population and Sample

The study population comprised 23 major industrial companies in Algeria's Eastern Industrial Zone. From this population, 15 companies were randomly selected, representing the largest and most prominent enterprises in the region. A purposive sampling technique was employed to distribute the study instrument to executive managers, their deputies, department heads, and organizational leaders. A total of 200 questionnaires were distributed, all of which were retrieved and subjected to statistical analysis.

3.2 Study Instrument

The questionnaire served as the primary data-collection instrument and was developed based on the relevant academic literature on the study variables. Because the dependent variable, organizational behavioral motivation, has not been statistically measured in prior empirical research, its items were developed using the theoretical framework proposed by Gavetti (2012) and Gavetti and Porac (2018). Academic experts in management sciences subsequently reviewed the instrument to assess its content validity, and the items were approved after expert evaluation. The initial version of the questionnaire consisted of 36 items, distributed across the study variable:

- *Independent variable:* Strategic Intelligence, measured through four dimensions: foresight, future vision, systemic thinking, and intelligent motivation.
- *Dependent variable:* OBM, comprising three dimensions: opportunity identification, flexibility, and shaping capability.
- *Mediating variable*: Digital technology-based organizational ambidexterity, comprising two dimensions: digital exploitation and digital exploration.

3.3 Instrument Validity

To test the research hypotheses and achieve the study objectives, we first assessed the quality of the results obtained from the measurement instrument using the reference theory to define the theoretical framework (Brown, 2015). Construct reliability was assessed using four main criteria: Cronbach’s alpha, Composite Reliability (CR),

rho-A, and rho-C. The values of these criteria should exceed 0.70 (Mekdade et al., 2026). Subsequently, construct validity was assessed to demonstrate the instrument's accuracy and soundness. Convergent validity was assessed using the Average Variance Extracted (AVE) with the requirement that AVE > 0.05.

Additionally, the questionnaire included items on the respondents' demographic and professional characteristics.

Table 1. *Convergent Validity Test Results*

No.	Cronbach's Alpha	rh_A	rh_C	AVE
Strategic Intelligence	0.902	0.904	0.919	0.535
Organizational behavioral motivation	0.901	0.904	0.919	0.560
Digital technology-based organizational ambidexterity	0.894	0.916	0.911	0.605

Source: Prepared by the researchers based on Smart Pls4 outputs

The indicators reported in Table 1 present the results of the convergent validity assessment. The reliability coefficients, including Cronbach's alpha, rho_A, and rho_C, range from 0.894 to 0.919, exceeding the recommended threshold of 0.70. In addition, the average variance extracted (AVE) values for the three variables range from 0.535 to 0.605, exceeding the acceptable cut-off of 0.50. These findings indicate that convergent validity was established and that the measurement instrument demonstrates high reliability.

3.4 Discriminant Validity

To avoid multicollinearity, we assessed discriminant validity to ensure that the constructs used to measure the causal relationship under study are distinct and do not measure the same construct. We relied on the HTMT criterion, applying bootstrapping to verify that the HTMT value differs statistically from 1.00 at the 95% confidence level (Hair et al., 2019).

The data presented in Table 2 indicate that the HTMT values for the study constructs range from 0.248 to 0.835, all below the maximum acceptable threshold of 0.90. Furthermore, after applying the bootstrapping procedure, the HTMT confidence intervals confirm that discriminant validity is established at the 95% confidence level.

Table 2. *Discriminant Validity Results*

No.	Original sample (O)	Sample mean (M)	2.5%	97.5%
Mediating <-> dependent	0.248	0.270	0.167	0.402
Independent <-> dependent	0.835	0.835	0.766	0.892
independent <-> mediating	0.403	0.412	0.306	0.531

Source: Prepared by the researchers based on Smart Pls4 outputs

Table 3. *Model Fit Results*

	Value	Acceptance Criterion
SRMR	0.060	>0.08
NFI	0.709	Between 0 and 1

Source: Prepared by the researchers based on Smart Pls4 outputs

Table 4. *Results of the Analysis*

No.	Variable	Mean	Degree of Agreement
1	Foresight	4.022	High
	Future vision	4	High
	Systemic thinking	3.99	High
	Intelligent motivation	4	High
	Intelligence strategic	4.003	High
2	Opportunity identification	4.15	High
	Flexibility	4.12	High
	Shaping capability	4.05	High
	Organizational behavioral motivation	4.10	High
3	Digital exploitation	3.90	High
	Digital exploration	3.18	Medium
	Digital technology-based organizational ambidexterity	3.54	High

Source: Prepared by the authors based on SPSS outputs

Table 3 reports the Standardized Root Mean Square Residual (SRMR), which was used to assess the overall model fit. Following the recommended criterion, an SRMR value below 0.08 indicates an acceptable model fit. The SRMR value of 0.06, therefore, suggests that the proposed model demonstrates a satisfactory level of fit. Accordingly, the results of the analysis are reliable and appropriate for interpretation.

4 MEASURING THE LEVEL OF PRACTICE OF THE STUDY VARIABLES

To analyze the levels of strategic intelligence, organizational ambidexterity in the context of digital transformation, and OBM for superior performance in the institutions under study, arithmetic means were calculated for each construct dimension. The results are presented as follows:

The statistical data presented in Table 4 indicate a high level of practice in strategic intelligence, digital technology-based organizational ambidexterity, and behavioral motivation for superior performance, as the arithmetic means of the variables fall within the range of [3.41-4.20], reflecting a high degree of practice.

The variable "behavioral motivation for superior performance" ranks first, with an overall mean of 4.10. Similarly, its dimensions-opportunity identification, flexibility, and shaping capability-also recorded high mean scores.

Strategic intelligence ranks second, with an overall mean of 4.003. The results show a high level of practice in foresight, future vision, intelligent motivation, and systems thinking, with very close mean values among these dimensions.

Finally, digital technology-based organizational ambidexterity ranks third, with an overall mean of 3.54. A high level of practice is observed for the exploitation dimension. In contrast, a moderate level of practice is noted for exploration, with a mean of 3.18, which falls within the range [2.61– 3.40].

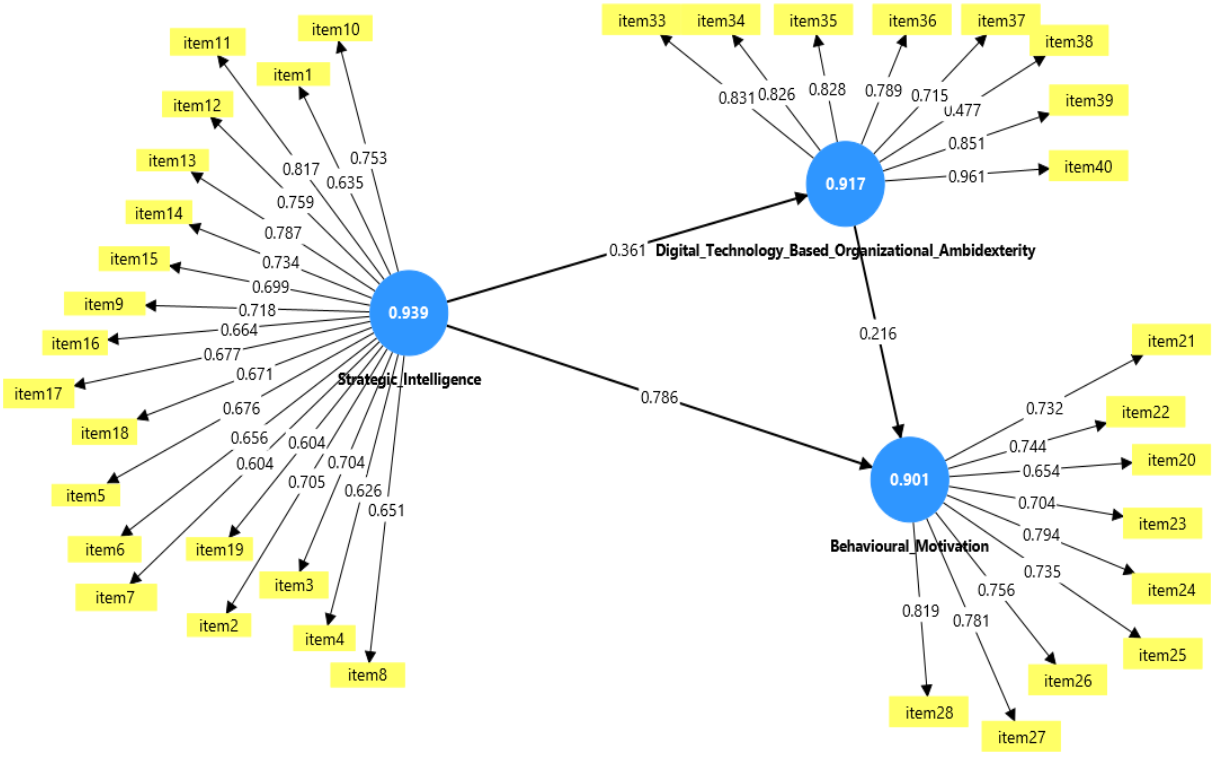


Figure 1. *Structural model of the study*
Source: Prepared by the authors, based on Smart Pls4 outputs

5 HYPOTHESIS TESTING

The research adopted the Partial Least Squares Structural Equation Modelling (PLS-SEM) algorithm. PLS-SEM is considered a predictive and causal approach to structural equation modelling in this study. The causal approach focuses on examining the overall relationship

between the independent and dependent variables and subsequently assessing whether this relationship weakens or disappears upon the inclusion of a mediating variable. Accordingly, the theoretical relationship derived from the conceptual framework is tested, and the proposed hypotheses are empirically validated.

The structural model of the study is presented in Figure 1. The figure illustrates the model estimated using the Partial Least Squares Structural Equation Modelling (PLS-SEM) algorithm, showing the relationships among the study variables and the corresponding path coefficients.

The results indicate statistically significant relationships among the main constructs. Specifically, a weak but statistically significant relationship was found between strategic intelligence and digital technology-based organizational ambidexterity at the 0.05 significance level. Similarly, digital technology-based organizational ambidexterity showed a weak but statistically significant relationship with organizational behavioral motivation. In contrast, strategic intelligence demonstrated a strong and statistically significant relationship with organizational behavioral motivation at the 0.05 significance level.

Table 5 presents the results related to Hypothesis 1, which proposes that strategic intelligence has a statistically significant direct effect on organizational behavioral motivation.

Table 5. *Results of the direct effect of strategic intelligence on behavioral motivation*

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Strategic Intelligence -> Behavioral Motivation	0.785	0.787	0.032	24.173	0.000

Source: Prepared by the researchers based on Smart Pls4 outputs

The results presented in the table indicate a direct effect of strategic intelligence on behavioral motivation. The magnitude of this effect was β = 0.785, with a T-statistic of 24.173 and a p-value of 0.000, which is below the significance level of 0.05. Therefore, this effect is statistically significant, confirming the validity of Hypothesis 1.

Table 6 illustrates the direct effect paths among the variables when the mediating variable is included.

Table 6. *Results of the direct effect paths*

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Organizational_Ambidexterity_in_Digital_ Context -> Behavioral_Motivation	0.095	0.093	0.045	2.095	0.036
Strategic_Intelligence -> Behavioral_Motivation	0.895	0.897	0.023	39.152	0.000
Strategic_Intelligence -> Digital technology-based organizational ambidexterity	0.307	0.313	0.057	5.408	0.000

Source: Prepared by the researchers based on Smart Pls4 outputs

Based on the statistical results presented in Table 6, significant positive relationships were observed among the study variables. Specifically, strategic intelligence had a statistically significant direct effect on digital technology-based organizational ambidexterity (β = 0.307, T = 5.408, p < 0.001). Since the p-value is below the 0.05 significance level, this result supports Hypothesis 2.

The results also show that digital technology-based organizational ambidexterity has a direct positive effect on organizational behavioral motivation (β = 0.095, p = 0.036). This indicates that higher levels of organizational ambidexterity are associated with higher levels of behavioral motivation. As this effect is statistically significant at the 0.05 level, Hypothesis 3 is supported.

In the overall structural model, the direct effect of strategic intelligence on organizational behavioral motivation remained statistically significant after including digital technology-based organizational ambidexterity as a mediating variable (β = 0.895, p < 0.001). This finding indicates that the relationship between strategic intelligence and behavioral motivation remains strong even in the presence of the mediator.

Moreover, the introduction of the mediating variable did not reduce the strength of the direct effect. Rather, the magnitude of the relationship increased compared with the non-mediated model. This suggests that the role of digital technology-based organizational ambidexterity may not follow a conventional mediation pattern. Instead, the results point to a more complex relationship involving both direct and indirect effects. In line with MacKinnon et al. (2000), this pattern may indicate the possibility of inconsistent mediation or a suppression effect within the model.

Therefore, the indirect effect should be examined separately to determine whether the mediating role of digital technology-based organizational ambidexterity is statistically significant, as reported in Table 7.

Table 7. *Indirect effect results*

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Strategic_Intelligence -> Behavioral_Motivation	0.200	0.211	0.097	2.052	0.040

Source: Prepared by the researchers based on Smart Pls4 outputs

According to Table 7, the test of the indirect effect of strategic intelligence on behavioral motivation through digitally based organizational ambidexterity shows that this effect is statistically significant, with a coefficient value of $\beta = 0.200)$, a t-value of 2.052, and a significance level of $p = 0.040)$, which is below 0.05.

Accordingly, there is a statistically significant mediating pathway from strategic intelligence to behavioral motivation through organizational ambidexterity. It is also observed that this indirect effect does not operate independently of the strong direct effect reported in Table 6, reflecting the simultaneous presence of both pathways within the structural model.

From a comprehensive perspective, the coexistence of a significant indirect effect alongside a sustained, strong direct effect suggests a non-standard mediation pattern, potentially indicating inconsistent mediation accompanied by a suppression effect. This reflects a redistribution of effects between the direct and indirect pathways within the model.

Considering these findings, it is necessary to interpret the relationships among the variables within a complex third-variable framework, as suggested by MacKinnon et al. (2000) in the literature on the equivalence of mediation and suppression effects.

6 RESULTS AND DISCUSSION

This study examined the impact of strategic intelligence, as an independent variable, on organizational behavioral motivation toward superior performance. It also explored the mediating role of digital technology-based organizational ambidexterity in the relationship between strategic intelligence and organizational behavioral motivation. The investigation was conducted through a case study of 15 industrial companies located in the Eastern Industrial Zone of Algeria.

The results revealed a direct and positive effect of strategic intelligence on organizational behavioral motivation. These findings are consistent with Paiuc et al. (2024), who, through a systematic literature review and bibliometric analysis, emphasized that strategic intelligence, from a leadership perspective, acts as a driver of organizational competitiveness and supports its sustainability. Similarly, the findings align with Ahmadi et al. (2020), who reported a positive relationship between strategic intelligence and organizational entrepreneurial behavior, highlighting its role in supporting organizational

growth through opportunity recognition. The results are also supported by Alkharbsheh et al. (2020), who found statistically significant positive effects of strategic intelligence dimensions—future vision, systems thinking, motivation, and strategic partnerships—on organizational excellence.

The study also revealed a direct effect of digital technology-based organizational ambidexterity on organizational behavioral motivation. Although this relationship has received limited empirical attention, the result is consistent with Kandoth and Shekhar (2025), who found that ambidexterity, through exploration and exploitation, positively contributes to innovative behavior in the information technology sector. Similarly, Ürü et al. (2024) highlighted the positive role of organizational ambidexterity and digital transformation in strengthening organizational outcomes. This argument is further supported by Hoessler and Carbon (2022), who suggested that market superiority requires the development of digital exploitation capabilities to improve process efficiency, while stronger organizational positioning depends on digital exploration capabilities, including the adoption of advanced technologies such as cloud computing, the Internet of Things (IoT), and data analytics.

Regarding overall organizational performance, the findings indicate that success depends on the balanced use of exploitation and exploration capabilities. This reflects the positive role of digital technology-based ambidexterity in guiding organizational behaviors toward improved performance and strengthening competitive motivation. These results are further supported by AlShaygy (2025), who argued that long-term organizational success is achieved when firms simultaneously pursue exploration and exploitation strategies and use advanced digital technologies, such as artificial intelligence, big data analytics, and digital platforms, to enhance organizational resilience and performance.

This interpretation is consistent with Jacobsson and Linderoth (2025), who distinguish between efficiency-seeking and innovation-seeking logics in the use of digital technologies. The efficiency-seeking logic reflects exploitation-oriented activities, such as process optimization and the reduction of manual effort. In contrast, the innovation-seeking logic reflects exploration-oriented activities involving process redesign and value creation, with digital technologies serving as an enabling infrastructure for both logics.

This distinction clarifies how the role of strategic intelligence is reinterpreted in the context of digital transformation. It is no longer limited to traditional analytical and decision-making tools; rather, it increasingly relies on digital technologies to support strategic foresight, knowledge generation, and decision quality. Accordingly, digital transformation not only changes the tools of strategic intelligence but also reshapes their underlying mechanisms and internal logic, thereby strengthening their ability to support both efficiency and innovation requirements in dynamic organizational environments.

Although digitally enabled organizational ambidexterity showed a statistically significant effect on organizational behavioral motivation, the relatively low magnitude of this effect ($\beta = 0.095$) suggests limited practical impact. This may be because organizational ambidexterity operates mainly as a contextual and operational mechanism that supports behavioral translation rather than as a primary antecedent of motivation. Accordingly, its effect appears practically limited and should not be interpreted as a core determinant of organizational behavioral motivation in the studied context.

This finding can also be understood considering the nature of the dependent variable. Organizational behavioral motivation may be more strongly influenced by leadership and competitive factors than by technological factors. Moreover, the relatively low level of digital maturity in the studied context may further explain the weak effect, as digital ambidexterity practices may not yet be sufficiently embedded in organizational processes to exert a strong independent influence on motivation.

Although the study assumed that digitally enabled organizational ambidexterity would serve as an intervening mechanism, the empirical results suggest that this role does not follow a conventional full or partial mediation pattern. Instead, the findings indicate a more complex mechanism, potentially reflecting inconsistent mediation accompanied by a suppression effect. In this case, the mediating variable changes the

magnitude of the direct effect by accounting for overlapping variance between the constructs, suggesting that digital ambidexterity operates alongside strategic intelligence rather than functioning as a pure transmission mechanism in its effect on behavioral motivation (Lacasa et al., 2020).

The results indicate that strategic intelligence is a higher-order cognitive and strategic resource directly linked to shaping organizational competitive behavior. This explains why its direct effect on behavioral motivation remains strong even after digital ambidexterity is introduced. Accordingly, a substantial portion of the effect does not depend on digital ambidexterity. Rather, it stems from the inherent nature of strategic intelligence as a leadership-based cognitive capability that directly influences organizational orientation and behavior.

In contrast, digitally enabled organizational ambidexterity does not function as an independent causal channel that fully transmits or replaces this effect. Instead, it serves as an organizational and operational mechanism that translates strategic cognitive outputs into faster, more flexible, and adaptive organizational responses, thereby enhancing the organization's capacity to convert strategic outputs into actionable behaviors.

Within this framework, inconsistent mediation and suppression-like patterns reflect the complex interaction between strategic and digital capabilities in industrial organizations. Strategic intelligence directly generates motivational drivers related to competitiveness and performance orientation, whereas digital ambidexterity reorganizes this effect through exploration and exploitation mechanisms. However, these mechanisms do not operate with sufficient strength in the studied context, which explains the persistence of a strong direct effect alongside a weaker indirect effect.

This pattern may also be explained by the limited digital maturity of the sampled organizations, where digital infrastructures are not yet sufficiently developed to serve as a dominant channel for transmitting strategic effects. Consequently, organizations continue to rely more heavily on leadership-based cognitive mechanisms than on digital systems in shaping behavioral motivation.

Accordingly, digitally enabled organizational ambidexterity in this model does not operate as a conventional mediating mechanism. Rather, it functions as an organizational enabler that facilitates the transformation of strategic intelligence into effective organizational behavior without replacing its direct influence. This produces a statistically significant indirect effect and reflects a complex structural pattern involving direct effects, inconsistent mediation, and suppression-like dynamics rather than a simple linear mediation model.

From this perspective, digital ambidexterity can be understood as a variable that reorganizes the relationship between strategic intelligence and behavioral motivation by distinguishing the strategic cognitive component from the operational digital component of organizational responsiveness. In doing so, it helps refine and clarify the original effect of strategic intelligence by isolating the operational variance associated with digital mechanisms, allowing the strategic effect to appear more clearly and robustly in the structural model.

7 CONCLUSIONS

This study offers theoretical and practical contributions to the scholarly debate on strategic intelligence. It proposes a more complex model that goes beyond the traditional mediating role by highlighting digital technology-based organizational ambidexterity as a mechanism that reorganizes the relationship between strategic intelligence and behavioral motivation toward superior performance, rather than acting as a primary or dominant explanatory pathway.

The study also provides a statistically supported contribution to the literature on organizational behavior and contemporary organizational strategies by identifying dimensions for measuring organizational behavioral motivation toward superior performance. Importantly, the study does not focus on employees' individual psychological motivation; rather, it examines the organizational drivers that shape behavior aimed at achieving success in competitive markets, thereby distinguishing it from previous research in this field.

The results confirm that strategic intelligence is a key driver of behavior directed toward achieving

superior performance relative to competitors in the current business environment. Furthermore, the findings reveal that digital exploitation and exploration capabilities, which reflect digital technology-based organizational ambidexterity, enhance the organization's ability to channel cognitive and strategic outputs into effective operational responses, rather than serving as a substitute for the direct effect of strategic intelligence.

Accordingly, the study's implications provide a scientific basis for decision-makers to formulate strategies and approaches that support organizational ambitions and visions, enhance performance, and achieve sustainable excellence. The findings also highlight the importance of accumulated knowledge, both explicit and tacit, generated by human and artificial intelligence in the workplace, in identifying strategic opportunities, understanding competitor behavior, and responding to environmental changes. This enables organizations to strengthen their competitive position by reshaping strategies and setting new objectives aligned with ongoing developments and fluctuations in the business environment, ultimately achieving institutional excellence.

Based on these results, it is essential to develop and invest in strategic intelligence capabilities among leaders, alongside investment in modern digital technologies.

8 LIMITATIONS AND DIMENSIONS FOR FUTURE RESEARCH

In this study, organizational behavioral motivation for achieving superior performance was measured through three dimensions. This study is among the first to address this construct quantitatively, highlighting the need for further research to deepen understanding of this concept, which has often been overlooked in prior literature. Moreover, there is an urgent need to develop the theoretical framework further to more precisely define the nature and dimensions of this construct, including digital technology-based organizational ambidexterity, and to provide a more detailed elaboration of this concept within the framework.

This study explored digital technology-based organizational ambidexterity as a mechanism that reconfigures the relationship between strategic intelligence and behavioral motivation to achieve superior performance within a more complex structural framework.

Accordingly, the study recommends the following:

- Expanding the theoretical framework of strategic intelligence and digital organizational ambidexterity to deepen understanding of their mechanisms and impact on organizational behavior, thereby contributing to the development of a more robust and comprehensive causal model in further research.
- Exploring the role of digital capabilities in relation to strategic intelligence in organizational performance, with a focus on understanding how digital exploitation and digital exploration interact to achieve optimal organizational outcomes.
- Developing more comprehensive measurement tools for digital exploration and exploitation capabilities, covering all aspects of digital transformation within organizations, including practical applications of digital technologies such as cloud computing, the Internet of Things (IoT), and big data analytics.
- Re-examining the relationship between strategic intelligence and behavioral motivation using alternative models (such as direct -effect or interaction models), rather than assuming the existence of mediating variables.
- Investigating whether digital technology-based organizational ambidexterity functions as a direct independent variable, a context-dependent variable, or a mediating variable.

Furthermore, this study was conducted through a field survey of 200 managers across 15 industrial companies in Algeria. Despite the sample's significance and size, limiting the study to a single industrial sector may restrict the generalizability of the findings to other sectors.

Therefore, the study also recommends that future research expand to include diverse industrial and service sectors, as well as companies from different geographical and economic environments.

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MACROECONOMIC DYNAMICS AND GDP TRENDS IN THE WESTERN BALKANS: 2019–2024

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ABSTRACT

This paper examines macroeconomic dynamics and gross domestic product (GDP) trends in the Western Balkans over the period 2019–2024, with particular emphasis on the effects of the COVID-19 crisis and the subsequent phase of recovery. Using a comparative macroeconomic approach based on officially published data from international financial institutions, the study analyzes GDP growth rates, cross-country differences, and variation in the pace of recovery across the region. The results show a sharp contraction in 2020, especially in tourism-dependent economies, followed by a strong rebound in 2021 largely driven by base effects and fiscal support measures. However, during 2022–2024 growth moderated, reflecting inflationary pressures, energy price shocks, weaker external demand, and persistent structural restrictions. Despite certain signs of stabilization, significant heterogeneity remains, linked to differences in economic structure, institutional capacity, and exposure to global shocks. The findings deepen understanding of macroeconomic performance in the Western Balkans during periods of crisis and normalization, while offering policy-relevant insights for strengthening economic resilience, accelerating structural transformation, and supporting more sustainable long-term growth.

1 INTRODUCTION

The Western Balkans represent a region that has historically undergone significant political, economic, and social transformations. Although not formally a unified economic entity, the region comprises six interconnected economies that share similar structural characteristics, historical legacies, and development challenges. Over the past three decades, these economies have gradually transitioned from socialist systems to

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market-based economies. This process has been supported by international institutions such as the World Bank and the International Monetary Fund (World Bank, 2024; International Monetary Fund [IMF], 2024). Initiatives aimed at economic integration with the European Union constitute an important driver of structural reforms. However, uneven progress in democratization and institutional strengthening continues to constrain regional convergence (Gill & Raiser, 2012).

The period from 2019 to 2024 represents a particularly dynamic phase in the economic development of the Western Balkans. The year 2019 can be regarded as the last “normal” year prior to the onset of a major global crisis. The COVID-19 pandemic in 2020 led to a sharp contraction in GDP across all countries in the region. The effects were especially severe in tourism-dependent economies such as Montenegro and Albania (European Bank for Reconstruction and Development [EBRD], 2023). This contraction was structurally uneven and revealed deeply rooted vulnerabilities in the regional economies. These include insufficient diversification, strong dependence on the service sector, low levels of investment, and a high degree of import dependence (Boljka & Mencinger, 2020).

The economic recovery observed in 2021 was strong across the region but largely short lived, driven primarily by base effects. According to economic convergence models, developing economies are expected to experience higher growth rates following negative shocks (Barro & Sala-i-Martin, 2004). Nevertheless, limited structural reforms and weak institutional quality continue to constrain the growth potential of the Western Balkans (Fetai, 2015). During the period 2022–2024, regional economies entered a phase of decelerating growth, driven by global inflationary pressures and the energy crisis. This slowdown was further reinforced by weaker economic activity in the European Union, the main trading partner for all Western Balkan countries (World Bank, 2023).

In addition to global shocks, countries in the region face specific internal structural challenges. Constraining factors such as labor emigration, declining birth rates, weak institutional capacity, political fragmentation, and corruption represent long-term obstacles to development. These structural challenges continue to limit growth potential across the region (Zuk & Polgar, 2019). Demographic trends further deteriorate labor market conditions by widening the gap between the supply and demand for skilled labor. Although remittances play an important role in sustaining household consumption, they cannot substitute for structural investments. Such investments are necessary to improve productivity and support long-term growth.

The economic structures of the Western Balkan countries vary considerably. Serbia has the most diversified economy, characterized by a strong ICT sector and a relatively developed manufacturing industry (Stojev & Petreski, 2022). Montenegro and Albania are predominantly dependent on tourism, rendering them particularly vulnerable to global shocks. North Macedonia and Bosnia and Herzegovina exhibit limited growth due to low productivity and persistent institutional weaknesses (Mukherjee & Kurokawa, 2021).

Economic convergence toward the European Union remains a strategic objective for the region. However, Western Balkan economies are still in a prolonged transition phase, constrained by substantial structural and institutional limitations. This study analyzes quantitative indicators of GDP growth. It also explores deeper systemic factors that shape economic development. In addition, it examines the constraints that limit the region’s ability to achieve higher growth. Finally, it considers how these restrictions affect the stability and sustainability of economic performance.

The main research question is whether institutional quality and sectoral composition explain cross country differences in post pandemic recovery across the Western Balkans.

2 METHODOLOGY

The methodological approach employed in this study is based on a combination of quantitative and qualitative methods. This mixed-methods design enables a more comprehensive understanding of economic growth dynamics in the Western Balkan countries. Given the complexity of economic processes, a single analytical perspective is insufficient. The economies of the region also differ profoundly in their structural characteristics. Therefore, multiple analytical approaches are required to provide an integrated picture of macroeconomic developments (World Bank, 2023; International Monetary Fund [IMF], 2024).

The primary quantitative indicator used in the analysis is gross domestic product (GDP) growth. GDP is considered the most relevant measure of economic activity because it removes the effects of inflation. It also allows for meaningful comparisons across economies over time and across different levels of development (Krugman et al., 2018). GDP data were obtained from international institutional sources, including Eurostat, the World Bank, and the IMF, ensuring methodological consistency and reliability of the time series (World Bank, 2024).

In addition to GDP, the analysis incorporates complementary macroeconomic indicators such as inflation, unemployment, exports, imports, public debt, and foreign direct investment. These indicators provide additional context for interpreting changes in economic activity. They also help identify structural weaknesses and potential comparative advantages within the economies of the region (European Bank for Reconstruction and Development [EBRD], 2023).

escriptive statistical methods are used to present the main trends. Comparative analysis is then applied to assess differences across countries, over time, and with respect to key structural characteristics. The comparative approach is particularly important in studies of the Western Balkans. These economies display different levels of diversification, institutional capacity, and dependence on external economic factors (Boljka & Mencinger, 2020).

Qualitative methods are applied to interpret institutional factors, political stability, governance capacity, and the quality of public policies. According to institutional economics, the quality of institutions has a direct effect on investment, productivity, and innovation. It also plays a crucial role in determining long-term economic growth, especially in transition economies (Acemoglu & Robinson, 2012; Fetai, 2015).

The theoretical framework of this study is grounded in several well-established economic models. It draws on the neoclassical growth model (Solow, 1956), endogenous growth theories (Lucas, 1988; Romer, 1990), and institutional development theory (Acemoglu & Robinson, 2012). It also incorporates insights from the Keynesian approach to economic stabilization (Keynes, 1936). These models provide a foundation for understanding the deeper causes of growth and economic slowdowns in the region.

The visual component of the analysis includes graphs and tables illustrating GDP trends across different countries. Data visualization facilitates the identification of patterns, structural differences, and cyclical movements, as well as efficient cross-country comparison (Zuk & Polgar, 2019).

GDP growth rates are year on year growth rates from World Bank WDI (series NY.GDP.MKTP.KD.ZG), seasonally unadjusted; data were accessed on 15 December 2025.

Finally, the study adopts a methodological approach that integrates empirical findings with theoretical models. This combination allows for a deeper interpretation of economic dynamics and supports the identification of possible causal relationships. By combining quantitative and qualitative methods, the analysis provides a more holistic perspective. This perspective is especially valuable for the Western Balkan economies. These countries find themselves at the intersection of economic transition, European Union integration, and ongoing structural modernization.

3 THEORETICAL FRAMEWORK

Understanding economic growth in the Western Balkan countries requires the establishment of a solid theoretical framework grounded in the leading schools of economic thought. This section presents the most relevant models and approaches that explain how economic growth emerges and which factors accelerate or constrain it. It also examines how institutional and structural conditions shape macroeconomic outcomes in the region. The theoretical framework draws on the seminal contributions of economists such as Solow (1956), Romer (1990), Lucas (1988), Acemoglu and Robinson (2012), and Keynes (1936). In addition, the framework incorporates findings from contemporary research on post-socialist and transition economies (Barro & Sala-i-Martin, 2004; European Bank for Reconstruction and Development [EBRD], 2023).

Classical economists Adam Smith, David Ricardo, and Thomas Malthus laid the foundations of modern economic theory. In their view, economic growth arises from the division of labor, capital accumulation, and efficient allocation of resources

within a free market system. The classical model assumes self regulating markets and a minimal role for the state in economic activity. Although these assumptions may appear overly simplistic in the contemporary context, they remain analytically useful for post-socialist economies. These countries have undergone a transition from centrally planned systems to market-based frameworks.

In the Western Balkans, the transition toward a market economy has been marked by price liberalization, enterprise privatization, and increasing trade openness. These processes rely to a large extent on classical principles of competition and efficiency (World Bank, 2024). However, due to weak institutions, competitive markets have not been fully developed, which limits the effectiveness of the classical growth model.

The neoclassical growth model proposed by Solow (1956) represents a cornerstone of modern macroeconomics. In this framework, economic growth depends on:

- capital accumulation,
- population (labor force) growth,
- technological progress (treated as an exogenous factor).

A key assumption of the neoclassical model is the existence of diminishing returns to capital. This means that each additional unit of capital contributes progressively less to output growth. According to Solow, sustained long-term growth is possible only through technological advancement.

Applied to the Western Balkans, this framework suggests that regional economies with limited investment and low levels of technological development face significant barriers. These barriers limit their capacity to generate sustained and higher rates of economic growth. Under such conditions, these economies are likely to achieve only moderate growth rates (EBRD, 2023). At the same time, low productivity and insufficient savings rates slow the convergence process described by Barro and Sala-i-Martin (2004). This helps explain why Western Balkan countries often lag behind the growth performance of Central European economies.

Endogenous growth theory emerged as a response to the limitations of the neoclassical approach. Romer (1990) and Lucas (1988) argue that technological progress is not exogenous but rather endogenous, resulting from:

- investment in research and development (R&D),
- human capital formation,
- innovation,
- knowledge accumulation.

This framework suggests that economies can accelerate growth through sustained investment in technology, education, and research.

In the context of the Western Balkans:

- investment in R&D remains low,
- the share of high technology sectors is limited,
- emigration of young and skilled workers erodes human capital (Zuk & Polgar, 2019).

These factors indicate that the region has not fully exploited the potential of endogenous growth, which helps explain why long-term growth trends remain insufficient for rapid economic convergence.

Keynes (1936) emphasized the importance of aggregate demand and government intervention, particularly during periods of economic crisis. According to the Keynesian framework:the state should intervene through public spending, stimulate investment, support employment, when the economy enters a recession.

This approach was clearly applied during the COVID-19 pandemic, when Western Balkan governments introduced: wage subsidies, financial assistance to firms, tax deferrals.

Empirical evidence suggests that these measures mitigated the decline in GDP, which is consistent with the Keynesian theory of economic stabilization (Mukherjee & Kurokawa, 2021).

One of the most influential contemporary approaches is institutional economics. Acemoglu and Robinson (2012) argue that long-term economic growth depends on institutional quality, the rule of law, political stability, protection of property rights, and low levels of corruption.

Inclusive institutions foster growth, whereas extractive institutions lead to stagnation.

In the Western Balkan countries, institutional deficiencies include: slow reform implementation, political fragmentation, corruption and weak public administration (Fetai, 2015).

The EBRD (2023) emphasizes that institutional constraints represent the most significant barrier to long-term growth in the region surpassing even infrastructure limitations or capital shortages.

The reviewed theoretical approaches indicate that:

- the neoclassical model explains moderate growth and limited convergence,
- endogenous growth theory explains long-term weaknesses stemming from insufficient investment in knowledge,
- the Keynesian approach accounts for short-term stabilization effects,
- institutional theory explains persistent political and structural barriers to growth.

This combination of theoretical perspectives closely corresponds to the actual economic processes observed in the Western Balkan economies.

4 ANALYSIS OF GDP TRENDS BY WESTERN BALKAN COUNTRIES (2019–2024)

This section provides a detailed analysis of macroeconomic developments in Serbia, North Macedonia, Bosnia and Herzegovina, Montenegro, and Albania. The analysis is based on data from the World Bank, the International Monetary Fund (IMF), Eurostat, and national statistical institutions (World Bank, 2024; International Monetary Fund [IMF], 2024; Eurostat, 2024).

The objective is to identify growth patterns and structural differences among countries, as well as to explain why the region has exhibited varying degrees of resilience to global shocks.

Table 1. *Comparative GDP Growth Rates (%)*

Year	Serbia	North Macedonia	Bosnia and Herzegovina	Montenegro	Albania
2019	4.7	3.6	2.7	4.1	2.2
2020	-1.0	-4.5	-4.0	-15.0	-4.0
2021	7.9	4.5	7.0	13.0	8.7
2022	2.6	2.8	3.0	3.6	4.0
2023	3.8	2.1	2.5	3.2	3.5
2024	3.9	2.3	2.3	3.0	3.4

Note. GDP growth rates are derived from World Bank WDI (NY.GDP.MKTP.KD.ZG), supplemented where necessary with IMF and Eurostat estimates. Annual values, not seasonally adjusted. Data accessed 15 December 2025.

The data in Table 1 reveal strong fluctuations in GDP growth across Western Balkan economies. All countries recorded a contraction in 2020, with particularly severe declines in Montenegro (- 15.0%) and Albania (-4.0%). The following year brought a sharp rebound, especially in Montenegro (13.0%) and Serbia (7.9%). However, during 2022–2024 growth moderated to more sustainable but comparatively modest levels (see Table 1, Serbia 3.9% in 2024), indicating the combined effects of external shocks and structural limitations.

4.1 Serbia

Serbia is the largest economy in the region and demonstrated the highest resilience to the COVID-19 pandemic. While most countries in the region experienced double digit contractions in 2020, Serbia recorded a decline of only -1%, one of the best performances in Europe (EBRD, 2023). This outcome can be attributed to a strong industrial base, the expansion of the ICT sector, public infrastructure investments, and Keynesian demand support measures (Keynes, 1936; Mukherjee & Kurokawa, 2021).

Post-pandemic growth in 2021 was high (7.9%), consistent with convergence models predicting accelerated growth following a recessionary period (Barro & Sala-i-Martin, 2004).

In the subsequent years, growth stabilized at moderate levels (2.6–3.9%). This pattern reflected the slowdown in the euro area, inflationary pressures, rising energy prices, and constraints on productivity growth (Krugman et al., 2018).

The development of the ICT sector, which accounts for a significant share of Serbia's exports, indicates potential for endogenous growth (Romer, 1990; Lucas, 1988). However, infrastructural and institutional barriers continue to slow more rapid modernization.

Mechanisms and supporting indicators

- ICT exports have expanded and now represent a significant share of total exports.
- Employment increased in ICT, construction, logistics, and infrastructure programs.
- Large fiscal packages (≈11–13% of GDP) mitigated the pandemic shock.

– Diversification and fiscal stimulus increased resilience, although institutional barriers still constrain productivity growth.

4.2 North Macedonia

North Macedonia entered the 2019–2024 period with moderate growth (3.6%), but the pandemic led to a significant contraction (-4.5%). The economy is structurally vulnerable due to a limited industrial base, high import dependence, and insufficient diversification (World Bank, 2024).

Post-pandemic growth of 4.5% in 2021 was insufficient to offset deeper structural limitations. This is confirmed by EBRD advisory models, which identify weak governance frameworks and low productivity as the primary growth limiting factors (EBRD, 2023).

Growth during 2022–2024 (2.1–2.8%) remained below the regional average. This outcome is consistent with endogenous growth theory, which emphasizes the role of human capital and innovation deficits in prolonged stagnation (Romer, 1990; Lucas, 1988).

Mechanisms and supporting indicators

– Exports rely heavily on lower-value manufacturing.
– Youth unemployment remains relatively high.
– Foreign direct investment (≈ 3–4% of GDP) remains moderate.
– Limited innovation and human-capital development slow post-pandemic recovery.

4.3 Bosnia and Herzegovina

Bosnia and Herzegovina is characterized by a complex political and administrative structure, recognized as one of the most significant institutional risks in the region (Acemoglu & Robinson, 2012; Fetai, 2015).

In 2019, GDP growth was moderate (2.7%), followed by a contraction of -4.0% in 2020. Although 2021 recorded strong growth (7.0%), this was driven primarily by demand recovery, diaspora remittances, and fiscal spending rather than structural reforms (World Bank, 2024).

Institutional fragmentation reduces policy effectiveness and slows convergence processes (Zuk & Polgar, 2019). Growth during 2022–2024 (2.3–3.0%) reflects low resilience to external shocks and weak productivity performance.

Mechanisms and supporting indicators

– Remittances account for roughly 9–10% of GDP, sustaining consumption rather than investment.
– Foreign direct investment remains low (≈ 3% of GDP).
– Regulatory divergence across entities increases transaction costs.
– Institutional fragmentation limits policy effectiveness and private-sector expansion.

4.4 Montenegro

Montenegro exhibits the highest GDP volatility in the region. As one of Europe's most tourism dependent economies, it experienced a contraction of -15% in 2020, followed by growth of 13% in 2021.

These fluctuations largely reflect the economic structure dominated by tourism and services (EBRD, 2023). According to aggregate demand theory, economies dependent on a single sector tend to display pronounced cyclical instability (Keynes, 1936).

The 2022–2024 period shows moderate growth (3.0–3.6%) but without significant structural transformation, suggesting that volatility cycles are likely to persist.

Mechanisms and supporting indicators

– Tourism accounts for over one-quarter of GDP in peak years.
– Labor markets show strong seasonality.
– Public debt remains elevated, limiting fiscal space.
– Dependence on a single sector generates high vulnerability to demand shocks.

4.5 Albania

Like Montenegro, Albania is highly dependent on tourism and services. The pandemic resulted in a contraction of -4%, followed by strong growth of 8.7% in 2021.

This pattern aligns with research indicating that small open economies experience large fluctuations during global shocks (Mukherjee & Kurokawa, 2021).

Growth stabilized during 2022–2024 (3.4–4.0%). However, endogenous growth models warn that economies reliant on low-technology sectors

cannot achieve rapid long-term convergence (Romer, 1990).

Mechanisms and supporting indicators

- Service-based growth dominates output and exports.
- Large-scale migration and remittances (≈ 8–9% of GDP) support consumption.
- FDI is moderate and concentrated mainly in real estate and services.
- Growth driven by services and remittances is insufficient to sustain rapid convergence.

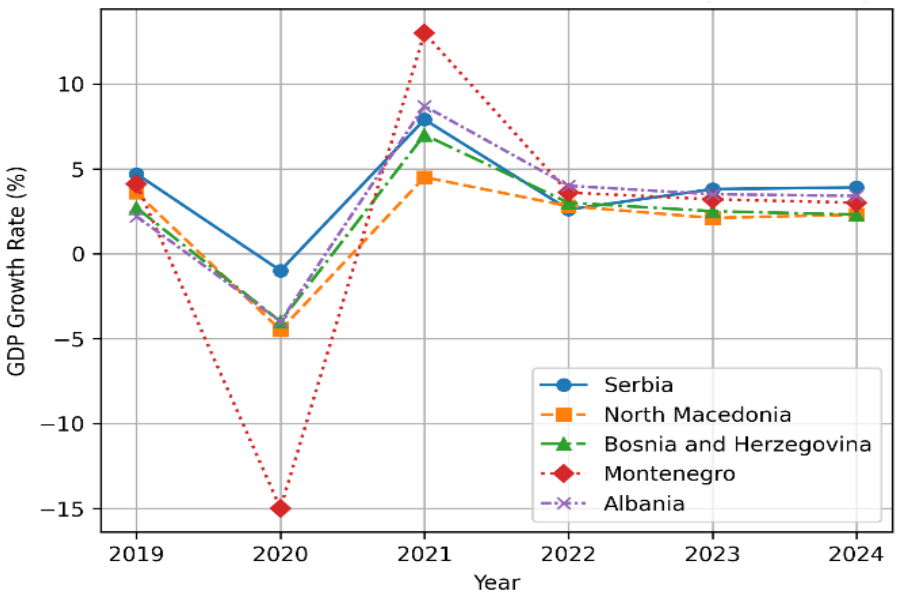


Figure 1. GDP Growth Trends in the Western Balkans (2019–2024)

Note: GDP growth rates from World Bank WDI (NY.GDP.MKTP.KD.ZG), harmonized where needed with IMF and Eurostat. Annual values, not seasonally adjusted. Accessed 15 December 2025.

Figure 1 confirms the pattern shown in Table 1. The abrupt decline in 2020 (e.g., –15% in Montenegro and –4% in Bosnia and Herzegovina) was followed by a rapid recovery in 2021. Growth subsequently slowed across the region, with most economies converging toward rates of around 2–4% by 2024.

5 REGIONAL COMPARATIVE ANALYSIS OF GDP TRENDS (2019–2024)

Regional comparative analysis enables deeper understanding of structural similarities and differences in economic performance across the Western Balkans. Despite national specificities, countries share common characteristics: transition status, strong dependence on the European Union, high import reliance, and limited industrial capacity (World Bank, 2024). However, the intensity and persistence of economic cycles vary significantly, indicating deeper structural differences.

Table 2 highlights notable differences in inflation, unemployment, and FDI. Inflation in 2022 exceeded 14% in Bosnia and Herzegovina and North Macedonia, compared with 6.7% in Albania. Unemployment remained particularly high in Montenegro (14.9%) and North Macedonia (14.4%). FDI inflows ranged from about 3.2% of GDP in Bosnia and Herzegovina to more than 6% in Serbia (see Table 2).

Table 2. *Key Macroeconomic Indicators (2022–2024)*

Country	Inflation 2022	Unemployment 2023	FDI (% of GDP)
Serbia	11.9%	8.2–8.3%	6.2%
North Macedonia	14.2%	14.4%	3.8%
Bosnia and Herzegovina	14.6%	14.0%	3.2%
Montenegro	13.2%	14.9%	6-8%
Albania	6.7%	11.2%	5.4%

Note. Data are taken from World Bank WDI, IMF, Eurostat, and EBRD databases. Accessed 15 December 2025.

5.1 Common Regional Macroeconomic Pattern

All regional economies follow a similar macroeconomic trajectory:

Phase 1: Pre-pandemic moderate growth (2019)

Growth rates of 2–4% align with neoclassical growth predictions for economies with limited capital accumulation (Solow, 1956).

Phase 2: Pandemic-induced contraction (2020)

The scale of declines varied widely, confirming that structural factors rather than the global shock alone determine recession depth (Mukherjee & Kurokawa, 2021).

Phase 3: Post-pandemic rebound (2021)

All countries experienced strong growth (4.5%-13%), largely reflecting base effects rather than structural transformation (Barro & Sala-i-Martin, 2004).

Phase 4: Deceleration during 2022–2024

Driven by inflation, energy price volatility, geopolitical tensions, and declining EU demand (Krugman et al., 2018).

5.2 Structural Factors Explaining Growth Differentials

Key differentiation factors include:

1. *Economic diversification*

Diversified economies exhibit more stable growth, while tourism dependent economies display higher volatility (Romer, 1990).

2. *Institutional quality*

Institutional variation significantly affects long-term growth prospects (Acemoglu & Robinson, 2012; EBRD, 2023).

3. *Demographic factors*

Declining fertility, emigration, and brain drain reduce human capital and constrain endogenous growth (Lucas, 1988).

4. *Trade dependence on the EU*

Heavy trade concentration with the EU increases vulnerability to external cycles (Eurostat, 2024; World Bank, 2023).

5. *Foreign direct investment structure*

FDI is largely directed toward low-productivity sectors, limiting long-term growth potential (Zuk & Polgar, 2019).

5.3 Synchronization of Economic Cycles

Research indicates high synchronization of recessions, recoveries, and inflation cycles across the Western Balkans due to trade integration, migration flows, euro pegged exchange rate regimes, and EU dominated financial systems (Mukherjee & Kurokawa, 2021).

Table 3 summarizes structural strengths and vulnerabilities rather than quantitative indicators. Serbia's diversification, North Macedonia's policy stability, and Montenegro's reliance on tourism illustrate how structural characteristics influence growth patterns observed earlier (see Table 1 and Table 2). Countries with stronger institutional frameworks and more diversified production structures tend to display greater resilience.

Table 3. Key Differences Among Western Balkan Countries

Country	Strength	Weakness
Serbia	Diversification, ICT	Institutional issues
North Macedonia	Policy stability	Weak industry
Bosnia and Herzegovina	Private sector	Political fragmentation
Montenegro	Tourism, FDI	High dependence, public debt
Albania	Tourism, integration	Corruption, emigration

Note. The table is based on synthesis of assessments from the World Bank, IMF, Eurostat, and EBRD reports, complemented by the author's interpretation. Accessed 10 December 2025.

5.4 Conclusion of the Regional Analysis

The primary differences among countries lie not in shock responses, but in economic structure, institutional quality, and shock absorption capacity. Economies with stronger institutions and diversification exhibit more stable growth, while tourism or remittance dependent economies display higher volatility.

6 CONCLUSION

The analysis of GDP dynamics in the Western Balkans during 2019–2024 shows that the region

remains highly exposed to external shocks. At the same time, limited diversification, persistent limitations in institutional capacity, and growing demographic pressures continue to shape its growth performance.

The strong rebound in 2021 was largely cyclical, driven by base effects and fiscal stimulus. The slowdown after 2022 reflected inflationary shocks, volatile energy prices, and weakening external demand. Sustainable convergence with the European Union therefore cannot rely primarily on short-term stabilization measures. It depends much more on structural transformation, productivity growth, and institutional strengthening.

In this context, several policy priorities emerge.

First, tourism-dependent economies should diversify toward higher-value and less seasonal segments and strengthen backward linkages with domestic suppliers, reducing vulnerability to global shocks.

Second, targeted programs are needed to retain and attract skilled labor, including incentives for return migration, stronger university–industry cooperation, and support for innovative start-ups.

Third, public investment in research, development, and innovation should be strategically concentrated in a few priority sectors, accompanied by transparent competitive funding and effective technology-transfer mechanisms.

Fourth, improving the investment climate requires digitalized administrative procedures, predictable regulation, and stronger anti-corruption safeguards.

Finally, policies that support productivity upgrading in small and medium-sized enterprises through technology adoption, export promotion, and improved access to finance, can foster more resilient growth. Such measures can also strengthen competitiveness and create more sustainable long-term development. Such policies can also contribute to greater economic inclusion and long-term competitiveness.

Overall, the region's ability to move from cyclical recovery to sustained development will depend on the consistent implementation of these reforms. It will also require stronger government capacity to coordinate economic, institutional, and demographic policies within a coherent long-term framework.

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ORIGINAL RESEARCH ARTICLE
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CRISIS MANAGEMENT STRATEGIES IN THE DISTRIBUTION SECTOR

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ABSTRACT

This paper investigates the role and implementation of crisis management strategies in the distribution sector, with a particular focus on logistics operations, supply chain systems, organizational structures, and communication processes. The theoretical framework addresses the core concepts of crisis management, different categories of crises, and contemporary strategic approaches, including organizational resilience, business continuity planning, and digital transformation. The empirical part of the research is based on a survey conducted among employees in distribution companies, aiming to assess the level of organizational preparedness for crisis situations. The findings indicate that, although companies demonstrate a moderate level of readiness, significant deficiencies remain in employee training, internal communication, and strategic crisis planning. The study further highlights the vulnerability of modern supply chains and emphasizes the necessity for greater operational flexibility and adaptability in times of crisis. Drawing on the results obtained, the paper proposes recommendations for improving crisis management practices through the adoption of an integrated management approach, enhanced digitalization, and the development of stronger organizational resilience.

1 INTRODUCTION

Contemporary society is characterized by continuous economic, political, and social transformations, which frequently emerge in the form of crises. These crises may be triggered by external factors, such as economic recessions, energy shortages, global pandemics, natural disasters, and geopolitical conflicts, or by internal organizational weaknesses, including insufficient adaptability, limited resources, and ineffective management practices. In this context, crisis management represents a crucial component of modern corporate governance, enabling organizations to prepare, respond to, and recover from disruptive events in a timely and effective manner.

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The distribution sector, as an intermediary link between production and end consumers, is particularly vulnerable to crises. Its performance is highly dependent on the stability of supply chains, transportation infrastructure, regulatory frameworks, consumer behavior, and overall market conditions.

In recent years, the distribution sector has been significantly affected by a series of global crisis events:

- The COVID-19 pandemic disrupted global supply chains, introduced border restrictions, and limited the movement of goods and people. As a result, distribution delays, product shortages, and the need for rapid operational adaptation became widespread.
- The energy crisis, along with rising transportation and storage costs, placed considerable pressure on corporate profitability.
- Inflation and increasing living expenses reduced consumers' disposable income, thereby decreasing purchasing power.
- Digitalization and the expansion of e-commerce created new opportunities but also introduced challenges for traditional distributors, who were required to invest in advanced technologies and logistics systems.
- Geopolitical crises contributed to disruptions in raw material supply, price volatility, and the necessity for supplier diversification.

These developments demonstrate that crises are an unavoidable aspect of modern business environments, and organizations lacking structured crisis management strategies are exposed to significant operational and financial risks.

Within the European Union, particularly in the post-pandemic period, crisis management has become an essential element of corporate governance. Companies are increasingly encouraged to develop Business Continuity Plans, implement risk management systems, and invest in digital technologies that enhance supply chain resilience.

In the Western Balkans, including North Macedonia, such practices are still in the process of development. Many distributors operate without formally established crisis management plans, which increases their vulnerability to disruptions. Furthermore, the region is additionally affected by political instability, underdeveloped transport infrastructure, and a high dependence on imports, all of which further complicate crisis response mechanisms.

The Macedonian distribution sector represents an important segment of the national economy, contributing significantly to trade and employment. However, it faces several structural challenges:

- High dependence on imports, as a large proportion of goods on the domestic market originates from abroad, increasing exposure to external shocks.
- Limited supplier diversification, with many companies relying on a small number of partners, increases operational risk during global disruptions.
- Insufficient financial resources for digital transformation, particularly among small and medium-sized enterprises.
- Regulatory instability, characterized by frequent changes in laws and regulations, creates uncertainty for business planning.

These factors clearly indicate the need for the development and implementation of comprehensive crisis management strategies aimed at ensuring resilience, continuity, and long-term stability within the distribution sector.

2 THEORETICAL FOUNDATIONS OF CRISIS MANAGEMENT

2.1 Definition and Conceptual Distinction

Crisis management is an integrated process that involves identifying, analyzing, and managing events that may result in severe negative consequences for an organization. Mitroff (2005) describes a crisis as a low-probability but high-impact event that threatens an organization's core values and survival. Similarly, Coombs (2014) emphasizes the importance of a systematic approach to crisis management, particularly in relation to communication processes and reputation protection.

Crisis management is a critical priority for organizations seeking to prevent or mitigate disruptions that may significantly affect operations

or threaten organizational continuity (Postolov & Postolov, 2025).

In literature, a clear distinction is made between risk, incident, and crisis. Risk refers to a potential adverse event with a certain probability of occurrence. An incident is an event with limited consequences that can typically be managed using existing resources. A crisis, however, represents a severe disruption requiring urgent and often non-standard decision-making (Fink, 1986).

Although closely related to risk management, crisis management differs in focus. Crisis management emphasizes response and recovery after a disruptive event, whereas risk management is primarily preventive (Coombs, 2014).

2.2 Types of Crises in the Distribution Sector

The distribution sector is exposed to various types of crises due to the complexity of supply chains and external environmental dependencies. Christopher and Peck (2004) noted that globalization and interdependence among markets significantly increase logistics system vulnerability.

Crises in this sector may be classified as:

- Operational crises (e.g., supply disruptions, transport failures, resource shortages)
- Technological crises (e.g., system failures, cyberattacks)
- Financial crises (e.g., liquidity problems, market instability)
- Natural disasters (e.g., events disrupting physical distribution flows)
- Reputational crises (e.g., loss of trust among customers and partners)

Sheffi (2005) argues that distribution organizations must develop adaptive and flexible systems, as even minor disruptions may create significant cascading effects across supply chains.

2.3 Crisis Management Models (Proactive, Reactive, Integrated)

Three primary crisis management models are identified in the literature.

The proactive model focuses on prevention and preparedness, including risk identification, scenario planning, and simulation training. Fink (1986) emphasizes that early detection of warning signals is crucial for minimizing crisis impact.

The reactive model focuses on response after a crisis has occurred, including damage control, communication with stakeholders, and operational stabilization (Coombs, 2014).

The integrated model combines proactive and reactive approaches and is based on continuous learning and adaptation. This model enables organizations to anticipate crises and reduce their impact while also responding effectively when they occur (Mitroff, 2005).

2.4 Modern Approaches (Resilience, Business Continuity, Digitalization)

Modern crisis management increasingly emphasizes organizational resilience and sustainability.

Resilience refers to the ability of an organization to adapt to change, maintain functionality during disruptions, and recover quickly afterward (Hollnagel et al., 2006). This is particularly important in dynamic and uncertain environments.

Business Continuity Management (BCM) ensures the continuity of critical business functions. The ISO 22301 standard provides a framework for planning, implementing, and improving continuity systems (International Organization for Standardization, 2019).

Digitalization also plays an increasingly important role. Technologies such as big data analytics, artificial intelligence, and automation improve risk detection and decision-making efficiency (Ivanov et al., 2019).

3 CRISIS MANAGEMENT IN THE DISTRIBUTION SECTOR

3.1 Role of Logistics and Supply Chain

Logistics and supply chain systems are central to the distribution sector, particularly during crises. Modern supply chains are highly complex and interdependent, making them vulnerable to disruptions. Christopher (2016) stated that

effective logistics management is essential for continuity and reducing crisis impacts.

Events such as transport failures, raw material shortages, or global disruptions (e.g., pandemics) may generate a ripple effect across the supply chain (Ivanov et al., 2019). Flexibility, supplier diversification, and digital integration are therefore essential for resilience.

Sheffi (2005) further highlights that organizations with resilient supply chains are better able to maintain operations during severe disruptions.

3.2 Organizational Structure and Human Resources

Effective crisis management requires a clearly defined organizational structure with assigned roles and responsibilities. This includes crisis teams, command hierarchies, and rapid decision-making procedures (Mitroff, 2005).

Human resources are a key determinant of crisis response effectiveness. Leadership, communication skills, and the ability to perform under pressure are essential (Boin et al., 2016). Training and simulations are widely used to prepare employees for crisis situations.

Organizational culture also plays an important role. Organizations that promote transparency, learning, and adaptability are better able to manage uncertainty (Hollnagel et al., 2006).

3.3 Communication Strategies in Crisis

Communication is one of the most important elements of crisis management. Lack of timely and accurate information can worsen crises and damage stakeholder trust. Coombs (2014) emphasizes that crisis communication must be timely, transparent, and consistent.

Communication occurs at multiple levels: internal, external, and public. Therefore, communication strategies should be pre-established within crisis plans.

The Situational Crisis Communication Theory (SCCT) suggests that communication strategies should be adapted based on crisis type and organizational responsibility level (Coombs, 2007).

3.4 Examples From Domestic and International Companies

Practical examples illustrate crisis management applications.

Toyota faced a major crisis involving vehicle recalls due to technical defects. Through transparent communication and rapid response, the company successfully restored customer trust (Liker & Ogden, 2011).

Amazon strengthened its logistics and digital systems during the COVID-19 pandemic to maintain delivery continuity, demonstrating strong organizational resilience (Ivanov & Dolgui, 2020).

In North Macedonia, distribution companies faced supply chain disruptions and increased demand. Many responded by diversifying suppliers and accelerating digital transformation, helping stabilize market conditions (OECD, 2021).

These examples demonstrate that successful crisis management depends on strategic planning, flexibility, and effective communication.

4 RESEARCH METHODOLOGY

The aim of this research is to examine how distribution companies manage crises, with a focus on logistics, organization, and communication.

A questionnaire was used and distributed to 50 employees and managers from different companies. It included demographic questions and Likert-scale statements.

Based on the presented data, one of the main limitations of the study concerns the size and representativeness of the sample. The sample consists of a total of 50 respondents, which represents a relatively small number for broader generalization of the results. A smaller sample size may reduce statistical reliability and limit the possibility of applying the obtained results to the entire population.

Additionally, the sample shows an uneven distribution across certain demographic characteristics. In terms of gender, male respondents (42) dominate compared to female respondents (8), indicating a gender imbalance. Furthermore, regarding educational level, the majority of respondents hold a bachelor's degree (37), while the categories with a master's degree

(3) and secondary education (10) are significantly less represented. Concerning age, certain categories are underrepresented, such as respondents over 50 years old (4) and those aged 44–49 years (2).

Due to these characteristics, the sample may not be fully representative of the target population, which constitutes a limitation in the interpretation and generalization of the research findings. Therefore, it is recommended that future studies include a larger and more demographically balanced sample in order to obtain more relevant and broadly applicable results.

The data were analyzed using descriptive statistics such as averages (Saunders et al., 2019).

Part 1 included three demographic questions related to the respondents' age group, gender, and level of education.

Part 2 consisted of closed-ended questions based on a Likert scale (1–5), aimed at measuring respondents' attitudes and perceptions.

According to Saunders et al. (2019), the survey approach is suitable for collecting standardized data and analyzing trends.

The data were processed using descriptive statistics and other methods, with results presented in mean values.

The first table presents the demographic characteristics of the respondents by gender, education level, and age. Its content is presented in Table 1.

We constructed Table 2 based on the answers received and obtained a mean score. The data from these demographic categories were used to better understand the respondents' backgrounds and their potential influence on perceptions of crisis management in distribution enterprises.

Table 1. *Demographic Characteristics of Respondents*

Sex	
Male	42
Female	8
Level of education	
High school	10
Graduated	37
M.A.	3
Age	
Under 25	5
Between 26- 31	15
Between 32-37	8
Between 38-43	16
Between 44- 49	2
Above 50	4

Source: Authors' original research, 2026.

Table 2. *Level of Organizational Preparedness and Crisis Planning*

No.	Finding	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Results
1.	Prepared for crisis	10	12	15	10	3	2.68
2.	The organization has a fully developed crisis plan	8	10	15	10	7	2.96

Source: (Authors' original research,2026)

According to the first question, "Prepared for crisis situation."

Calculated values are:

- Mean = 2.68
- SD = 1.17

The standard deviation (SD = 1.17) indicates a moderate dispersion of opinions around the mean value. Respondents do not have completely consistent views regarding the organization's preparedness for crisis situations.

Since the mean value is below the neutral point (3), respondents tend to disagree that the organization is adequately prepared for a crisis.

According to the second question, "The organization has a fully developed crisis plan."

Calculated values:

- Mean = 2.96
- SD = 1.26

The standard deviation (SD = 1.26) indicates slightly greater variability in responses compared

to the first question. Respondents have differing perceptions of whether the organization has a fully developed crisis plan.

The mean value (2.96) is almost identical to the neutral value (3), indicating uncertainty or divided opinions among respondents.

A reliability analysis was performed using Cronbach's Alpha to examine the internal consistency of the variables "Prepared for Crisis Situation" and "The Organization Has a Fully Developed Crisis Plan." The analysis yielded a Cronbach's Alpha coefficient of 0.885, indicating excellent internal consistency between the items. Therefore, the scale demonstrates a high level of reliability and can be considered suitable for further analysis.

The subsequent phase of the empirical investigation was devoted to the systematic examination of organizational practices concerning the implementation of structured training programs and simulation-based exercises aimed at enhancing employee preparedness for crisis situations. The corresponding empirical evidence is presented in Figure 1.

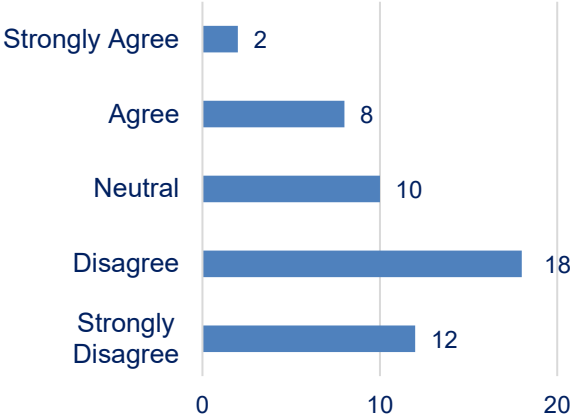


***Figure 1**. Distribution of Responses Regarding Crisis Training and Simulation Activities*
Source: (Authors' original research, 2026)

The findings indicate that organizations operating within the distribution sector in the Republic of North Macedonia exhibit a limited implementation of structured training programs in structured training and simulation activities related to crisis management. This indicates that crisis preparedness is not yet fully embedded within organizational human resource development strategies, thereby reflecting a limited degree of maturity in the implementation of proactive resilience-building mechanisms.

From a theoretical standpoint, such deficiencies may be interpreted as a lack of integration of anticipatory crisis management practices within organizational learning systems.

Based on the given table, we calculated the standard deviation, which in this case equals 1.13. A standard deviation of 1.13 in this case means that respondents answered relatively similarly, but there are still some individual differences in their attitudes.

Using the original research data, where respondents were categorized according to age, gender, and level of education, the following analyses were conducted in order to obtain more relevant results.

For our data, where the first variable is Age (ranked or in categories from 1 to 6) and the second variable is a Likert scale response (from 1 to 5), the value of Spearman's coefficient (ρ) is - 0.10, with a statistical significance p-value 0.50.

This means that there is no statistically significant relationship between the age of the respondents and their responses on the Likert scale.

An independent samples t-test was conducted to determine whether there is a statistically significant difference in responses on the Likert scale depending on the gender of the respondents. Levene's test for equality of variances indicated that the assumption of homogeneity of variances was met ($F = 0.10$, $p = 0.750$).

The results indicate a statistically significant difference between groups, $t(48) = -2.81$, $p = 0.007$. Female respondents achieved a significantly higher mean score ($M = 3.38$, $SD = 1.06$) compared to male respondents ($M = 2.21$, $SD = 1.07$). Since the p-value is below the 0.05 threshold (and even below 0.01), the null hypothesis is rejected, indicating that gender has a significant effect on the responses.

A one-way ANOVA analysis was conducted to examine the influence of education and age on responses on a Likert scale. The results showed a highly significant difference in responses depending on the level of education, $F(2,47) = 8.12,\ p = 0.001$. Respondents with a

lower level of education (Level 1) showed significantly higher scores on the scale compared to those with Level 2.

In the domain of crisis communication, the results demonstrate that:

- 70% of respondents perceive organizational crisis communication as insufficiently structured;
- 65% of respondents report the absence of formally established communication protocols.

These findings point to substantial deficiencies in both the formalization and operationalization of crisis communication frameworks. Within the theoretical framework of Situational Crisis Communication Theory (Coombs, 2014), such structural weaknesses may significantly increase the probability of reputational damage, reduce organizational legitimacy, and amplify stakeholder uncertainty during crisis events.

With respect to logistics and supply chain operations, 74% of respondents confirmed that crisis events most frequently manifest through disruptions in supply chain processes. This empirical outcome aligns with contemporary scholarly discourse on supply chain vulnerability and resilience, particularly the work of Ivanov, Dolgui, and Sokolov (2019), who emphasize that modern supply chain systems are characterized by high levels of interconnectivity and structural fragility, rendering them highly susceptible to cascading disruptions under conditions of uncertainty.

4.1 Discussion of Results

The interpretative analysis of the empirical data suggests that organizations within the distribution sector demonstrate a moderate overall level of crisis preparedness; however, this preparedness remains fragmented and unevenly developed across key organizational dimensions.

Firstly, logistics systems constitute the most critically vulnerable subsystem. This vulnerability is primarily attributable to the inherent complexity, global interdependencies, and limited redundancy within supply chain structures. In line with Christopher's (2016) conceptualization of supply chain resilience, the absence of multi-sourcing strategies, adaptive logistics frameworks, and contingency planning mechanisms significantly constrain organizational responsiveness and recovery capacity in crisis conditions.

Secondly, the findings indicate insufficient institutionalization of crisis preparedness and strategic crisis planning. This suggests that crisis management practices are largely reactive rather than proactive, which contradicts established resilience-oriented management paradigms emphasizing preparedness, anticipation, and adaptive capacity as core organizational competencies.

Thirdly, human resource preparedness remains underdeveloped. The lack of systematic training programs, scenario-based simulations, and experiential learning mechanisms indicate deficiencies in organizational learning capabilities. From the perspective of organizational learning theory, this reflects limited knowledge codification and weak feedback-loop integration within human capital development systems, thereby reducing overall organizational adaptability in crisis contexts.

Finally, communication emerges as a critical structural vulnerability. The absence of clearly defined communication protocols and insufficient transparency mechanisms undermines the effectiveness of crisis response coordination and increases the likelihood of information asymmetry. Within the framework of SCCT (Coombs, 2014), such deficiencies may significantly amplify reputational risk exposure and erode stakeholder trust during crisis escalation phases.

4.2 Recommendations for Improvement

Based on the empirical findings and theoretical insights presented in this study, several strategic measures can be proposed to enhance crisis management effectiveness within companies operating in the distribution sector.

First, organizations should focus on the development of comprehensive crisis management plans and strategies. These plans need to be formalized and systematically structured, incorporating clearly defined

scenarios, roles, responsibilities, and procedural guidelines. As emphasized by Mitroff (2005), well-developed crisis frameworks significantly increase organizational preparedness and enable more coordinated responses during disruptive events.

Second, there is a strong need for continuous investment in training and development of human resources. Companies should implement regular training programs, simulations, and crisis response exercises aimed at strengthening employees' competencies and situational awareness. According to Boin et al. (2016), such preparatory activities are essential for improving decision-making capacity and leadership performance under pressure.

Third, organizations should prioritize the enhancement of logistical flexibility and supply chain resilience. This can be achieved through supplier diversification, the establishment of alternative transportation routes, and the integration of advanced digital technologies. These measures contribute to reducing vulnerability and improving adaptive capacity in supply chain operations (Christopher, 2016; Ivanov et al., 2019).

Fourth, it is essential to ensure the development and standardization of crisis communication strategies. Clear communication protocols must be established to guarantee timely, accurate, and transparent information exchange with all relevant stakeholders. Effective communication is a critical determinant of trust, reputation management, and overall crisis response effectiveness (Coombs, 2014).

Finally, companies should invest in the implementation of business continuity management systems in accordance with internationally recognized standards such as ISO 22301. Such systems enable organizations to maintain essential functions during disruptive events and facilitate faster recovery and organizational stabilization (International Organization for Standardization, 2019).

Overall, these recommendations highlight the necessity of a proactive, structured, and integrated approach to crisis management, with a strong emphasis on preparedness, flexibility, communication, and continuity planning.

5 CONCLUSION

Crisis management represents an essential element in modern organizational management, especially in the distribution sector, which is characterized by high complexity, dynamism, and dependence on global supply chains. The theoretical analysis showed that crises are an inevitable part of the business environment and that their effective management requires a systematic, integrated, and proactive approach.

Through the review of theoretical concepts, it was determined that successful crisis management is based on a clear distinction between risk, incident, and crisis, as well as on the application of appropriate management models. The integrated model, which combines preventive and reactive measures, stands out as the most effective under conditions of increased uncertainty.

The analysis of the distribution sector indicated that logistics and supply chains are among the most critical segments in times of crisis. Their vulnerability, especially in the context of global disruptions, highlights the need for developing flexible and resilient systems (Christopher, 2016; Ivanov et al., 2019).

The empirical research confirmed that companies in the distribution sector have partial preparedness for dealing with crisis situations, but at the same time face significant challenges. Particularly notable are the shortcomings in human resource training, underdeveloped communication strategies, and the limited implementation of formalized crisis plans.

Additionally, the results showed that communication represents one of the weakest segments in crisis management, which can have serious consequences for the trust and reputation of organizations. This indicates the need for developing clear and structured communication protocols.

Overall, it can be concluded that crisis management in the distribution sector is in a developmental phase, with significant room for improvement through the application of modern approaches such as organizational resilience, business continuity, and digitalization.

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ORIGINAL RESEARCH ARTICLE
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DIAGNOSING THE MANAGEMENT OF DIGITAL CIRCULAR ECONOMY FOR SUSTAINABLE INNOVATION IN ALGERIA

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ABSTRACT

This research paper aimed to explore the revolution the world has witnessed in integrating digital technologies into circular economy models and their positive impact on promoting sustainable innovation, particularly in light of the Algerian government's efforts to expand the use of digital solutions in institutions, protect the environment, and achieve sustainable development. The study employed descriptive and analytical methodologies, utilizing data and statistics obtained from official websites and reports. Among its key findings, the study concluded that the transition to a circular economy cannot achieve tangible economic efficiency without relying on digital tools (such as the Internet of Things and artificial intelligence). Furthermore, the studied global models demonstrated that adopting digital circular solutions provides institutions with resilience against raw material price fluctuations and opens new international markets, which is essential for Algerian institutions to diversify their non-hydrocarbon exports. Finally, the study emphasized the need for the Ministry of Startups to direct its support towards projects that innovate technological solutions (platforms, smart recycling applications) to serve national strategies.

1 INTRODUCTION

Given the challenges facing the world regarding resource conservation and health security, all evidence indicates that the circular economy is the cornerstone of sustainable development and achieving its goals, through its practices in recycling, manufacturing, clean energy, and extending product lifespan.

At the same time, in the era of technological advancement, the Fourth Industrial Revolution, driven by digital technologies such as big data, artificial intelligence, the Internet of Things, and cloud computing, is reshaping the relationship between digital transformation and sustainable innovation, especially considering growing environmental concerns.

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The theoretical foundations and practical experiments that combined digital innovation with transformations in the circular economy proved that it was not a mere coincidence. Digital solutions have enhanced the vital role of environmental governance in managing pollution levels and improved companies' ability to manage the environment. Therefore, digital data can significantly improve the efficiency of storage, sales, and delivery of economic activities across various industries, equipment, products, and services. Experts and specialists reported that the circular economy currently needs more innovation and new skills, and this can only be achieved by integrating digital technology into it.

In response to increasing global pressure for sustainable innovation, Algeria has developed several comprehensive and integrated plans aligned with the Sustainable Development Goals and has accelerated the adoption of digital technologies. This could very well yield benefits, especially since the circular economy is still in its early stages, with limited economic, environmental, and social awareness of its importance.

1.1 Research problem

Algeria has recently adopted an ambitious vision to accelerate digital transformation and support the circular economy as a strategic option for achieving sustainable development outside the hydrocarbon sector. However, the reality on the ground has revealed a regulatory and technical gap that has hindered the emergence of genuine sustainable innovation capable of translating government plans into tangible economic and environmental results. Based on the above, the following research question arises:

RQ: *What are the most significant challenges between digital transformation and the realities of circular economy practices in Algeria to achieve sustainable innovation?*

1.2 Objective of the study

This research paper seeks to identify the progress the world has made in the field of the circular digital economy and to examine relevant theoretical literature, applying it to the reality of Algeria to develop solutions and proposals to bridge the gaps.

1.3 Methodology and approaches

The descriptive approach was used to accurately describe the phenomenon under study by collecting recent references related to the circular digital economy and sustainable innovation, even regarding the lived reality in Algeria.

As for the analytical approach, work was done to assess the global situation of the circular digital economy and interpret the case studies of selected companies. The data were obtained from reliable and approved reports and official websites.

The research design was divided into three sections:

- Literature Review
- Digital Circular Economy Revolution Globally
- Diagnosing the reality of the circular digital economy in Algeria

2 LITERATURE REVIEW

The term "circular economy" has gained increasing popularity among governments, international organizations, regulatory bodies, academics, and researchers (Anwar, 2022); it represents a radical shift from the linear model as part of the modern economy, as circularity seeks to separate growth from resource consumption through the optimal exploitation of goods and products. But over time, despite the promises of circularity, flaws began to emerge, particularly a lack of data and knowledge to evaluate products and manage waste (UNECE, 2023).

Studies and research have confirmed that digitalization and technology play a crucial role in the circular economy transformation. Digital tools are powerful enablers for implementing the circular economy. However, this process requires a comprehensive approach that integrates various technological advancements and regulatory changes to effectively apply its principles and achieve sustainability. The digital economy utilizes data as a fundamental element and digital technology as a driving force to achieve deep integration between the digital and real economies (Afolabi, 2025).

2.1 Digital technology as the circular economy enabler

The intersection of digital transformation and the circular economy has generated significant momentum, evident in the impacts of Fourth Industrial Revolution technologies such as artificial intelligence, the Internet of Things, blockchain, and big data analytics, by restructuring models at both operational and strategic levels and moving towards more sustainable and efficient systems (Li et al., 2026).

Given the advantages offered by digital transformation and technology, the circular economy leverages the internet and big data technologies to reorganize production factor resources and improve traditional production processes. Artificial intelligence can significantly improve energy efficiency and reduce pollution emissions in the production process. The application of technologies such as smart monitoring, smart homes, telemedicine, and smart cities not only reduces energy consumption by the population but also improves social well-being (Zheng et al., 2025). The Internet of Things (IoT) enables companies to remotely monitor product usage, status, and location in real time, and to recycle scrap products, contributing to the transition to a circular economy. By leveraging the results of process analytics and big data processing in the digital economy, digital data can significantly improve the efficiency of storage, sales, and delivery across various industries, technologies, equipment, products, and services (Liu et al., 2021). Data analytics is a powerful approach to improving decision-making. Leveraging software and business intelligence systems, analytics enables companies to transform data into insights, providing a foundation for better decisions. This contributes to driving management towards a circular economy by providing the necessary information for sustainability-focused decision-making processes (Benkarouba & Benbouzian, 2022). 3D printing as a potential tool for repair and remanufacturing. As a real-time physical twin simulation infrastructure, powered by industry data, digital twinning enables the filling of a digital health card for products. Self-operating or collaborative robots are also used to train production workshop workers on operations and to provide advice and information about their work or the product (Perry et al., 2024).

The application of modern technologies is considered a promising way to overcome obstacles to the transition to a circular economy. It can provide opportunities for the manufacturing sector, such as upgrading equipment, increasing worker efficiency and motivation, building smart factories based on resource efficiency, and designing closed-loop manufacturing chains (Liu et al., 2022).

Digitalization and technology also work to remove many of the obstacles facing the circular economy, including: financial obstacles (measuring financial benefits, profitability); structural obstacles (lack of information exchange, lack of clarity in the distribution of responsibilities); operational obstacles (infrastructure, supply chain management); and behavioral obstacles (the concept of sustainability, avoiding risks) (Benkarouba & Benbouzian, 2022).

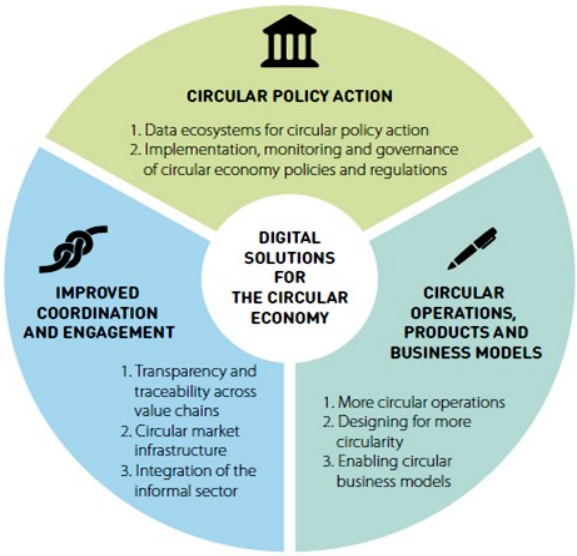


Figure 1. *Opportunities of Digitalization for Scaling up the Circular Economy*
Source: Compiled by Author

2.2 Technology and sustainable innovation

According to the United Nations Environment Program, digital technologies such as cloud computing, high-speed internet, and extended reality can help achieve the 17 Sustainable Development Goals (Florek-Paszkowska &

Ujwary-Gil, 2025). Despite the relatively recent convergence between digitization and sustainability trends, this phenomenon is gaining significant momentum as all parties call for the more sustainable and socially oriented use of digital technologies. Among the innovative sustainable outcomes, technology leads to energy efficiency, cleaner production, improved working conditions, and job creation. Adopting multiple digital technologies could enable companies to unleash sustainable innovation by leveraging the potential environmental and/or social benefits of each digital technology as sources of value creation (Ardito, 2023).

Cloud computing produces significantly fewer emissions than traditional server infrastructure. And, as with traditional software, when the Internet of Things is integrated with energy and utility systems, it supports smart grids that monitor energy consumption in real time, encouraging more sustainable use.(Mavi & Singh, 2025) Artificial intelligence and predictive analytics support preventative maintenance, helping various sectors use fewer resources, reduce costs, and increase efficiency. Smart homes also benefit from AI, which helps control heating, cooling, and lighting (Gülmez & Denktaş-Şakar, 2025). Many researchers have concluded that information and communication technologies play a crucial role in promoting sustainability, improving transparency, and enhancing evaluation capabilities through big data analysis and management. They also encourage high levels of development and entrepreneurial trends. (De Pascale et al., 2024). Digital media and communication technologies have undergone a radical shift towards "reducing reliance on materials" in recent years. This has made innovation more accessible and reduced the use of materials in manufacturing and recycling processes (OECD, 2024).

3 DIGITAL CIRCULAR ECONOMY REVOLUTION

Although the circular economy is a modern concept that focuses on strategies and solutions to improve how materials are used and achieve social welfare and ecosystem services that form the basis of an efficient economy, between 2018 and 2021, the Circularity Index was 6.9%, while the remaining Circularity Gap was 93.1%. The data revealed alarming facts: despite progress in some areas, the negative impacts remain significant, raising the question of what tools and innovations can make the world more sustainable (Rakowski et al., 2026).

In 2025, the UN Environment Program worked in 151 countries, advising governments and supporting businesses to become more sustainable in the face of the climate crisis related to emissions, chemicals, waste, and pollution. 17 countries were enabled in the field of technology to confront climate change through a financial envelope of US$70 million, and a partnership was formed with 4 countries in digital technology to make energy sustainable. For example, small and medium-sized enterprises in Africa and Asia contribute 25% of pollution. In this context, an alliance of 200 companies, including 37 technology companies, was launched to ensure more sustainable artificial intelligence (United Nations Environment Programme, 2026). But from another perspective, although these stimulus measures are appreciated, they cannot be considered a sovereign investment capable of bridging the technological gap, as providing a permanent financial envelope requires new financing mechanisms or "tax exemptions".

Despite the lack of data on the direct returns of the circular economy and the substantial capital costs required for ecological transformation, market forces are beginning to shift towards digital circularity as a competitive imperative. This is evident in the anticipated surge in the size of this market, which is projected to increase fivefold to reach $12 billion by 2032. This growth is not merely digital expansion, but rather an economic response to the effectiveness of technologies like the Internet of Things (IoT) in reducing long-term operating costs, thus transforming green practices from an investment burden into an engine for producing high-value-added sustainable goods.

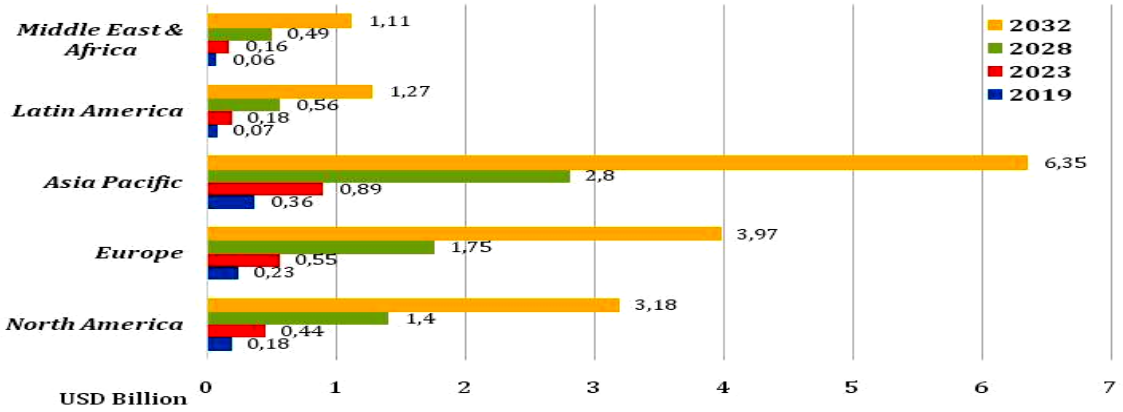


Figure 2. *Digital Circular Economy Market Size 2019-2032(USD Billion)*
Source: Author, based on (Agarwal, 2024)

According to a 2019 survey, approximately 28% of firms revealed that they had already integrated circular design methodologies into their innovation strategy. In contrast, around 39% stated that they intended to implement circular economy methodologies in their innovation strategy within the next two years. That's because many companies often announce green initiatives to improve their market reputation, but when it comes to implementation, they encounter high transition costs, also 12% of firms immediately decided to link the circular economy to the supply chain, This category is the most mature group, because a circular economy only succeeds if it includes supply.

A 2024 OECD survey found that 52% of respondents currently use smart devices, and 5% of them use the internet to reduce environmental impact. According to the International Energy Agency, demand for digital solutions will reach between 1.5% and 3% globally by 2026. The expansion in the use of artificial intelligence has contributed significantly to this growth and is expected to lead to a 160% increase in energy demand in data centers by 2030 (Gray & McSpedden-Brown, 2025).

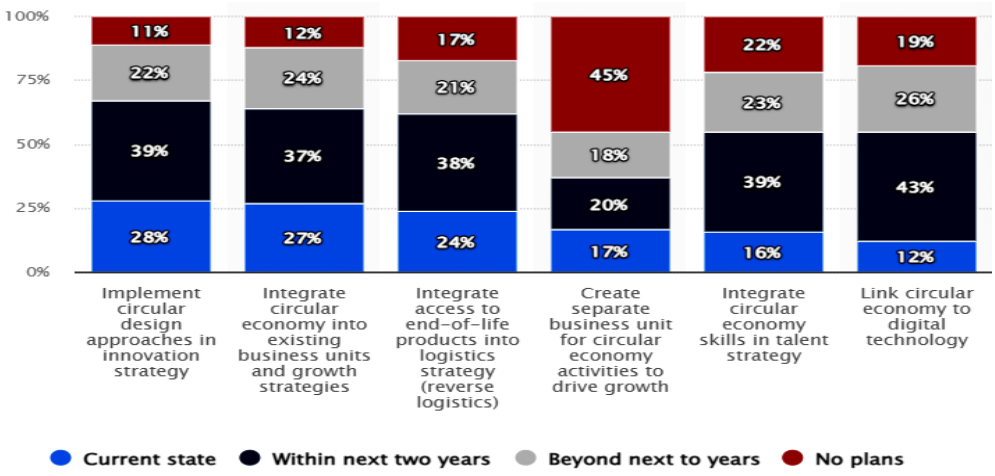


Figure 3. *Strategy of Supply Chain Firms to Integrate Circular Economy Practices*
Source: (Statista Research Department, 2025)

Due to the recent technological revolution, many companies and enterprises have transformed their linear business models into a circular format and considering the effects of human activities (such as climate change, pandemics, and resource scarcity), the strategic orientation and operational procedures of production companies are a clear contribution to sustainability.

Therefore, it will maintain and enhance its competitiveness while minimizing the negative environmental impact of commercial and production activities and manufacturing products with high efficiency. However, it is essential to always focus on building a mature digitalization model and expanding it to include sustainability considerations. This will provide more options in

strategy development processes that integrate sustainability in terms of social, economic, and environmental aspects (Kohl et al., 2023).

Table 1 illustrates the most prominent achievements of major related companies.

Table 1. *The 3 Largest Companies Relying on the Digital Circular Economy*

BMW GROUP (GER)	UNILEVER (UK)	CATERPILLAR (USA)
∗ The BMW Group is currently undergoing the biggest transformation in its history, having developed a strategic plan that sets new standards for sustainability and competitiveness: lean production, green production, and digital transformation. ∗ The company now uses more than 100 electronic applications including virtualization and digital twinning, to improve production quality, automate logistics processes, and reduce the burden on workers. The company is working to reduce Co2 by embracing technology, through the production of electric cars and fuels made from renewable raw materials.	∗ As part of Unilever's GAP 2030 strategy, the marketing department is leading a rapid and radical transformation to unlock greater creative potential. Technology is helping to expand creative ideas that strengthen brands and drive sales. ∗ Within the framework of the circular digital economy, the company has a set of goals, the first of which is to reach net-zero emissions by 2030.Innovative smart refill stations were launched for users, eliminating the need for plastic, and a chemical recycling technology was developed using artificial intelligence and the value chain to convert traditional non-recyclable waste into usable food products.	∗ The company is one of the largest factories in the construction and mining sectors. ∗ It is also a pioneer in adopting technologies in the recycling process, restoring products to their original state with 90% less energy, saving 90% of raw materials, and reducing greenhouse gas emissions using the Internet of Things and big data analytics. The company's competitive advantage lies in its constant pursuit of sustainable innovation, particularly for its workers. Caterpillar's advanced software and cloud computing enable engineers to complete tasks in a fraction of the time, and the ambition now is to leverage artificial intelligence to enhance its business outcomes.

Source: (BMW Group, 2026; Unilever, 2026; Caterpillar, 2026)

The case study of the three companies reveals that the point of similarity between them is the gradual transition from a product-selling model to a product lifecycle management model through digital tools such as cloud and artificial intelligence. Digitalization is also used as a competitive shield to reduce dependence on raw materials, energy and emissions to open up new environmentally conscious consumer markets. The three companies have also linked technology to reducing the burden on workers and innovating for them, which is an important dimension in the social economy to ensure the acceptance of digital transformation:

1. *BMW Group:* The Company uses digital twinning to reduce trial-and-error costs. By digitally simulating the factory and testing production lines without disrupting the actual plant, it improves asset return and reduces waste in fixed capital. It focuses on investing in renewable fuels alongside electricity and pursues a strategy of diversifying its technology portfolio to cope with fluctuating energy prices and lithium supply chains. This raises the quality of the final product, enhancing its competitive advantage in the luxury goods sector.
2. *Unilever:* It is trying to move from the traditional sales system to selling without packaging, as the latter represents a large part of the cost of the final product; by eliminating it, it can improve the profit margin or offer competitive prices while reducing the risks of future plastic taxes.
3. *Caterpillar:* Saving 90% of raw materials and energy further reduces the cost of goods sold. The company resells the same material several times after refurbishing it, which dramatically increases the cumulative return on a single raw material. It uses the Internet of Things and big data as a tool for predictive maintenance. This reduces the opportunity cost resulting from the downtime of heavy equipment in mines or construction sites. Also, focusing on reducing task time through cloud computing means accelerating the innovation cycle, which keeps the company

technologically ahead of less digital competitors.

4 ANALYSIS OF THE SITUATION OF ALGERIA

Digital applications in the circular economy have become highly sought after in the Middle East and North Africa region, particularly in Algeria, especially after the COVID-19 health crisis and its negative impact on the economies of these countries, as well as the current challenges in environmental protection and waste management.

Although the circular economy is well-established and documented in national laws and regulations in Algeria, its concept is still in its early stages among the public and companies, due to a lack of awareness and its limitation to waste management and renewable energy solutions (Hadjivasiliouet al., 2023).

4.1 C-economy local problems

Algeria is considered a developing country where adopting a circular economy represents a real challenge that requires overcoming obstacles. The obstacles that Algerian companies face can be summarized as follows:

- *Technical Constraints*: Equipment and software are crucial for achieving the goals of the circular economy and are specifically used for environmental protection. However, their absence or inadequate availability creates challenges regarding the lack of qualitative and quantitative information on waste management and recycling practices.
- *Social and Cultural Challenges:* As previously mentioned, many industrialists, professionals, and businesspeople are unfamiliar with the modern concept of the circular economy. The prevailing negative view of waste, lack of awareness, absence of initiatives, and insufficient coverage by media and educational institutions have all contributed to the weak adoption of the circular economy (Adel & Guendouz, 2023).
- *Financial and legal obstacles:* Despite efforts to adopt the principles of the circular economy, Algeria continues to suffer from a lack of financial resources, regulatory frameworks, and laws, which could lead to a lack of public safety and health (Toumi, 2024).
- *Economic and Financial Constraints:* Investment in modern waste treatment technology remains low, and funding for circular economy initiatives is limited (Boudia & Djamil, 2025).

4.2 Government efforts in adopting digitalization and innovation

Since the years of independence, Algeria has been undertaking many initiatives to reach the digital revolution, especially since the higher authorities stressed the need to generalize the use of information and communication technologies and raise the level of digitization in the belief in the issues of energy, food and water security, and many bodies were created such as the Ministry of Digitalization and Statistics and the High Authority for Digitalization.

In June 2023 the National Digital Transformation Strategy 2025-2030 was launched, which aims to create a favorable business environment for the digital market, attract investments in this field, and improve Algeria's global ranking in digital development, also stimulating national social and economic development by promoting innovation, productivity, access to information, education, and social and financial inclusion (High Commission for Digitalization, 2024).

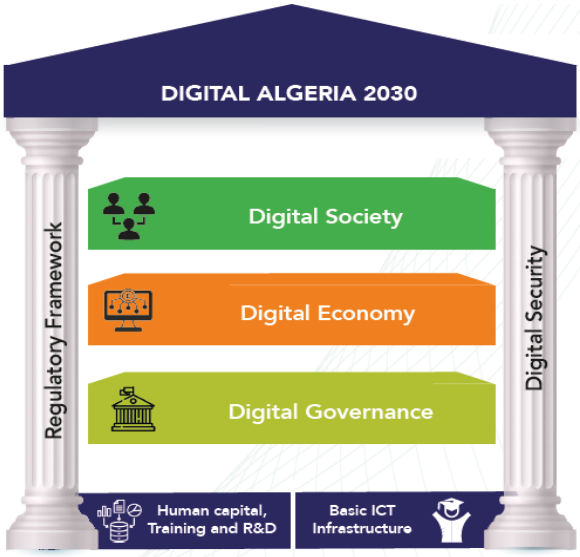


Figure 4. *The Algeria Digital 2030 Strategy*
Source: (High Commission for Digitalization, 2024)

To support innovation, the Algerian government has developed the National Innovation System Vision 2030-2040-2050. The first phase focused

on policy coherence and human capital development, given the weakness in scientific research and the lack of policy coordination. The second phase witnessed foundational work through creating integration between institutions, sectors, and regions, and promoting government innovation. The final step aimed for Algeria to become a global producer of knowledge, rather than just a user, and to distinguish itself with advanced innovations and competitive capabilities coupled with institutional maturity *(Zidane, 2025)*.

The Algerian strategies demonstrate a remarkable economic ambition to transition from a resource-based economy to a knowledge-based economy. However, they also present significant structural challenges. On the strengths side, Algeria has successfully established a specialized institutional framework and developed a long-term vision that transcends temporary solutions. This fosters investor confidence in the technology sector and startups and promotes financial and social inclusion. Furthermore, it reflects an awareness of the need to direct technology towards serving vital productive sectors, not just consumer ones. On the weaknesses side, the long timeframe of these strategies may clash with the accelerating pace of global technological advancements, potentially causing some objectives to fall behind schedule. Additionally, a potential gap exists between strategic texts and bureaucratic realities, which could hinder the agility of innovation. The transition from a consumer of knowledge to a global producer requires substantial investments in research and development (R&D) that exceed traditional financial capabilities. It also necessitates a more proactive legislative environment to transform academic human capital into tangible market-based economic value.

Table 2. *Cost-Benefit of Digital Technology Tools*

Technology	Cost (1000 USD)	Productivity Gain%
Cloud ERP	50-150	25-35%
IoT Sensors	20-80	15-25%
AI Analytics	100-300	30-45%
Automation	200-500	40-60%
Digital Training	10-30	10-20%

Source:(Zidane, 2025)

The purpose behind intensifying efforts and programs is to enable digital technologies to play a significant role in reducing the depletion of natural resources. This allows companies in Algeria to easily transition towards cleaner and more efficient production. Table 2 illustrates that investment in digital systems such as IoT sensors and artificial intelligence analytics enables the monitoring of energy flows and water, this a crucial step in diversifying Algeria's sources of income away from oil and natural gas revenues.

4.3 Programs to promote the circular economy

The following series of national and sectoral strategies have been developed to address a range of issues that hinder the operation of the circular economy in Algeria, and these are mainly as follows:

- *The National Integrated Waste Management Strategy for 2035* is a project of the Ministry of Environment and Renewable Energies, co-financed by the European Union, which will enable Algeria to develop better integrated waste management to contribute to the development of a green and circular economy and reduce environmental pollution.
  The main objective of this strategy is to reduce and recover value from the waste produced in Algeria. Algerian cities will have a more efficient and effective waste collection and treatment system. Selective waste sorting—by separating organic waste, paper and cardboard, glass, and other materials – will allow the government and the private sector to recover value from these materials and convert them into raw materials (Ministry of the Environment and Quality of Life, 2022).
- *Sustainable Consumption and Production National Action Plan (SCP-NAP*) established by the Ministry of Environment and Renewable Energy within the framework of the EU-funded SwitchMed program, with advisory services and technical support from the United Nations Environment Programme (UNEP)enables Algeria to renew its commitments to achieving the 17 Sustainable Development Goals (SDGs) more specifically Goal 12, and emphasizes the need to utilize digital solutions in this regard (The United Nations Environment Programme, 2020).
- *The Green Digital Innovation Plan 2025-2030* aims to develop and implement national

strategies for transitioning to renewable energy, promoting sustainable agricultural practices, and advancing low-carbon industrial development. It seeks to mitigate the effects of climate change, ensure energy security, and achieve economic diversification simultaneously*(Mahachi, 2025)*.

- *The Algerian National Blue Economy Strategy 2030 (NBES)* focusing on maritime and coastal areas, aims to drive and promote sustainable economic development throughout Algeria, with particular attention to supporting and developing employment opportunities and creating value across all value chains of the national economy (Economie Blue, 2022).

These Algerian national strategies represent a structural ambition and a qualitative leap aimed at digitizing vital sectors and valuing waste as an alternative raw material to reduce the import bill. The advantages are evident in the comprehensiveness of the vision that links food, water, and energy security with digital innovation, giving Algeria a "roadmap" that is compatible with international standards and attractive to foreign investments, especially through partnerships with the European Union and the United Nations Environment Program. However, gaps stand out in the heavy reliance on external financing and government support, which raises questions about the sustainability of these projects without direct investments from the local private sector. They also suffer from conflict between major strategic objectives and the bureaucratic and technical reality.

5 CONCLUSIONS

This article discusses the role of the digital economy as a key driver of sustainable innovation and the promotion of circular economy principles, and its application to the Algerian context.

The findings highlighted that digital technology, including automation, artificial intelligence, the Internet of Things, cloud computing, and data analytics, has the potential to contribute to environmental sustainability by reducing energy consumption, minimizing emissions, and promoting resource-efficient production processes.

The comparison between BMW, Unilever, and Caterpillar shows that digital technology is no longer just a tool for improving production but has become the main driver for restructuring the economic business model to ensure sustainability and profitability. The companies also share that “circular digitalization” has given them immunity against fluctuations in raw material prices and a greater ability to comply with strict environmental legislation, making them more attractive to investors looking for long-term and sustainable financial performance.

Algeria today possesses a range of visions. This integration proves the existence of a political will to break free from dependence on hydrocarbons by transforming environmental and digital challenges into investment opportunities to create added value. However, the problem remains the slow pace of transforming these strategies into an active "economic market" in which the private sector participates as a key player. Despite the focus on digitalization, the technological gap in data centers and artificial intelligence still constitutes an obstacle to the actual application of the smart circular economy, such as digital tracking of waste or predictive maintenance of industrial assets.

Some suggestions can be offered on the core of the subject: modernizing the legal and legislative framework by reviewing and updating laws related to waste management to adopt the principles of the circular economy, encouraging startups to innovate modern solutions and technologies for waste management and clean production, especially in the industrial sector; developing bank financing mechanisms for projects that adopt the green economy, allocating substantial capital to advanced recycling technologies, and raising environmental awareness.

Algerian companies must intensify their efforts in developing artificial intelligence algorithms specifically designed to improve logistics and manage waste sorting with precision, while promoting a culture of responsible consumption.

In conclusion, Algeria 2026 stands on the cusp of a new industrial revolution, its motto being intelligence in the service of sustainability. Furthermore, successfully integrating digitalization with circularity is not merely an economic project

but a national commitment towards future generations.

Regarding research limitations, there is a scarcity and difficulty in accessing accurate and up-to-date digital data on actual waste recycling rates in Algeria. This limited the analysis to the challenges and strategies adopted, making the study somewhat prospective, with the hope of future advancements.

Future research directions include the need to study mechanisms for implementing carbon taxes as a tool to incentivize Algerian industrial companies to adopt circular solutions, while also exploring the role of startups in developing local software for managing "reverse supply chains." It is also suggested to focus on analyzing "digital twinning" in the renewable energy and desert agriculture sectors to reduce material waste.

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REVIEW ARTICLE
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DIGITAL ALGERIA 2030: AN ANALYSIS OF THE DIGITAL TRANSFORMATION STRATEGY

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ABSTRACT

The present study analyzes the Algeria Digital 2030 strategy by situating it within the dual context of organizational digital transformation and the evolution of Algerian public policies. It first defines digital transformation as a process of reconfiguring organizational models, information systems, and competencies. Then, it traces the gradual development of the digital economy in Algeria, from the liberalization of telecommunications to the launch of the National Digital Transformation Strategy 2025–2030. The study then outlines the strategy's objectives and pillars, emphasizing infrastructure modernization, improved public services, a competitive digital economy, and a strengthened legal and cybersecurity framework. It presents the Algeria Digital 2030 vision through five structural axes (ICT infrastructure, human capital, digital governance, digital economy, and digital society) and two cross-cutting foundations (regulatory framework and information system security), accompanied by ambitious quantitative targets. Finally, the study discusses the challenges, issues, and prospects of this transformation, emphasizing both its strategic role in national sovereignty, state modernization, and economic diversification, as well as the persistent constraints related to territorial disparities in access, skills deficits, digital governance, and citizens' adoption of online services.

1 INTRODUCTION

Digital transformation has become a central focus of investigation in management sciences, economics, and public policy studies, as it fundamentally reshapes modes of production, regulation, and mediation between the state, businesses, and citizens. In countries of the Global South, and particularly in Algeria, this dynamic assumes a heightened significance with the recent adoption of the National Digital Transformation Strategy 2025–2030 and the vision of Digital Algeria 2030, which aim to position digital technology as a structuring lever for administrative modernization, economic

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diversification, and the reduction of inequalities in access to services. Within this context, the present study seeks to critically examine the capacity of this strategic framework to move beyond a logic of project accumulation toward the establishment of a systemic transformation, integrating infrastructure, human capital, digital governance, the economy, and society.

2 RESEARCH PROBLEM

From the foregoing discussion, the principal research question can be formulated as follows: "To what extent does the Digital Algeria 2030 strategy enable effective digital transformation?"

To further explore this central question, it can be broken down into several complementary sub-questions, addressing the strategic framework, the resources mobilized, and the observable effects of the digital strategy, as follows:

- Is the current strategic and institutional framework sufficiently coherent and operational to steer digital transformation effectively?
- Are the available digital infrastructures and competencies adequate to achieve the objectives set for 2030?
- To what extent does the strategy actually reduce territorial and social inequalities in access to digital services?

3 METHODOLOGY

This study adopts a qualitative policy analysis approach to examine Algeria's public digitization policies, ensuring methodological transparency.

The analysis is based on a corpus of 25 documents, including official texts (such as the National Digital Transformation Strategy 2025–2030 and institutional reports), communications, and academic studies on digital transformation, e-governance, and the digital economy. Documents were selected for their relevance to national digital policies and strategic objectives

A thematic content analysis combining deductive and inductive coding was employed to identify the main axes of the strategy (ICT infrastructure, human capital, digital governance, digital economy, digital society), its transversal foundations (regulatory framework, cybersecurity), and the alignment between announced objectives and persistent infrastructural, institutional, and sociocultural constraints. Coding selection criteria included relevance to digital infrastructure, skills development, governance, cybersecurity, and innovation ecosystems.

This documentary approach is appropriate for analyzing national digital strategies, as it allows a comprehensive assessment of policy intentions, institutional frameworks, and implementation challenges without relying on new primary data. It captures both explicit goals and implicit priorities, highlighting the alignment between strategy design and structural constraints.

In this study, digitization refers to data conversion, whereas digital transformation denotes organization-wide, strategic change enabled by digital technologies, encompassing broader reconfigurations of structures, business models, and value creation mechanisms. While related, these concepts are distinct and used consistently throughout the analysis.

3.1 Strategic Framework for Digital Transformation in Algeria

The strategic framework for digital transformation in Algeria can be introduced by emphasizing that it lies at the intersection of organizational, historical, and programmatic dynamics, which need to be presented in a coherent and integrated manner. First, it is essential to examine digital transformation within organizations, understood as a process of reengineering management practices, information systems, and user relations, to show how digital technologies are reshaping administrative and productive practices. This perspective is then placed within the historical context and evolution of digital policies in Algeria, from the initial telecommunications sector reforms to e-governance programs and state modernization initiatives. This approach allows for an understanding of both the genesis and the discontinuities of public choices regarding ICT. Finally, the analysis focuses on the primary objectives and pillars of the National Digital Transformation Strategy 2025–2030, detailing the structuring axes (infrastructure, governance, human capital, digital economy, and digital society) and quantified targets, to assess the overall coherence of Algeria's transition toward a fully digital economy and administration.

3.1.1 Digital Transformation within Organizations

Digital transformation can be understood as a managerial process aimed at integrally reconfiguring organizational culture, strategic orientations, operational processes, and competencies through the adoption and exploitation of digital technologies. It has proven to be a decisive lever for the growth of many emerging enterprises that, within a relatively short time, have achieved significant economic performance. Consequently, any project to integrate these technologies into organizational activities entails a revision of the business model, combining traditional approaches with the logics of the digital era to align them with organizational objectives.

Digital transformation results from the combination of multiple technological innovations, fostering the emergence of a plurality of actors—both direct and indirect—who carry value systems, representations, and practices that are continuously evolving, thereby profoundly redefining the "rules of the game" across different areas of organizational activity. Moreover, it holds particular strategic importance as an option for value creation and performance enhancement, provided it is conceived and managed appropriately by the organization's leadership (Zeriouh & Hamidi, 2024).

3.1.2 Historical Background and Evolution of Digital Policies in Algeria

Digital policies in Algeria began in the 1980s with the emergence of the first IT companies, followed by a liberalization of the telecommunications sector after 38 years of state monopoly. This marked a transition toward infrastructures such as fiber optics and satellites. During the post-independence period, the focus was placed on identity reconstruction through ICT (Aoudia, 2021).

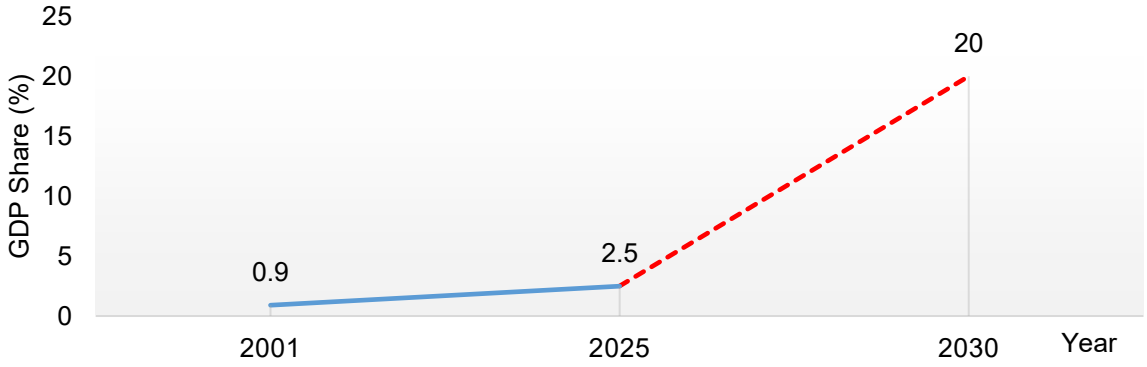


Figure 1. *Evolution of the Digital Sector's Contribution to Algeria's GDP from 2001 to 2030*

Source: Compiled by the authors based on data from the National Strategy for Digital Transformation in Algeria: Toward a Digital Algeria 2030 (Haut-Commissariat à la Numérisation, 2024).

Figure 1 illustrates the trajectory of the digital and ICT sector within the Algerian economy over three decades. It shows a moderate progression from 0.9% in 2001 to 2.5% in 2025, followed by an expected acceleration toward the ambitious target of 20% by 2030.

Rather than a forecast, the 20% target should be interpreted as a strategic ambition contingent upon sustained reforms, investment, and institutional capacity.

This trend reflects the commitment of the National Digital Transformation Strategy 2025–2030 to making digital technology a major lever for economic diversification.

The foundations of a digital economy in Algeria were laid in the early 2000s with the adoption of Law No. 2000-03 on August 5, 2000, which established the general rules for postal and telecommunications services and aimed to introduce competition in the sector. In 2001, revenues from the ICT sector represented approximately 0.9% of GDP, corresponding to an average annual consumption of about USD 16 per capita. ICT development strategies included revising institutional and regulatory frameworks, reorganizing operational structures, and improving telecommunications infrastructure, with the primary objective of adopting ICTs to modernize

operations and produce competitive goods (Bouberka et al., 2023).

Over the 2010s, digital uses diversified, including social networks for political mobilization and distance learning during lockdown periods (Aoudia, 2021).

Since 2023, Algeria has launched a *National Strategy for Digital Transformation (NSDT) 2025–2030*, approved by the Presidency, aimed at modernizing public services, training 500,000 ICT specialists, and increasing the digital economy's share of GDP to 20% by 2030 (Njoya, 2025). This strategy emphasizes digital sovereignty, with the creation of a High Commission for Digitization and a scientific committee in 2025, as well as the digitization of 110,990 university educational resources. Currently, the digital sector accounts for 2.5% of GDP, with efforts directed toward unified governance and digital inclusion (Bouaricha, 2025).

The period 2025–2030 represents a major transformation phase for Algeria's digital sector. Between 2025 and 2030, the contribution of the digital sector to GDP is expected to rise from 2.5% to 20%, an increase of 17.5 percentage points over five years. This projection reflects a significant acceleration and demonstrates the Algerian government's ambition through the *National Strategy for Digital Transformation 2025–2030*.

Achieving this ambitious target requires not only massive investments in infrastructure and training but also effective governance, citizen adoption of digital services, and stability in regulatory frameworks and cybersecurity.

3.1.3 Main Objectives and Pillars of the 2025–2030 National Digital Transformation Strategy

The Presidency of the Republic has approved the *2025–2030 National Digital Transformation Strategy*, which now serves as the official reference framework and regulatory instrument for the digitization process in Algeria. This adoption reflects the President of the Republic's firm commitment to establishing digital transformation as a strategic public policy and a national priority.

Under the slogan *"Towards a Digital Algeria 2030,"* this strategy sets out a comprehensive roadmap aimed at coordinating and streamlining digitization initiatives across the national territory, with a view to building a modern, innovative, and competitive digital society and economy.

The strategy is structured around three major pillars:

1. The modernization and expansion of digital infrastructure;
2. The simplification and optimization of public services through the use of effective digital solutions; and
3. The promotion of innovation and the development of a diversified and dynamic digital economy.

Its implementation is based on two essential foundations: firstly, the establishment of a robust legal and regulatory framework that ensures the structuring and sustainability of the digitization process; and secondly, the strengthening of cybersecurity to guarantee the protection of national data and information infrastructure (Algérie Poste, 2025).

3.2 Strategic Axes and Levers of Digital Transformation in the Digital Algeria 2030 Strategy

Figure 2 illustrates the strategic axes of Algeria's 2025–2030 National Digital Transformation Strategy. The architecture of this strategy is based on:

The five central strategic axes:

1. Digital Society;
2. Digital Economy;
3. Digital Governance;
4. Human Capital, Training, and R&D; and
5. Core IT Infrastructure.

The two transversal pillars that structure the entire strategy:

- Regulatory Framework (left column): Development of a comprehensive digital law and harmonization of existing texts to create a conducive legal environment; and
- Digital Security (right column): Systematic integration of cybersecurity requirements to protect critical data and information systems.

The illustration shown in Figure 2 presents an architectural representation of the Digital Algeria 2030 strategy, structured like a temple, evoking

the idea of a coherent edifice supported by foundations, pillars, and a pediment symbolizing the overarching vision. At the center, three horizontal blocks—"Digital Society," "Digital Economy," and "Digital Governance"—represent the three priority impact areas of digital transformation: the socio-cultural dimension, the productive sphere, and the functioning of the state.

The two lateral columns bear the inscriptions "Regulatory Framework" and "Digital Security," suggesting that the sustainability of the edifice depends on the robustness of law (regulation, standards, data protection) and the management of cyber risks, conceived as structuring conditions rather than mere technical components.

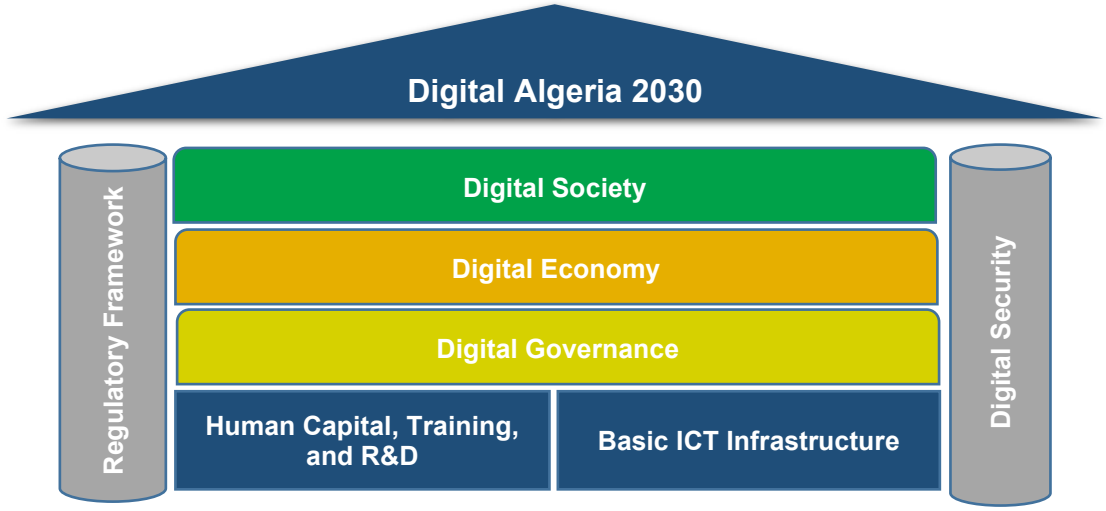


Figure 2. *Strategic Axes and Pillars of the Digital Algeria 2030 Strategy*
Source: (Haut-Commissariat à la Numérisation, 2024).

Finally, the base combines "Human Capital, Training, and R&D" with "Basic ICT Infrastructure," indicating that the strategy rests simultaneously on both skills and innovation on one hand, and networks, data centers, and equipment on the other.

Overall, this conveys a systemic conception of digital transformation: far from being limited to technological deployment, Digital Algeria 2030 is presented as a comprehensive transformation project integrating human resources, infrastructure, regulation, security, and socio-economic objectives.

3.2.1 Algeria Digital 2030 Strategy: Strategic Axes and Objectives

The Algeria Digital 2030 Strategy is structured around five strategic axes, each encompassing a set of targeted objectives aimed at fostering a sustainable and inclusive digital ecosystem. The purpose and focus of each axis are summarized in Table 1.

Table 1. *Strategic Axes and Objectives of the Algeria Digital 2030 Strategy*

Axis	Designation	Main Objective
Axis 1	ICT Core Infrastructure	Upgrade and modernize telecommunications networks, data centers, and connectivity to ensure resilient, equitable, and high-performance digital access across all services.
Axis 2	Human Capital, Training & Research & Development (R&D)	Establish a robust pool of ICT specialists, mitigate brain drain, and continuously align education and professional training with emerging technological trends.
Axis 3	Digital Governance	Digitalize internal administrative processes and public services, implement digital identity systems, promote interoperability, and facilitate open data initiatives to enhance governance efficiency and transparency.

Axis	Designation	Main Objective
Axis 4	Digital Economy	Position digital technologies as a principal driver of economic growth, transform traditional businesses, expand the digital industry and market, and attract Foreign Direct Investment (FDI), as well as leading global enterprises.
Axis 5	Digital Society	Promote inclusive and equitable access to digital technologies, strengthen online citizen engagement, and support the creation and dissemination of national digital content for all social groups.

Source:(Haut-Commissariat à la Numérisation, 2024)

In addition to the strategic axes, the Algeria Digital 2030 Strategy is underpinned by two cross-cutting foundational pillars, as presented in Table 2, which provide the institutional and security conditions necessary for effective implementation.

Table 2. *Pillars Supporting the Strategic Axes*

Pillar	Designation	Main Objective
Pillar 1	Legal and Regulatory Framework	Develop a comprehensive digital legislation and harmonize existing regulatory texts to establish a coherent, enabling environment for a sustainable digital ecosystem.
Pillar 2	Information Systems Security	Integrate cybersecurity principles systematically into all digital initiatives to protect critical data and systems, in alignment with the national information systems security framework.

Source:(Haut-Commissariat à la Numérisation,2024)

Table 2 above highlights the two foundational pillars supporting the strategic axes of Algeria's digital transformation strategy: the Legal and Regulatory Framework and Information Systems Security. The first pillar emphasizes the development, modernization, and harmonization of digital legislation, which is essential for creating a stable and enabling regulatory environment conducive to innovation, investment, and long-term sustainability. The second pillar focuses on the systematic integration of cybersecurity principles across all digital initiatives to safeguard critical data, ensure system reliability, and build trust among users, in line with the national information systems security framework.

Taken together, these pillars strengthen the sustainability, resilience, and credibility of Algeria's digital transformation efforts by ensuring both a robust legal foundation and effective protection of digital assets, which are critical prerequisites for achieving the objectives of the Algeria Digital 2030 Strategy.

3.2.2 Algeria Digital 2030 Strategy: Inclusive Development and Priority Objectives

The *Algeria Digital 2030 Strategy* was developed through an inclusive process, engaging government ministries, experts, enterprises, and other stakeholders in the digital ecosystem. The strategy aims to guide Algeria's digital transformation through five strategic axes, targeting *27 priority objectives* to be achieved between 2025 and 2030.

Axis 1: ICT Core Infrastructure

1. Establish more than 5 national data centers.
2. Promote widespread adoption of the national domain (.dz).
3. Achieve full high-speed broadband coverage across urban and rural areas.
4. Ensure universal access to ultra-high-speed broadband for all households and public institutions.
5. Promote the export of national cloud services.

Axis 2: Human Capital, Training & R&D

6. Train 500,000 active ICT specialists by 2030.
7. Reduce ICT skill emigration by 40%.
8. Foster digital research and innovation.
9. Enhance the attractiveness of the public sector for ICT talent, reducing departures by 20%.
10. Integrate digital competencies into school and university curricula.

Axis 3: Digital Governance

11. Digitize 100% of internal administrative procedures in the public sector (Percentages may not sum to 100 due to rounding).
12. Digitize 100% of public services for citizens and businesses (Percentages may not sum to 100 due to rounding).
13. Implement a digital identity for every citizen and enterprise.
14. Achieve interoperability across all public information systems.
15. Enable broad access to and sharing of public data.
16. Digitize approximately 40 public services by 2025–2026.

Axis 4: Digital Economy

17. Increase the contribution of the digital sector to 20% of national GDP.
18. Promote the adoption of digital systems by 80% of SMEs and SMIs.
19. Establish 100,000 digital start-ups.
20. Achieve USD 500 million in exports of ICT products and services.
21. Develop 50 national digital champions.
22. Attract USD 1 billion in Foreign Direct Investment (FDI).
23. Host 10 major global digital players in Algeria.
24. Expand e-payment solutions and eliminate cash transactions above 500,000 DZD.

Axis 5: Digital Society

25. Ensure equitable and inclusive access to digital technologies for all.
26. Increase citizen engagement through online public services.
27. Develop rich and diversified national digital content (Haut-Commissariat à la Numérisation, 2024).

4 STAKES, CHALLENGES, AND OPPORTUNITIES

This section examines the actual scope of the digital strategy in Algeria by linking its objectives, constraints, and potentialities within an integrated analytical framework. It first outlines the key stakes of the digital strategy in Algeria, demonstrates how digital transformation constitutes a central lever for the modernization of the State, economic diversification, and the reduction of inequalities in access to services. It then addresses the main challenges facing this strategy—whether infrastructural, institutional, human, or sociocultural—in order to highlight the limitations that hinder the realization of the stated ambitions. Finally, the analysis focuses on the opportunities offered by Algeria's digital strategy, including the development of an innovation ecosystem, the improvement of public governance, and deeper integration into the regional and global digital economy, thereby emphasizing the profound transformative potential embodied in this strategic undertaking.

4.1 Stakes of the Digital Strategy in Algeria

The stakes of the digital strategy in Algeria lie at the intersection of sovereignty, modernization of public action, and economic transformation. First, digital transformation is expected to become an instrument of sovereignty through the control of critical infrastructures, data, and cybersecurity, supported by a unified legal and regulatory framework capable of governing all digital uses. Second, the strategy seeks to redesign public services in order to achieve near-total dematerialization of administrative procedures, with a view to enhancing administrative efficiency, improving transparency in public management, and strengthening citizens' trust in the State. Finally, from an economic perspective, public authorities assign the digital sector the role of a key driver of diversification, aiming to significantly increase its contribution to gross domestic product, develop large-scale specialized human capital, and position the country as a regional hub for digital services and innovation.

4.2 Challenges of the Digital Strategy in Algeria

The main challenges facing the digital strategy in Algeria are primarily related to the inadequacy and uneven distribution of infrastructure between urban and rural areas, as well as to the heterogeneous quality of connectivity. While major urban centers benefit from denser access to high-speed Internet, optical fiber networks, and next-generation mobile systems, vast rural areas remain poorly served or even marginalized, thereby limiting the adoption of digital services by a significant segment of the population. This

territorial digital divide is compounded by issues related to service quality—such as unstable bandwidth, frequent outages, and high latency—which undermine the reliability of critical digital uses, including online public services, dematerialized economic activities, and e-governance initiatives. These disparities create a risk of exacerbating socio-spatial inequalities, compromise the objective of digital inclusion, and reduce the effectiveness of public policies based on the widespread deployment of information and communication technologies.

Figure 3 illustrates several e-governance indicators in Algeria, comparing urban areas, rural areas, and the national level.

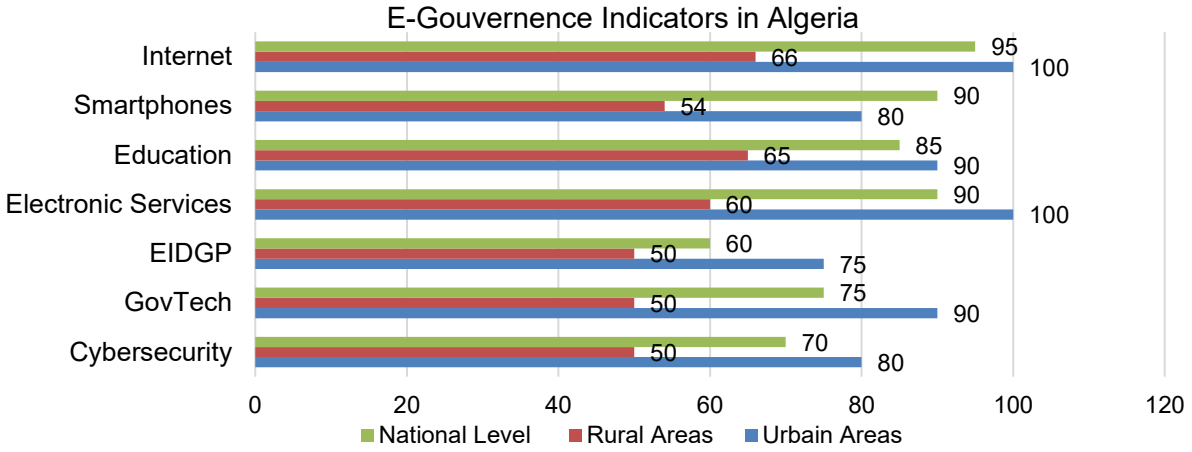


Figure 3. *E-Governance Indicators in Algeria: Urban, Rural and National Comparison*
Source: (HSE Center of African Studies, 2025)

E-governance indicators highlight a pronounced territorial disparity between urban and rural areas. Urban spaces exhibit very high levels of access to electricity, the Internet, and smartphones, with values close to 100, indicating a solid material foundation for the deployment of e-governance. By contrast, although rural areas achieve an electrification rate equivalent to the national level (100), they remain significantly lagging in terms of Internet access (66) and smartphone penetration (54), revealing the existence of a territorial digital divide.

More specifically, Internet access is universal in urban settings (100), whereas the rural value (66) indicates that the national average—aligned with the urban level—tends to obscure the specific difficulties faced by rural territories. Similarly, smartphone diffusion, which is maximal in urban areas (100), remains limited in rural areas (54), thereby constraining mobile access to digital public services in these spaces. Electricity, by contrast, appears as a quasi-universal service (99–100) across all areas, suggesting that the main obstacles to the development of e-governance do not stem from energy availability but rather from connectivity and access to end-user devices.

Institutional performance indices confirm these disparities: the EGDI100 reaches 60 in urban areas compared with 50 in rural areas, indicating a slight urban advantage in the provision and use of online public services. The GovTech100 index, set at 50 for both environments, reflects a medium and relatively homogeneous level of GovTech solutions, with no marked territorial differential. Finally, the cybersecurity indicator, reported only for urban areas (80), may be interpreted either as evidence of a higher level of protection in the most connected environments or as a reflection of a lack of available data for rural areas and the national scale (HSE Center of African Studies, 2025).

4.3 Transformative potential of the digital strategy in Algeria

The opportunities offered by Algeria's digital strategy are numerous and structurally significant for the country's development. From an economic perspective, digital transformation is conceived as a driver of diversification, capable of increasing the contribution of digital activities to GDP, fostering innovation, and generating new skilled jobs in ICT services, start-ups, and related industries. This dynamic also opens up prospects for deeper integration into regional and

international value chains, through the export of digital products and services and the attraction of foreign direct investment in infrastructure, platforms, and software solutions.

Moreover, the expansion of online public services, combined with the development of digital inclusion, offers the potential to substantially improve citizens' and businesses' access to public administration, education, healthcare, and financial services, while reducing transaction costs and processing times. Finally, the establishment of a coherent strategic framework and institutions dedicated to digital transformation creates a window of opportunity to catch up technologically, align with international best practices, and position Algeria as a leading regional actor in the digital domain.

4.4 Risks, Trust, and Cybersecurity: A Critical Evaluation

The transition from a project-based approach to a systemic digital transformation extends beyond technological infrastructure. It depends fundamentally on the establishment of trust between public institutions and citizens, supported by a coherent legal, organizational, and cybersecurity framework. The literature converges on the idea that trust, rather than technology alone, constitutes a central condition for the sustainability of digital transformation initiatives in Algeria.

4.4.1 Legal and Regulatory Maturity: Law 18-07 in comparative perspective

Algeria's regulatory environment has evolved significantly with *Law No. 07-18* (amended by *Law No. 11-25* in 2025). While inspired by the European Union's General Data Protection Regulation (GDPR) (Regulation [EU] 2016/679) and NIST Cybersecurity Framework (USA) (National Institute of Standards and Technology [NIST], 2024), several critical differences remain at the principal level:

Table 3. Comparison of Core Data Protection Principles

Principle	GDPR (EU Standard)	Algeria (Law 18-07 / 25-11)
Enforcement model	Proactive compliance (DPOs, DPIAs)	Authorization-based oversight
Individual data rights	Broad (erasure, portability)	Primarily access and rectification
International transfers	Adequacy and safeguards	Prior authorization
Sanctions	Administrative fines (up to 4% of turnover)	Administrative and criminal sanctions

Source: Author's synthesis based on reviewed legal and policy documents.

The Critical Angle: While the 2025 amendments introduced Data Protection Officers (DPOs) and Impact Assessments (DPIA), the framework remains centralized and authorization heavy. This can create a "compliance bottleneck" for startups, where the protection of sovereignty may inadvertently slow the agility of the digital economy (World Bank, 2025).

These laws are, in fact, the "Superior Standards" that the Haut-Commissariat à la Numérisation must follow when implementing the 2030 Strategy.

4.4.2 Cybersecurity: Moving Toward a National "NIST" Approach

Algeria has adopted a "Defense-in-Depth" strategy, centralizing cybersecurity under the Information Systems Security Agency (ASSI). Aligning this with the NIST Cybersecurity Framework (CSF 2.0) reveals a shift in focus toward holistic risk management (NIST, 2024):

- Identify & Protect: High maturity in protecting "Critical National Infrastructure" (Energy, Finance). The 2025 mandate for all state agencies to appoint a Chief Information Security Officer (CISO) reflects NIST's *Governance* function.
- Detect & Respond: The strategy emphasizes "Sovereign Infrastructure" (National Cloud/Data Centers) to reduce reliance on foreign providers, a move designed to minimize "supply chain risk"—a core pillar of the updated NIST v2.0 (NIST, 2024).

4.4.3 The "Trust Paradox": Literacy and Resistance to Change

The most significant risk to the 2030 vision is not technical, but behavioral. Recent studies (Zouaouid, 2025) indicate that while infrastructure is adequate, adoption is moderated by a "Trust Gap" rooted in historical institutional skepticism.

- Digital Literacy: High mobile penetration does not equate to "e-governance literacy." Many citizens remain "consumers" of social media rather than "users" of digital public services.
- Resistance to Change: Within the administration, "bureaucratic inertia" persists. Digitization often faces internal resistance from middle management who perceive transparency as a loss of discretionary power.
- The Awareness Vacuum: The strategy recognizes this by targeting a 40% reduction in talent emigration. However, without aggressive national awareness campaigns to humanize the "Digital Citizen," the risk remains that the system will be built, but not utilized.

5 OPERATIONALIZING STRATEGIC GOALS: IMPLEMENTATION & MONITORING

To move beyond a "logic of project accumulation," the Digital Algeria 2030 strategy utilizes a structured framework for monitoring and accountability.

5.1 Institutional Responsibility & Governance

The feasibility of these goals rests on a decentralized yet coordinated institutional architecture:

- High commission for digitization: the central authority responsible for cross-sectoral coordination and strategic oversight.
- Sectoral ministries: responsible for the 100% (Percentages may not sum to 100 due to rounding). digital transformation of internal procedures within their specific domains (education, health, justice).
- Regulatory authority for post and electronic communications (ARPCE): tasked with monitoring infrastructure rollout and service quality (QoS).

5.2 Strategic Timeline & Success Measurement

Rather than a static plan, the strategy is phased to allow for iterative adjustments. Success is measured through specific key performance indicators (KPIs) categorized by their implementation horizon:

1. Short-term (2025–2026) foundations: number of administrative portals unified; implementation of the national interoperability framework.
2. Medium-term (2027–2028) adoption: percentage of households with high-speed fiber, number of active digital identities issued, and e-payment transaction volume.
3. Long-term (2029–2030) impact on the digital sector: percentage of GDP (target: 20%); reduction in skill emigration (target: -40%); FDI inflow in ICT.

5.3 Monitoring Mechanisms

The strategy shifts from "announced objectives" to "measurable outcomes" through:

- The national digital observatory: (proposed) to provide real-time data on e-service adoption and infrastructure gaps.
- Citizen feedback loops: utilizing the BawabaTIC portal to measure user satisfaction and digital literacy levels among the population.

6 FEEDBACK AND PERSPECTIVES

This section adopts a reflexive approach to examine the concrete outcomes of Algeria’s digital transformation strategy, as well as the possible trajectories of its future evolution. It first focuses on feedback from implementation, highlighting the main achievements, limitations, and lessons learned from the rollout of digital policies across different sectors (public administration, the economy, public services, and territorial development). It then turns to future perspectives, identifying potential scenarios, success conditions, and the strategic adjustments required to deepen digital transformation and make it a sustainable lever for modernization and development.

6.1 Feedback

Recent experience with the implementation of Algeria's digital transformation strategy reveals substantial progress that remains, however, only partially consolidated. Between 2020 and 2024, the country launched more than 500 digital projects, with strong priority given to the modernization of public services—particularly in public administration, education, health, justice, and finance. This effort has translated into a marked increase in the use of online services and an improvement in connectivity indicators (Internet penetration rate exceeding 70%, increased fixed and mobile broadband speeds).

Observed results in international indices (EGDI, NRI) confirm gradual progress, notably in human capital and telecommunications infrastructure, but also point to a persistent lag in the quality and accessibility of e-services, as well as a gap relative to the regional average. These gains remain fragile due to structural and institutional weaknesses, including insufficient intersectoral coordination, bureaucratic inertia, still incomplete legal frameworks for data governance and cybersecurity, uneven connectivity infrastructure across regions, and, above all, a critical shortage of digital skills exacerbated by talent emigration. In addition, limited digital literacy among a part of the population and the persistence of traditional administrative practices constrain the social appropriation of the mechanisms put in place, thereby reducing the overall impact of the strategy.

Feedback from this experience, therefore, leads to recommendations to refocus on digital governance (through an independent observatory, a national digital identity, and platform unification), to significantly strengthen human capacities and infrastructure in disadvantaged areas, and to pursue an active policy of inclusion and awareness-raising—conditions deemed essential to transform quantitative progress into a sustainable and systemic digital transformation. (Zouaouid, 2025)

6.2 Perspectives

The prospects for "Digital Algeria," as they emerge from the state of e-governance in 2025, rest on the consolidation of a foundation of infrastructure, regulatory frameworks, and institutions already largely engaged in the digital transformation of public action, but still facing structural challenges in terms of inclusion, skills, and cybersecurity.

The expansion of the fiber-optic network, the preparation of more than 500 digital transformation projects for 2025–2026, and the adoption of the National Digital Transformation Strategy 2025–2030 suggest a trajectory of continued modernization of public services and strengthened interoperability of information systems, notably through the National Interoperability Framework and unified portals such as BawabaTIC or single windows for tax and customs services.

At the same time, the widespread deployment of tools such as the biometric national identity card, the Jibayatic and Moussahamatic platforms, the digitization of the agricultural registry, and e-procurement systems indicates significant potential for increased transparency, reduced transaction costs, and improved traceability in key sectors, including agriculture and health, where applications of artificial intelligence and telemedicine are beginning to emerge.

However, these prospects remain contingent on reducing territorial and social divides, raising the level of digital skills among a population of which a significant share remains unfamiliar with e-governance platforms, and substantially strengthening cybersecurity, which is still considered vulnerable despite legal and institutional advances.

Finally, the growing role of international cooperation (ITU, UNDP, the European Union, Smart Africa, partnerships with China and other technological actors) points to an enhanced capacity for Algeria to capture know-how, financing, and cutting-edge technologies. In the medium term, this could accelerate the maturation of Digital Algeria, provided that bureaucratic rigidities are overcome and citizens' trust in online public services is consolidated (HSE Center of African Studies, 2025).

7 CONCLUSIONS

The analysis shows that the Digital Algeria 2030 strategy, underpinned by the National Digital Transformation Strategy 2025–2030, represents a structuring choice aimed at placing the State and

the national economy on a trajectory of modernization and digital sovereignty. By articulating five major pillars—ICT infrastructure, human capital, digital governance, the digital economy, and the digital society—supported by a renewed legal framework and strengthened cybersecurity, the strategy offers a systemic vision of digital transformation. This vision goes beyond a purely technological dimension to encompass the organization of public action, economic models, and social practices. Quantified objectives, such as training 500,000 ICT specialists, creating 100,000 start-ups, and increasing the digital sector's share of GDP to 20%, reflect a high level of ambition to reposition Algeria as a regional actor in the digital economy.

However, this strategy is unfolding in a context marked by persistent structural constraints. Territorial inequalities in access to digital services are caused by (infrastructure costs, population density, governance fragmentation) and partially addressed through targeted policies (USO funds, regional PPPs). Skills deficits within segments of the population, a mismatch between education and labor market needs, and the role of universities and vocational training, coupled with fragmentation of information systems and still significant vulnerabilities in cybersecurity, currently limit the effective reach of the envisaged measures. Institutional capacity gaps and limits in regulatory enforcement also restrict progress. International e-government and GovTech indicators point to a public sector that is increasingly digitized but still in need of improvement, requiring additional efforts to enhance interoperability, the quality of online services, and citizens' trust. Similarly, the transition toward a value-creating digital economy remains contingent on the capacity to digitalize SMEs, attract investment, and stabilize an innovation ecosystem that is still emerging.

Ultimately, Digital Algeria 2030 appears less as an endpoint than as an open-ended process, whose success will depend on the gradual implementation of the projects set out in the National Digital Transformation Strategy 2025–2030, the reduction of social and territorial divides, and the continuous strengthening of digital skills. The progress already achieved in terms of infrastructure, regulatory frameworks, and e-governance mechanisms suggests a genuine dynamic of transformation. Yet this momentum must be consolidated through more integrated governance, improved inter-institutional coordination, and greater appropriation of digital services by citizens and economic actors. The future of Digital Algeria thus lies in the ability of public authorities and socio-economic partners to translate an ambitious strategic vision into lasting changes in administrative, productive, and social practices, thereby making digital transformation an effective lever for development and economic diversification.

8 RECOMMENDATIONS

In light of the above-mentioned findings, the Digital Algeria 2030 strategy offers significant levers for modernization while simultaneously facing structural challenges that must be anticipated and addressed. In order to move from an ambitious strategic vision to an effective and sustainable transformation of the State, the economy, and society, it is necessary to formulate a set of operational recommendations. These recommendations aim to strengthen the governance of digital transformation, consolidate infrastructure, develop human capital, and foster broader appropriation of digital uses by all stakeholders, both public and private:

- At the strategic level:
  - Establish a detailed operational roadmap for the National Digital Transformation Strategy (NDTS) 2025–2030, with clearly defined phases, timelines, and performance indicators.
  - Strengthen coherence between sectoral strategies (education, health, industry, agriculture) and the national digital strategy.
- At the institutional and governance level:
  - Create or consolidate a centralized steering body for digital transformation, endowed with coordination and arbitration powers.
  - Generalize interoperability frameworks and shared platforms in order to avoid fragmentation of public information systems.

- At the infrastructure and inclusion level:
  - Accelerate the deployment of broadband and high-speed broadband in rural and remote areas to reduce territorial digital divides.
  - Implement targeted support programs (subsidies, shared equipment, public digital access spaces) for the most vulnerable populations and territories.
- At the human capital level:
  - Strengthen initial and continuing training in digital skills, with greater integration of digital competencies into school and university curricula.
  - Encourage partnerships between universities, research centers, and firms to promote R&D and digital innovation.
- At the economic level:
  - Introduce fiscal and financial incentive schemes for start-ups, SMEs, and innovative projects in the digital sector.
  - Promote the export of Algerian digital services and the integration of local firms into regional and international value chains.
- At the societal level and in terms of trust:
  - Develop awareness-raising and support campaigns to assist citizens in the use of online public services.
  - Strengthen personal data protection and cybersecurity in order to consolidate trust in the digital platforms of the State and private enterprises.

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FINANCIAL DEVELOPMENT, ENERGY TRANSITION, AND CARBON EMISSIONS IN ARAB ECONOMIES

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ABSTRACT

This paper investigates the role of financial development in accelerating the energy transition and reducing carbon dioxide emissions in Arab countries over the period 2000–2022. The study uses a panel autoregressive distributed lag model, estimated via the pooled mean group approach, to examine the long-run and short-run effects of financial development, foreign direct investment, economic growth, carbon dioxide emissions, and political stability on renewable energy consumption. The results show that financial development has a negative and statistically significant long-run effect on renewable energy consumption, indicating that domestic financial systems in Arab countries remain weakly oriented toward green investment. Conversely, foreign direct investment and economic growth positively support the transition toward renewable energy, while political stability has no statistically significant effect. These findings suggest that financial deepening alone is insufficient unless it is supported by green finance instruments, stronger regulatory incentives, and climate-oriented economic policies. The paper is relevant to researchers, policymakers, financial institutions, and energy regulators.

1 INTRODUCTION

In recent decades, the global energy system has undergone a structural transformation in the ways energy is produced and consumed, driven by mounting climate pressures, the intensification of global warming, and the growing commitments of countries under multilateral climate agreements, particularly the 2015 Paris Agreement. This transformation has reinforced the strategic importance of renewable energy as an alternative to fossil fuels, especially for economies seeking to reshape their development models toward more sustainable and diversified pathways. However, achieving such a transition requires a set of enabling conditions, including resilient energy infrastructure, a stable institutional environment, and an effective financial framework capable of mobilizing resources toward clean-energy innovation.

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Within this context, financial development has emerged as a critical driver of energy transition through its role in mobilizing domestic savings, expanding access to finance, reducing the cost of capital, and stimulating investment in low-carbon projects. As financial systems become deeper, more efficient, and more stable, their capacity to finance the structural shift toward sustainable energy models is expected to increase. Recent economic literature has therefore emphasized the channels through which financial development may affect energy-sector performance, either directly through green finance or indirectly through economic growth and technological progress (Beck et al., 2007; Zhang et al., 2024).

Despite this theoretical momentum, the Arab region remains largely underrepresented in rigorous empirical research on this topic, although it constitutes a distinctive case characterized by abundant fossil-fuel resources, growing renewable-energy commitments, and highly heterogeneous financial systems. These systems range from traditional bank-dominated structures to emerging capital markets, raising important questions about their ability to support the energy transition effectively, particularly in contexts marked by institutional fragility or weak regulatory incentives.

Accordingly, this study addresses the following central research question: To what extent does financial development contribute to accelerating the energy transition and reducing carbon dioxide emissions in Arab countries? To answer this question, the study tests three hypotheses: financial development has a significant long-run effect on renewable energy consumption; foreign direct investment and economic growth support the energy transition; and political stability is positively associated with the transition, although its effect depends on the presence of an effective institutional framework.

The study estimates the dynamic effect of financial development on renewable energy consumption (ENRR) and carbon dioxide emissions (CO_2) in a sample of eleven Arab countries over the period 2000–2022. It adopts a flexible econometric framework that captures short- and long-run causal interactions among financial, economic, environmental, and institutional variables, including foreign direct investment (FDI), economic growth (GDPG), and political stability (PS). Its contribution lies in its comparative regional focus on an empirically underexplored area and in its use of a dynamic Panel ARDL model estimated through the PMG approach, supported by CS-DOLS and System-GMM robustness checks.

The paper is organized as follows. The first section presents the theoretical background and defines the core concepts of energy transition, financial development, and green finance. The second section reviews the relevant empirical literature and identifies the research gap. The third section presents econometric analysis, discusses the results, and interprets the findings in light of economic theory and previous studies.

2 REVIEW OF THE SCIENTIFIC LITERATURE

Figure 1 maps the reviewed literature according to four analytical dimensions: key studies, research themes, empirical contexts with methods, and main findings. Overall, the literature shows that the relationship between financial development and the energy transition is neither linear nor uniform. Rather, its direction depends on the type of financial development examined, the institutional setting, the structure of the energy system, and the methodological framework adopted.

A first strand of research examines the role of financial inclusion and financial depth in promoting clean energy. Sohail et al. (2024), using a Panel NARDL approach for BRICS economies, show that disaggregated financial inclusion indicators can accelerate the clean-energy transition and contribute to reducing carbon emissions. Similarly, Parashar and Jaiswal (2025), relying on System GMM for a sample of emerging economies, find that financial access, depth, and efficiency improve energy equity, energy security, and environmental sustainability. These studies suggest that financial development can support the energy transition when it expands access to capital and channels financial resources toward sustainable energy uses.

A second group of studies focuses on financial innovation, digital finance, and technological progress. Zhang et al. (2024), using evidence from China, demonstrate that financial innovation and

environmental regulation significantly enhance renewable energy generation and accelerate the energy transition. Liu et al. (2023) further show that digital financial development contributes to reducing pollution and carbon emissions through green technological innovation. Benfica and Marques (2024), in the Latin American context, confirm that technological and financial development can improve energy-transition efficiency, although the magnitude of this effect differs across countries. This strand indicates that finance becomes more environmentally effective when it is linked to innovation, regulation, and clean technology diffusion.

Key studies	Theme	Context (with method)	Main results
Sohail et al. (2024)	Financial inclusion and clean energy transition	BRICS economies (2004–2022) [Panel NARDL]	Promotes clean energy and lowers CO_2 emissions in BRICS.
Zhang et al. (2024)	Financial innovation and renewable energy	China, 31 provinces (1990–2021) [MMQR, 2SLS, Wasteland cointegration]	Financial innovation and regulation boost renewable energy transition.
Jackson and Jackson (2025)	Macroeconomic and financial dynamics of energy transition	United Kingdom of global implications [SHC-IO model]	Rapid transition may cause instability; gradual transition is safer.
Parabhar and Jairwal (2025)	Financial access, depth and energy sustainability	18 emerging economies (1995–2020) [System GMM]	Financial access, depth and efficiency improve energy sustainability.
Harvey et al. (2024)	Digital payments, financial development and energy transition	Africa (2008–2019) [System GMM, dynamic threshold model]	Threshold effect between finance, digitalization and renewable energy.
Benfica and Marques (2024)	Technology, finance and energy transition efficiency	Latin America [DFA, fractional regression model]	Technology and finance improve transition efficiency, with heterogeneity.
Petrović and Lobanov (2022)	Financial development and CO_2 emissions	24 advanced and developing countries [Panel cointegration with structural breaks]	Finance can raise CO_2 when it supports carbon-intensive sectors.
Subhan et al. (2023)	Renewable/non-renewable energy, finance and CO_2 emissions	India (1971–2019) [NARDL, wavelet coherence]	Finance raises CO_2 by boosting non-renewable energy use.
Li (2023)	Financial markets and clean technology investment	Global sample (1990–2018) [SYS-GMM]	Financial markets support clean-tech and renewable expansion.
Liu et al. (2023)	Digital finance and pollution-carbon reduction	China (2011–2019) [Fixed effects–mediation analysis]	Digital finance reduces pollution and CO_2 through green innovation.
Prempeh (2023)	Financial development and renewable energy consumption	Ghana (1990–2020) [ARDL, VECM, FMOLS, DOLS, CCR]	Finance supports renewable energy when institutions are strong.
Zhao and Yang (2020)	Financial development and CO_2 emissions (regional evidence)	Chinese provinces (2011–2018) [PCA, FMOLS, DOLS, PVAR]	Finance can reduce CO_2, but effects vary across regions.
This study (2025)	Tinancial development, energy transition and CO_2 (Arab region)	11 Arab countries (2000–2022) [Panel ARDL (PMG) and CS-DOLS and System-GMM]	In Arab countries, effects depend on institutions, FDI, growth and political stability.

Figure 1. *Comparative Mapping of the Scientific Literature on Financial Development and Energy Transition*

Source: Prepared by the author.

A third strand addresses the macroeconomic and systemic risks associated with energy transitions. Jackson and Jackson (2025), through a stock-flow consistent input-output model, show that a rapid and poorly managed transition may generate macroeconomic and financial instability, while a gradual transition is more sustainable. This perspective is important because it highlights that the financial system is not only a source of transition finance but also a channel through which transition risks may spread across the broader economy.

Another important strand of the literature investigates the relationship between financial development and carbon emissions. This line of research is particularly relevant because it questions the assumption that financial deepening necessarily produces environmental benefits. Petrović and Lobanov (2022) find that financial development may increase carbon dioxide emissions when credit expansion and financial resources are directed toward carbon-intensive sectors. In such cases, financial development strengthens conventional economic activities rather than supporting environmental transformation. Subhan et al. (2023) reach a similar conclusion in the Indian context, showing that financial development can increase emissions by stimulating non-renewable energy consumption and facilitating investment in pollution-intensive activities. These findings suggest that, in the absence of green regulatory frameworks, financial development may reinforce existing fossil-fuel-based production and consumption patterns.

In contrast, Zhao and Yang (2020) show that financial development can reduce carbon emissions in Chinese provinces, although the magnitude and direction of this effect differ across regions. Their findings indicate that the environmental impact of finance depends on local economic structures, regional energy profiles, and

the degree to which financial resources are allocated to cleaner technologies. Taken together, these mixed results confirm that financial development is not intrinsically green. Its environmental outcome depends on the direction of credit allocation, the structure of investment, the presence of environmental regulation, and the ability of financial institutions to support renewable energy and low-carbon innovation rather than carbon-intensive activities.

The literature also emphasizes the importance of regional heterogeneity in shaping the finance–energy transition nexus. Horvey et al. (2024), focusing on African economies, identify a nonlinear threshold relationship between financial development, digitalization, and renewable energy consumption. Their results suggest that financial development may support renewable energy only after reaching a certain level of maturity and when complemented by digital infrastructure. Li (2023) provides broader global evidence showing that financial market development can support clean technology investment and renewable energy expansion, particularly where capital markets are capable of mobilizing long-term funding for green projects. Prempeh (2023), using evidence from Ghana, similarly finds that financial development can stimulate renewable energy consumption when supported by sound institutional and policy conditions.

Overall, these studies show that the effect of financial development on the energy transition is strongly context-dependent. Finance can either accelerate renewable energy adoption or deepen carbon lock-in, depending on the institutional environment, the structure of the financial system, the quality of energy policies, and the availability of green financial instruments. This reinforces the need to examine Arab economies as a distinct empirical context, given their heavy dependence on fossil fuels, heterogeneous financial systems, and emerging commitments to renewable energy development.

3 METHODOLOGY

This study examines the dynamic effect of financial development on the energy transition in a selected sample of Arab countries over the period 2000-2022. The empirical analysis models the interaction between renewable energy consumption and a set of financial, economic, environmental, and institutional determinants. The methodological framework is based on a dynamic panel specification that captures both long-run equilibrium relationships and short-run adjustments.

Table 1 summarizes the variables used in the empirical model, their corresponding symbols, the study period, and the official data sources from which they were obtained. The purpose of this table is to clarify the measurement structure of the study and ensure transparency regarding the construction of the dataset used in the subsequent dynamic panel analysis.

Table 1. *Variables and Data Sources*

Variable	Symbol	Period	Source
Renewable energy consumption	ENRR	2000-2022	World Bank, World Development Indicators
Financial development index	FD	2000-2022	International Monetary Fund, Financial Development Index Database
Foreign direct investment, net inflows (% of GDP)	FDI	2000-2022	World Bank, World Development Indicators
Real GDP growth rate	GDPG	2000-2022	World Bank, World Development Indicators
Carbon dioxide emissions per capita	CO_2	2000-2022	World Bank / Our World in Data
Political stability index	PS	2000-2022	Worldwide Governance Indicators

Source: Prepared by the autho.

As shown in Table 1, the dependent variable is renewable energy consumption (ENRR), which is used as a proxy for the progress of the energy transition. The main explanatory variable is the financial development index (FD), which captures the depth, access, and efficiency of the financial system. Foreign direct investment (FDI) is

included as a channel of external finance and technology transfer, while real GDP growth (GDPG) reflects macroeconomic dynamism. Carbon dioxide emissions per capita (CO_2) are introduced as an environmental pressure variable, and political stability (PS) is used to account for the institutional capacity required to implement long-term energy policies.

3.1 Model Specification

The baseline long-run relationship is specified as follows:

$$ENRR_{it} = \alpha_i + \beta_1 FD_{it} + \beta_2 FDI_{it} + \beta_3 GDPG_{it} + \beta_4 CO2_{it} + \beta_5 PS_{it} + \varepsilon_{it}$$

where:

i refers to the country ($i = 1, \dots, N$), and

t refers to time ($t = 2000, \dots, 2022$).

$ENRR_{it}$ denotes renewable energy consumption in country i at time t; FD_{it} represents financial development; FDI_{it} denotes foreign direct investment; $GDPG_{it}$ represents the real GDP growth rate; $CO2_{it}$ captures carbon dioxide emissions; PS_{it} denotes political stability; α_i represents country-specific effects; and ε_{it} is the error term. To capture short-run dynamics and long-run adjustment, the study adopts the Panel ARDL error-correction representation estimated through the Pooled Mean Group estimator:

$$\begin{aligned}\Delta ENRR_{it} = {} & \phi_i\big(ENRR_{i,t-1} - \theta_1 FD_{it} - \theta_2 FDI_{it} \\ & - \theta_3 GDPG_{it} - \theta_4 CO2_{it} - \theta_5 PS_{it}\big) \\ & + \sum_{j=1}^{p-1} \lambda_{ij}\, \Delta ENRR_{i,t-j} \\ & + \sum_{j=0}^{q-1} \delta_{1ij}\, \Delta FD_{i,t-j} + \sum_{j=0}^{q-1} \delta_{2ij}\, \Delta FDI_{i,t-j} \\ & + \sum_{j=0}^{q-1} \delta_{3ij}\, \Delta GDPG_{i,t-j} \\ & + \sum_{j=0}^{q-1} \delta_{4ij}\, \Delta CO2_{i,t-j} + \sum_{j=0}^{q-1} \delta_{5ij}\, \Delta PS_{i,t-j} \\ & + \mu_i + \eta_{it}\end{aligned}$$

In this specification, denotes the first-difference operator. The parameter is the error-correction coefficient, which measures the speed at which deviations from the long-run equilibrium are corrected. A negative and statistically significant result confirms the existence of long-run convergence. The parameters represent the long-run coefficients, while the parameters capture short-run effects. The PMG estimator is suitable because it allows short-run coefficients and adjustment speeds to differ across countries, while imposing homogeneity on the long-run coefficients

3.2 Sample

The sample includes eleven Arab countries selected based on data availability and statistical consistency over the period 2000-2022. The selected countries are distributed as follows: Qatar, the United Arab Emirates, and Kuwait from the Gulf region; Algeria, Libya, Tunisia, and Morocco from North Africa; Iraq, Jordan, and Lebanon from the Mashreq region; and Mauritania from the Arab Sahel.

3.3 Methodological Rationale

The use of the Panel ARDL-PMG approach is appropriate for this study for three reasons. First, it accommodates variables integrated at different orders, provided that none is integrated of order two. Second, it distinguishes between short-run country-specific dynamics and common long-run relationships, which is important given the heterogeneity of Arab economies in terms of financial structure, energy dependence, and institutional quality. Third, it provides a coherent framework for assessing whether financial development supports or constrains the energy transition over time. To strengthen the reliability of the findings, the analysis is complemented by robustness checks using CS-DOLS and System-GMM, which help address cross-sectional dependence, long-run endogeneity, and dynamic-panel bias.

4 RESULTS

This section presents and discusses the empirical findings obtained from the panel econometric analysis. The analysis proceeds in three stages. First, panel unit-root tests are used to examine the order of integration of the variables. Second, panel cointegration tests are conducted to verify the existence of a stable long-run relationship. Third, the long-run and short-run dynamics are estimated using the PMG-ARDL model, followed by robustness checks to assess the reliability of the results.

4.1 Panel Unit-Root Tests

Before estimating the dynamic model, the stationarity properties of the variables were examined using the Levin-Lin-Chu (LLC) and Im-Pesaran-Shin (IPS) panel unit-root tests. The results indicate that all variables-carbon dioxide emissions (CO_2), real GDP growth (GDPG), financial development (FD), foreign direct investment (FDI), political stability (PS), and renewable energy consumption (ENRR)-are non-stationary at the level but become stationary after first differencing. This implies that the variables are integrated of order one, I(1).

Methodologically, this finding supports the use of a Panel ARDL framework, provided that none of the variables is integrated of order two, I(2). The ARDL approach is particularly appropriate in this context because it can accommodate variables with mixed orders of integration, I(0) and I(1), while allowing the estimation of both short-run dynamics and long-run equilibrium relationships. The stationarity results, therefore, provide a valid preliminary basis for proceeding with the cointegration analysis.

4.2 Panel Cointegration Test

After establishing the integration properties of the variables, the study applies the Pedroni panel cointegration test to determine whether a long-run equilibrium relationship exists among renewable energy consumption and its financial, economic, environmental, and institutional determinants. The results show that three out of the seven Pedroni statistics-namely, the Panel PP-statistic, Panel ADF-statistic, and Group ADF-statistic-are statistically significant at the 1% level.

These findings allow the rejection of the null hypothesis of no cointegration and support the existence of a stable long-run relationship among the variables. In substantive terms, this means that renewable energy consumption (ENRR), financial development (FD), foreign direct investment (FDI), political stability (PS), carbon dioxide emissions (CO_2), and real GDP growth (GDPG) move together over time within a long-run equilibrium structure. This result justifies the estimation of the PMG-ARDL model and confirms that the relationship under study is not merely short-term or incidental, but reflects a persistent dynamic interaction.

Table 2. *Long-run estimates of the PMG-ARDL model*

Variable	Long-run coefficient	Statistical significance	Economic interpretation
FD	-13.03	Significant at 1%	Domestic financial development does not appear to be directed toward renewable energy projects
FDI	0.33	Significant at 1%	Foreign direct investment supports technology transfer and stimulates renewable energy investment
PS	0.014	Not significant	Political stability alone is insufficient without targeted clean-energy policies
CO_2	0.97	Significant at 1%	High-emission countries tend to increase renewable energy adoption as part of transition responses
GDPG	0.21	Significant at 1%	Economic growth expands the fiscal and investment capacity needed to finance renewable energy projects

Source: Prepared by the author.

4.3 Long-Run Estimates of the PMG-ARDL Model

The PMG-ARDL(1, 2, 2, 2, 2, 2) model was estimated to assess the long-run effects of the explanatory variables on renewable energy consumption. The long-run results are summarized in Table 2, which reports the estimated coefficients, their statistical significance, and their economic interpretation. The purpose of this table is to provide a concise overview of how financial development, foreign direct investment, political stability, carbon emissions, and economic growth affect renewable energy consumption in the long run.

The most striking result reported in Table 2 is the negative and statistically significant coefficient of financial development. This finding suggests that

financial deepening in Arab countries does not automatically translate into greater renewable energy consumption. Instead, it may indicate that domestic financial systems remain largely oriented toward conventional sectors, including hydrocarbon-related activities, real estate, trade finance, and short-term credit, rather than long-term green investment. In this respect, the result supports the argument that finance is not inherently green; its environmental effect depends on the direction of credit allocation, the design of regulatory incentives, and the existence of dedicated green financial instruments.

Foreign direct investment has a positive and statistically significant effect on renewable energy consumption. This result suggests that external capital can contribute to the energy transition by facilitating technology transfer, improving project financing, and introducing cleaner production practices. In many Arab economies, where domestic green finance mechanisms remain underdeveloped, foreign investment may therefore play a compensatory role by providing access to technical expertise, advanced renewable-energy technologies, and international financing standards.

The coefficient of carbon dioxide emissions is also positive and statistically significant. This result can be interpreted as evidence of a policy-response mechanism: countries facing higher environmental pressures may gradually increase renewable energy deployment to reduce dependence on carbon-intensive energy sources. However, this should not be interpreted as emissions directly causing sustainability; rather, high emissions may generate policy, social, and international pressure that encourages governments to incorporate renewable energy into their energy mix.

Economic growth also exerts a positive and statistically significant effect on renewable energy consumption. This finding indicates that higher growth can expand the fiscal and investment space required to finance renewable energy infrastructure. In economies where renewable energy projects require substantial upfront capital, macroeconomic expansion may improve the ability of both public authorities and private investors to support clean-energy initiatives.

By contrast, political stability has a positive but statistically insignificant coefficient. This suggests that institutional stability alone does not necessarily generate progress in renewable energy adoption. Political stability may provide a favorable general environment, but it must be translated into concrete policy instruments, such as renewable energy targets, green finance regulations, investment guarantees, feed-in tariffs, fiscal incentives, and transparent procurement mechanisms. Without such operational policy channels, institutional stability remains insufficient to drive the energy transition.

4.4 Error-Correction Mechanism and Short-Run Dynamics

The error-correction coefficient is negative and statistically significant at the 5% level, with an estimated value of:

$$ECT = -0.072$$

This confirms the existence of a long-run adjustment mechanism. The coefficient indicates that approximately 7.2% of deviations from the long-run equilibrium are corrected each year. Although the speed of adjustment is relatively slow, it is consistent with the structural nature of energy transitions, which typically require long planning horizons, large-scale infrastructure investment, institutional coordination, and gradual changes in the energy mix.

In the short run, most coefficients are statistically insignificant, except for a limited number of first-difference terms. This result indicates that changes in financial development, institutional conditions, and macroeconomic variables do not immediately affect renewable energy consumption. Such a finding is theoretically plausible because the impact of financial reforms and clean-energy policies usually materializes over longer horizons. Renewable energy projects are capital-intensive, require regulatory preparation, and often depend on long-term planning, grid integration, and institutional implementation capacity. Therefore, the weak short-run effects reinforce the interpretation that the finance-energy transition nexus in Arab economies operates primarily through long-run channels.

4.5 Robustness Checks

To assess the reliability of the baseline PMG-ARDL results, the study applies additional robustness checks using CS-DOLS and System-GMM estimators. The CS-DOLS estimator accounts for cross-sectional dependence and long-run endogeneity, while System-GMM helps address dynamic-panel bias and potential endogeneity arising from the persistence of renewable energy consumption and the interaction between financial development and economic performance.

The robustness results remain broadly consistent with the baseline findings in terms of signs and statistical relevance. This consistency strengthens the credibility of the empirical results and suggests that the estimated relationships are not driven by model-specific assumptions. In addition, the Hausman test supports the use of the PMG estimator rather than the Mean Group estimator, indicating that imposing long-run coefficient homogeneity is acceptable while allowing short-run heterogeneity across countries.

5 DISCUSSION OF THE FINDINGS

Taken together, the findings provide evidence that the relationship between financial development and the energy transition in Arab countries is conditional and structurally constrained. The negative long-run effect of financial development indicates that the existing financial architecture does not sufficiently channel resources toward renewable energy. This may reflect several characteristics of Arab financial systems, including the dominance of traditional banking, limited depth of green capital markets, weak environmental risk pricing, and continued preference for financing established carbon-intensive sectors.

The positive role of foreign direct investment and economic growth suggests that the energy transition in the region is more likely to advance when financial resources are combined with external technology, productive investment, and macroeconomic capacity. This finding is consistent with the view that renewable energy expansion requires not only domestic financial depth but also technological upgrading and stable investment conditions.

The positive association between carbon emissions and renewable energy consumption further suggests that environmental pressure can act as a catalyst for policy response. However, the effectiveness of this response depends on whether countries transform climate pressure into concrete renewable energy strategies. The insignificance of political stability reinforces this point: broad institutional stability is not enough unless it is supported by targeted regulations, green finance frameworks, and credible implementation mechanisms.

Overall, the results challenge the assumption that financial development automatically promotes sustainability. In the Arab context, finance appears to support the energy transition only when it is explicitly redirected through green financial instruments, environmental regulation, and investment incentives. Therefore, the key policy implication is that financial development must be reoriented from conventional financial deepening toward climate-aligned financial transformation.

6 CONCLUSIONS

This study provides a dynamic empirical assessment of the role of financial development in shaping the energy transition across eleven Arab countries over the period 2000–2022. The results show that financial development plays a decisive but conditional role in supporting renewable energy adoption. More specifically, the findings indicate that financial systems do not automatically operate as catalysts for clean-energy transition. Their impact depends on long-run interactions among financial, economic, institutional, and environmental factors.

The negative long-run effect of financial development suggests that financial deepening in Arab economies may remain insufficiently aligned with green investment priorities. In the absence of targeted regulatory incentives and sustainable finance instruments, financial resources may continue to flow toward conventional and carbon-intensive sectors. By contrast, foreign direct investment and economic growth appear to support renewable energy consumption, indicating that external capital, technological transfer, and macroeconomic capacity are important drivers of the transition process. The statistically insignificant effect of political stability

further suggests that institutional stability alone is not sufficient unless it is translated into concrete clean-energy policies and implementation mechanisms.

These findings reinforce the theoretical view that the relationship between finance and energy transition is complex, context-dependent, and potentially nonlinear. They also highlight the importance of local structural conditions in determining whether financial development contributes to environmental sustainability or reinforces existing carbon-intensive pathways. Unlike static or purely linear approaches, this study provides a dynamic framework that distinguishes between short-run adjustments and long-run equilibrium effects, thereby offering a more precise understanding of the mechanisms linking finance, renewable energy, and emissions in Arab economies.

The main contribution of this paper lies in reframing the finance–energy nexus as a developmental and transformative relationship. Financial development should not be treated merely as a source of capital accumulation, but as a policy channel that must be explicitly aligned with climate objectives. In this sense, the energy transition requires not only more finance, but better-directed finance.

Based on the empirical results, the study proposes several policy implications for Arab economies.

First, domestic financial systems should be reoriented toward green investment. This requires integrating sustainability criteria into banking regulations, credit allocation, and investment decisions, while encouraging banks and financial institutions to develop dedicated financing lines for renewable energy projects.

Second, Arab countries should develop sustainable financial instruments, including green bonds, climate funds, renewable-energy credit guarantees, and blended-finance mechanisms. These instruments can reduce investment risk, lower the cost of capital, and attract private-sector participation in clean-energy infrastructure.

Third, institutional incentives should be redesigned to support the energy transition. This includes reforming fossil-fuel subsidies, introducing carbon-pricing mechanisms where feasible, and providing fiscal incentives for firms investing in clean technologies and renewable-energy systems.

Fourth, climate considerations should be incorporated into national financial strategies. Governments and central banks should integrate climate-risk assessment into macroprudential regulation, public investment planning, and fiscal policy evaluation.

Fifth, innovation-oriented finance should be strengthened through digital finance, financial technology, crowdfunding platforms, and public–private partnerships. These mechanisms can improve access to clean-energy finance, especially in underserved regions and small-scale renewable projects.

Finally, stronger institutional coordination is required among ministries of finance, energy authorities, central banks, environmental agencies, and private financial institutions. Such coordination is essential to ensure policy coherence, improve regulatory credibility, and transform financial development into an effective driver of low-carbon transition.

Future research may extend this analysis in several directions. First, broader samples including other developing and resource-dependent economies could be used to compare the Arab experience with similar regional contexts. Second, future studies may incorporate additional institutional variables, such as governance quality, regulatory effectiveness, environmental policy stringency, and the role of green Islamic finance. Third, nonlinear and threshold models could be employed to test whether financial development begins to support renewable energy only after reaching a certain level of institutional or financial maturity. Finally, structural equation modelling and advanced dynamic-panel techniques may provide deeper insights into the causal channels linking finance, technology, institutions, and environmental performance.

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THE ROLE OF CONCURRENT ENGINEERING IN REDUCING PRODUCT DEVELOPMENT COSTS: AIRBUS CASE STUDY

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ABSTRACT

This study aims to identify the concurrent engineering (CE) technique and examine its role in reducing costs during product development phases by leveraging functional and technological practices that support cost reduction. Given the nature of the study, we adopt a descriptive and analytical approach. Based on a case study of Airbus, which is considered one of the most powerful companies in the global aeronautical sector, and which has adopted concurrent engineering technique through its project ACE (Airbus Concurrent Engineering), the findings indicate that concurrent engineering reduces the product's overall cost by lowering design costs through the elimination of design errors and by reducing the number of engineering changes required during product design. Additionally, it reduces labor inputs by utilizing cross-functional teams. By incorporating supply chain requirements early in the development process, the overall cost decreases while maintaining a strong focus on quality improvement, thereby enhancing flexibility and responsiveness to market demands.

1 INTRODUCTION

Rapid and successive developments in the modern global manufacturing environment—including the information and communications technology revolution, expanding and increasingly open markets, intensified competition, and advances in technologies related to product design and production processes—have placed significant pressures and challenges on firms. These pressures require organizations to keep pace with such changes, respond effectively, improve efficiency and effectiveness, and build competitive capabilities that enable them to achieve their objectives and ensure growth and continuity. Achieving these outcomes has required a high degree of flexibility in product development and a stronger focus on cost management.

Accordingly, firms have increasingly emphasized strategic cost management and sought alternative methodological approaches that combine higher production rates with improved efficiency in the shortest possible time, while also improving quality, reducing production time, and strengthening integration between design and

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manufacturing. In this context, many companies in complex and innovative industries—such as automotive, aerospace, electronics, pharmaceuticals, and defense—have adopted concurrent engineering as a long-term business strategy. This approach promotes an integrated development system aimed at enhancing flexibility and responsiveness while reducing costs and time and improving product quality.

Considering the preceding discussion, this study addresses the following research question:

RQ: What is the role of concurrent engineering in reducing costs across all stages of product development?

1.1 Research Hypotheses

From the main research question, we formulate the following hypotheses to guide our study:

H1: Concurrent engineering reduces product development costs from the design phase through delivery to the customer.

H2: Concurrent engineering helps companies improve products already in the market.

1.2 Objectives and Significance of Research

This research highlights the importance of concurrent engineering as a contemporary technique for reducing the costs of developing complex and innovative products through simultaneous work, considered the core principle of this approach, and the use of cross-functional teams. Airbus, a leading commercial aircraft manufacturer, was among the first companies to adopt and further develop concurrent engineering. Airbus has reportedly achieved cost savings, generated significant revenues, and increased its market share through this approach. Concurrent engineering is also used to monitor aircraft throughout their life cycles and implement necessary enhancements, thereby improving product quality.

2 THE CONCEPT OF CONCURRENT ENGINEERING (CE)

2.1 Definition of CE

In 1988, CE was introduced in a report submitted by the Institute for Defense Analyses (IDA) titled *The Role of Concurrent Engineering in Weapons System Acquisition*. The report described concurrent engineering as a systematic approach to the integrated, concurrent design of products and their associated processes, including manufacturing and support. This approach encourages producers, from the outset, to consider all elements of the product life cycle—from concept to sale—including quality, cost, scheduling, and customer requirements (Salamn Daoud & Mazen, 2016).

Accordingly, concurrent engineering can be understood as a cross-functional and systematic approach that integrates design and supports the concurrent development of complex products and their related operations. It involves multiple functions, such as marketing, manufacturing, service, sales, customer support, and product disposal. The objective is to increase productivity, decrease costs, and reduce product development time, thereby shortening time to market. In this approach, stakeholders consider life-cycle requirements early in the process, from conception through disposal, including cost, quality, and time (Amr, 2021).

Based on these definitions, concurrent engineering is a technique that integrates design, development, and assembly activities simultaneously throughout the product development cycle. It relies on cross-functional and multidisciplinary teams that develop an appropriate business plan and ensure the availability of necessary information across the value chain, thus achieving cost and time savings while improving quality.

2.2 CE and Sequential Engineering (SE)

In sequential engineering (SE), key functions—such as design, manufacturing, and customer service—are separated, and information flows linearly from one phase to the next. For example, after a prototype is verified through simulation, physical prototyping, or both, the design is reviewed for manufacturability, quality, and serviceability. Following this review, modifications are typically proposed.

- If the proposed design changes are implemented, product development costs and time will increase. That can delay market launch.

– If changes cannot be implemented because of market pressure to launch quickly or because the design is behind schedule, specialists in other functional areas—as well as manufacturing, quality, and service managers—must adapt to the design as delivered.

Accordingly, in SE, a department does not begin work on a project (or a component of it) until the preceding department has completed its tasks. Because information flows primarily in one direction, feedback and iterative replanning are limited.

By contrast, in CE, functional areas are integrated into the design process, and information flows continuously in both directions across functions. Decision-making occurs throughout each phase while accounting for the constraints and objectives of the entire product's life cycle. As a result, issues that would otherwise be discovered later can be identified and addressed earlier, improving the likelihood of reaching an optimal solution. Integrating additional functional areas into the design process facilitates early detection of problems that are difficult to resolve after design completion. Therefore, when the final design is validated, it is more likely to be manufacturable, testable, operable, and aligned with high-quality standards (Amr, 2021).

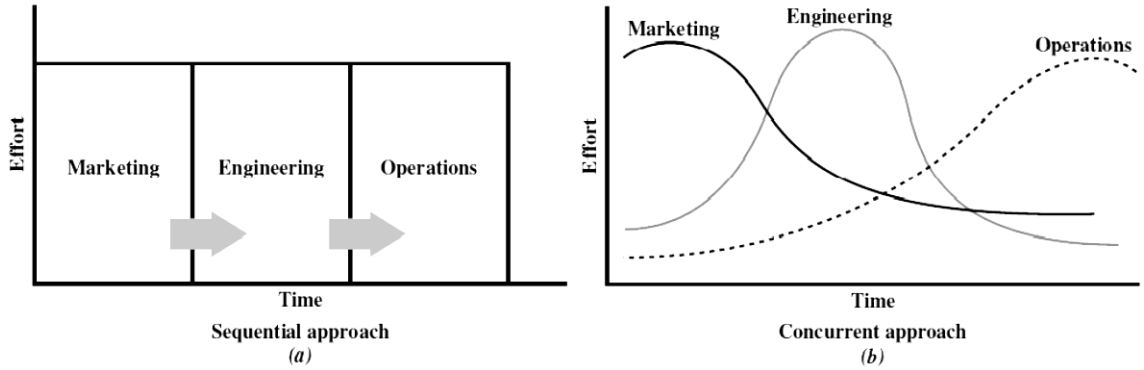


Figure 1. *Difference Between Concurrent Engineering and Sequential Engineering*
Source: (Deherieb & Abdullah Yaqoub, 2020)

2.3 Importance of CE

The importance of CE in achieving corporate objectives (reducing costs, maintaining product quality, increasing sales, and achieving competitive advantage) can be explained as follows:

– *Reducing product development costs:* by decreasing the number of redesigned cycles and incorporating customer requirements from the outset of design planning for product development.
– *Improving product quality:* by producing products with engineering and technical specifications aligned with customer requirements.
– *Enhancing and sustaining competitive advantage:* Concurrent engineering integrates customer requirements and after-sales service considerations during product planning.
– *Reducing product testing (trial-run) costs:* Product complexity can increase trial-run costs; however, concurrent engineering can reduce these costs through supportive tools such as Design for Assembly (DFA), which optimizes the number of assembled parts and the materials and processes required to produce each part, thereby reducing complexity.
– *Increasing sales* through the introduction of new products and cost reductions can increase profit margins (Alkawaz & Ali, 2020).

3 CE: PRODUCT DEVELOPMENT CYCLE AND COST REDUCTION

3.1 Cost Reduction

Cost reduction refers to prioritizing cost-improvement initiatives by focusing on short-term cash savings; through such prioritization, costs are rationalized and reduced (Obuamamh & Al-Hamdani, 2021).

The primary goal of cost reduction is to make optimal use of available resources in an

economical manner by reducing waste and misuse and directing expenditures toward necessary value-adding activities. A central objective is to achieve customer satisfaction by providing quality products with the required specifications at the lowest possible cost. Cost reduction should also address the sources of costs, enabling reductions not only in internal activities and operations but also in areas beyond the firm's boundaries, such as after-sales services (Al-Samarrai & Al-Zamili, 2017).

3.2 Ways to Reduce Costs Through CE

Concurrent engineering reduces production costs in several ways, including:

- *Reducing design-phase errors:* minimizing errors early in design prevents downstream rework, shortens the product life cycle, and lowers production costs.
- *Enabling simultaneous manufacturing and assembly planning:* parallel work across manufacturing and assembly helps firms reduce the total product cost by eliminating non-value-added time.
- *Improving cost control and resource utilization:* concurrent engineering supports tighter control of costs, reduces unnecessary expenditures, and promotes more effective use of available resources.
- *Reducing waiting time:* reported benefits include reducing setup time by 30%–70% and reducing time to market by 20%–90% (Obuamamh & Al-Hamdani, 2021).
- *Supporting target costing decisions:* to ensure cost reduction, the total product cost should be less than or equal to the target cost; on this basis, the proposed design is accepted or rejected (Ali Husam & Mohameed, 2021).

3.3 Product Development

The product development process refers to creating concepts, designs, and programs (or plans) for products that an industrial organization intends to introduce to the market. This process includes analyzing the market to identify needs, designing the product to meet those needs, and designing and planning the production process, as well as product planning (Daoud & Nouri, 2008).

Product development requires attention to four basic aspects:

- *Operational aspects:* such as information systems management, planning and scheduling, energy planning, and workforce training and management.
- *Social and living aspects.*
- *Engineering aspects: including:*
  - Production capacity: how a specific product is manufactured.
  - Support: market policies, financing, manufacturing, and maintenance activities across upper and lower organizational levels.
  - Material resources: the product's material resources and the degree of interdependence among them.
  - Maintenance capacity: design quality; the ability to repair and replace components; and the degree of interdependence among components.
  - Availability: time to market and the ability to deliver expected orders on time.
- *Administrative aspects*: including time management (scheduling), cost management (e.g., total operating cost), and the integrated management of time and cost across the engineering aspects listed above (Shokr, 2022).

3.4 CE - Product Development Phases – Reducing Costs

A fundamental principle of product development and design is to keep the product as simple as possible to facilitate both production and use. Product simplification can reduce assembly waiting time and, in turn, improve productivity—through stronger alignment between product design and production system design—while also enhancing quality, flexibility, and the ability to meet consumer demand. The product development process includes a set of activities such as production design, design and redesign, interchangeable parts, standardization, simplification, modeling, modular design, specification development, and quality engineering (Daoud & Nouri, 2008). These activities can be grouped into three main phases:

- *Setup and preparation phase:* In this phase, the firm's capabilities and resources are identified; system functions and the specialists responsible for each function are defined; appropriate tools for implementing

concurrent engineering are selected; relevant participants are identified; and a business plan aligned with the firm's strategic vision is developed.

- *Design phase:* In this phase, concurrent engineering is implemented according to the established plan. A shared database is created to support coordination and communication among members of a cross-functional team. This phase is central to concurrent engineering because it enables real integration between the concurrent engineering team environment and the expertise of the firm's specialists. In addition, an "open office" concept—adopted by some Japanese companies—may be used to create an environment that encourages open discussion and rapid problem-solving. Such an integrated workspace helps address urgent questions and resolve new issues that may arise during the design phase (Obuamamh & Al-Hamdani, 2021).

3.5 Importance of CE in Reducing Costs – Design Phase

During the design phase, CE aims to ensure that decisions made in product design lead to the lowest possible total cost over the product life cycle. It is widely argued that approximately 60%–90% of a product's total cost is determined during this phase. Accordingly, concurrent engineering is often considered a foundational approach to product development: although its application during product design may account for less than 5% of total development cost, it can reduce the final product cost by more than 70%.

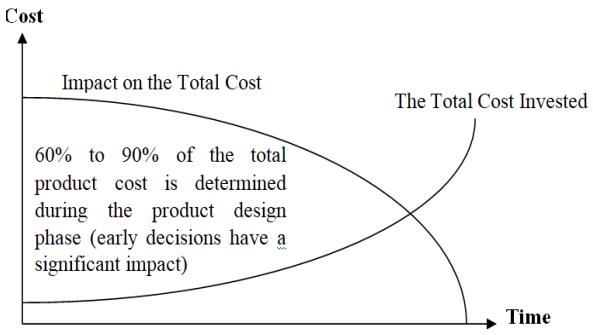


Figure 2. *Effect of CE on cost reduction during the product design phase*
Source: (Amr, 2021)

Once a product has been designed and developed, at least 80% of its cost, quality, and life-cycle characteristics are effectively determined, which reduces the likelihood of product failure (Amr, 2021).

3.5.1 Transition to the Production Phase

After the final design is established and implemented, the process transitions to production. In this phase, manufacturing and assembly activities are carried out in parallel while ensuring adherence to the proposed product design, process plan, and processing chain in order to achieve target outcomes related to cost, quality, time, and flexibility. Continuous improvement and ongoing development of production processes are emphasized (Obuamamh & Al-Hamdani, 2021).

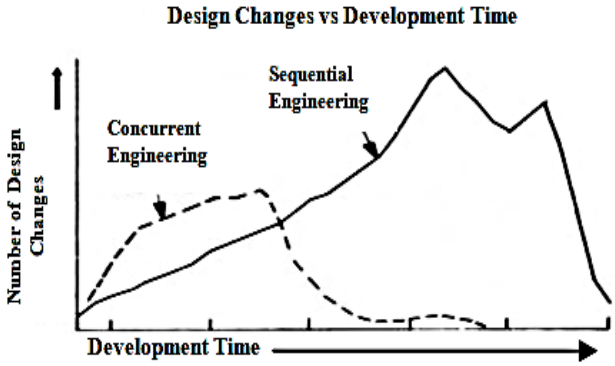


Figure 3. *Comparison of costs under Concurrent and Sequential Engineering across the product development and design phase*
Source: (MFGRobots – Industrial Manufacturing, 2025)

3.5.2 Cost Patterns Under CE vs SE

Under concurrent engineering, product design costs tend to be relatively high and increase rapidly during the early stages of product development, when multiple design iterations are performed to reach an appropriate final design. This pattern reflects intensive early-stage activity and substantial involvement of cross-functional teams. Afterward, design-related costs typically decline and may become minimal during assembly and manufacturing because iterative loops are shorter and fewer downstream problems arise.

By contrast, under sequential engineering—where work is transferred from one department to the next—design costs are often lower during the initial design phase and rise more gradually. However, costs may increase substantially during assembly and manufacturing due to a higher number of change requests and longer iteration

loops. In practice, change management becomes more complex because revisions must be communicated back across departments.

Overall, a comparison of the two approaches suggests that total costs under concurrent engineering are lower than under sequential engineering, supporting the conclusion that concurrent engineering reduces costs throughout product development and can significantly lower overall cost relative to sequential processes (Morenton, n. d.).

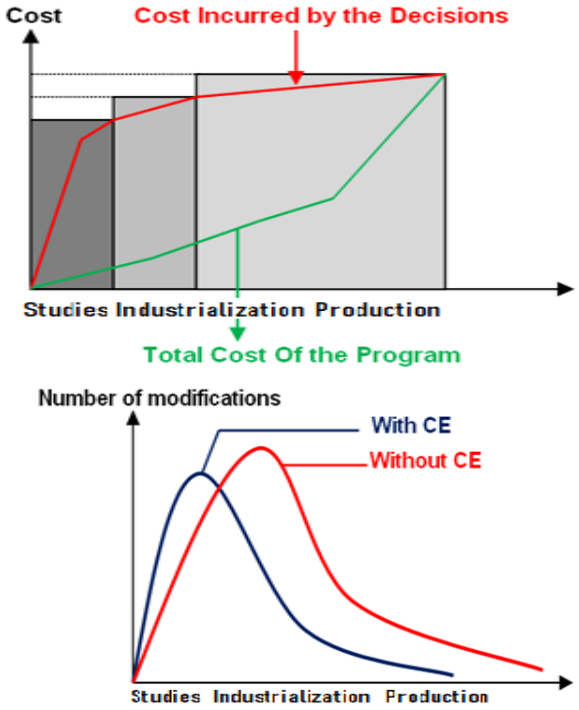


Figure 4. *Product Development Costs under CE*
Source: (Morenton, n. d.)

To reorganize development of the same product with minimal additional resources, firms can adopt a simultaneous (concurrent) engineering workflow in which departments consult one another—or relevant personnel—before completing their tasks. The firm can also jointly define the Product Design Specification (PDS) after consulting manufacturing and production teams to evaluate design feasibility and manufacturability.

4 CE TOOLS AND CHALLENGES OF APPLICATION

To achieve the "trilogy" of cost reduction, quality improvement, and shorter product development cycles, concurrent engineering relies on several supporting tools. Among the most important is Quality Function Deployment (QFD), which integrates customer requirements with the product's functional and technical requirements early in the development cycle. Other widely used tools include Design for Assembly (DFA), Design for Manufacturing (DFM), and Design for Manufacturing and Assembly (DFMA). These tools can also support sustainability by enabling the design, development, and production of products that meet sustainability standards and strengthen the firm's competitive position.

4.1 Quality Function Deployment (QFD)

Quality Function Deployment (QFD) originates from the Japanese phrase hin shitsu ki no ten kai, where: hin shitsu refers to quality (attributes or characteristics), ki no refers to function, and ten kai refers to deployment (diffusion or development). In this sense, QFD involves deploying customer-desired product or service attributes across all relevant organizational components (Elomri et al., 2021).

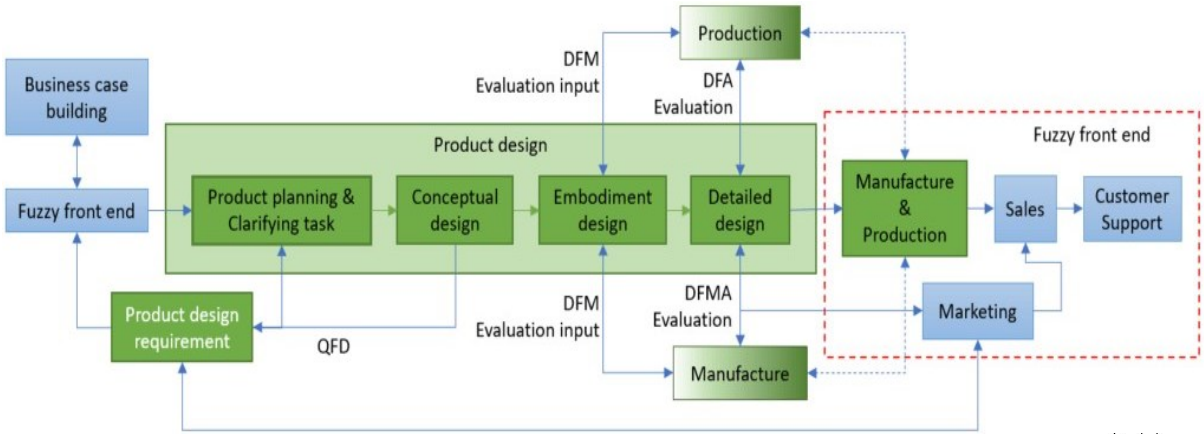


Figure 5. *Role of CE in enhancing the product development cycle*
Source: (MFGRobots – Industrial Manufacturing, 2025)

According to Akao, QFD is a comprehensive methodology for new product design because it provides specific methods to ensure quality at every phase of product development, beginning with design. In other words, QFD introduces quality from the design stage in order to satisfy the customer and then translates customer requirements into design objectives and key characteristics that become critical during production. QFD, therefore, represents a structured approach to quality planning that incorporates technological considerations, reliability, and costs when designing and developing new products (Gautier, 2009).

4.2 Design for Manufacturing and Assembly (DFMA)

DFMA combines two techniques, Design for Assembly (DFA) and Design for Manufacturing (DFM), as follows:

- *DFA:* a design approach that emphasizes ease of assembly by reducing the number of parts. Fewer parts typically reduce assembly time and can lower the total cost of components required for assembly. Although DFA improves assimilability, it may be less effective for generating design concepts that reduce costs during the functional modeling stage. Because formal functional modeling standards and cost benchmarks may not be available at this stage, designers often rely on experience and engineering judgment when developing functional models (Abd El-aleem Fateh, 2019).
- *DFM:* a design approach focused on manufacturability. It supports the development of designs aligned with manufacturing and assembly requirements, including the selection of raw materials and processes that simplify production as much as possible, thereby reducing cost, development time, and time to market (Alkawaz & Ali, 2020).

Taken together, DFA and DFM both aim to reduce part count by integrating multiple functions into fewer components. However, excessive part integration can complicate manufacturing and substantially increase costs; automated handling of such parts may also become difficult. To mitigate these trade-offs, DFA and DFM are integrated into DFMA, which provides a more balanced framework for concurrent consideration of manufacturing and assembly during new product development (Abd El-aleem Fateh, 2019). This integration is often described as a “structured methodology” because DFMA involves systematic evaluation of manufacturability and assemblability when creating a new product (Al-Samarrai & Al-Zamili, 2017). In this sense, DFMA operationalizes concurrent engineering by emphasizing alternative design evaluation and quantitative assessment of manufacturing and assembly difficulty. As a result, it requires designers to have substantial knowledge of manufacturing methods and product life-cycle considerations.

4.3 Requirements for Successful CE to Reduce Cost

The successful implementation of CE requires a combination of factors related to: the concurrent flow of work; the early inclusion of stakeholders involved in product development, including representatives of the supply chain and work teams. Therefore, these factors can be divided into organizational factors and technological auxiliary factors.

4.3.1 Organizational Factors

Organizational factors can be divided into factors related to the design team and factors related to the activities necessary to implement CE, which we explain as follows:

A. Multi-functional Team: Design – development of a product

The team includes individuals representing internal functions (e.g., purchasing, production, marketing, and warehousing) as well as external stakeholders (e.g., customers, suppliers, and distributors). To ensure effective concurrent work and facilitate team performance, several conditions are important, including senior management support, a strong teamwork culture, and active information sharing. The team should be cross-functional and multidisciplinary, supported by effective communication and training that builds skills for synchronized work. Early involvement of customers and suppliers can also support early problem identification and resolution.

B. Activities Required to Implement CE

These are commonly grouped into three categories:

- *Activities required for product design and development:* market research, defining initial design specifications, conceptual design, detailed design, and supply chain design activities aligned with the product.
- *Activities required for simultaneous work:* training and practices related to communication, organization, relationship-building, and mechanisms for information flow and cooperation among individuals.
- *Decision-making activities:* early problem detection and early decision-making (Amr, 2020).

4.3.2 Supporting Technologies Factors

Supporting technologies include QFD; Design for X (DFX) systems; Flexible Manufacturing Systems (FMS); Design for Cost Reduction (DFCR); Design-to-Cost (DTC); Computer-Aided Design (CAD); Computer-Aided Manufacturing (CAM); and Failure Mode and Effects Analysis (FMEA). More recently, concurrent engineering has increasingly depended on digital tools and software that enable multidisciplinary teams to collaborate more effectively, share information in real time, and make data-driven decisions. Examples include Product Lifecycle Management (PLM) systems and tools such as MCAD, CAE (often used instead of "CAO"), and BIM, among others.

5 CONCURRENT ENGINEERING AT AIRBUS

Airbus is a leading company in the aviation industry. In the early 1990s, it adopted concurrent engineering as a strategic approach to aircraft development, integrating design, manufacturing, and engineering functions in parallel. This approach significantly reduces development time, lowers costs, and enhances product quality by enabling early identification of design-related issues.

5.1 The Project of Airbus Concurrent Engineering (ACE)

At the beginning of the 1990s, the adoption of PDM (Product Data Management) and 3D solid design allowed Airbus to begin constructing a DMU (Digital Mock-up) prototype, with the aim of verifying functional design overlaps. This led to the adoption of concurrent engineering within the company and the launch of a project, ACE (Airbus Concurrent Engineering), to develop and deploy methods, processes, and tools across all functional design disciplines (Mas et al., 2013).

Airbus has deployed concurrent engineering capabilities at all Airbus sites. About 1800 workstations fully equipped with CAD/PDM capabilities are deployed in the company.

To facilitate the exchange of DMUs across different sites, dedicated processes have been established. Because DMU Exchange (DEX) contributes to development team performance, it is supported by performance indicators and is therefore closely monitored (Pardessus, 2004).

5.2 Application of CE in the Aircraft Development Cycle

Concurrent engineering was implemented at Airbus during the development of the A340-500/600, with the purpose of reducing costs by 30%, removing physical models and replacing them with the DMU digital model, and reducing time by 25% in the product development cycle and 50% in the Focus cycle (Morenton, n. d.).

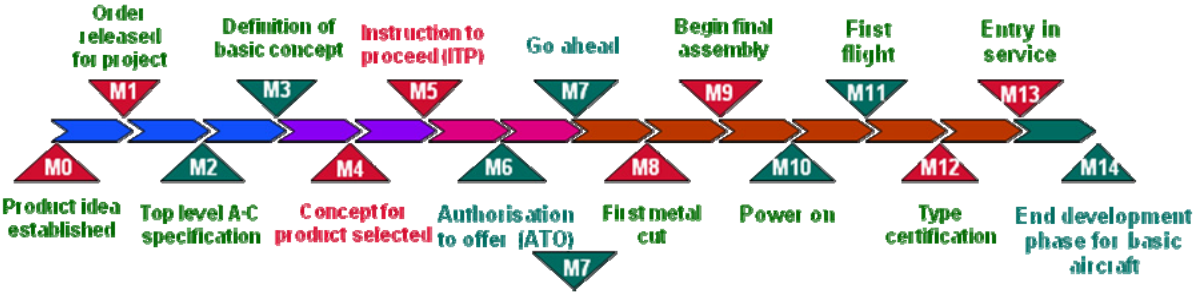


Figure 6. *Product Development Cycle at Airbus*

Source: (Mas et al., 2013)

CE bridges the gap between functional design and industrial design and feeds functional design with manufacturing information to facilitate work with DFM and DFA techniques. The functional design model, DMU, is a basic component in the early stages of the product development cycle.

The DMU model helps Airbus determine the aircraft's key geometry and locate systems and equipment. In addition, it enables the teams responsible for design support to evaluate the ease of performing maintenance operations once the aircraft enters service.

Recently, the company has been using techniques of Model-Based Systems Engineering (MBSE) to ensure a consistent path that enables tracking of development stages from tasks and processes to customizing functions for components. The many interconnections are evaluated using multidisciplinary analysis and optimization capabilities to explore the design space and find the best solution (**Airbus**, 2024**a**).

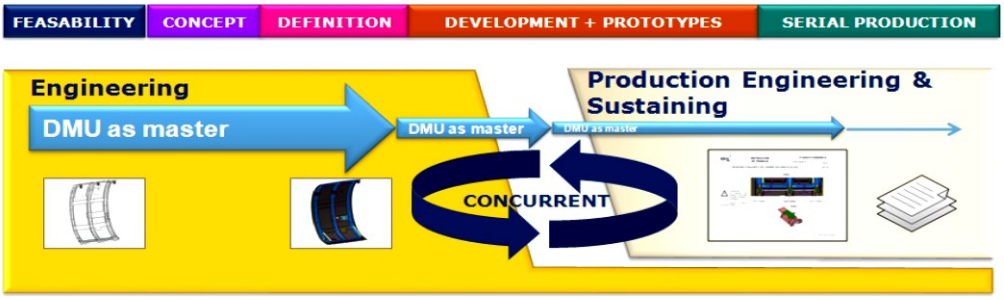


Figure 7. *Use of the DMU Model in CE at Airbus*

Source: (Mas et al., 2013)

Table 1. *Product Development Cycle at Airbus*

No.	Phases	Statement
1	Design	Aircraft's development process follows several phases to ensure that Aircraft software meets market needs including performance, timely market access, maturity upon entry into service and increased production. The stages are: – *Feasibility and concept:* Market expectations and requirements are determined, and the latest technologies, structural concepts and systems engineering are used to determine the initial design model and detailed specifications of parts and equipment suppliers. – *Engineering in action:* At this phase, Concurrent Engineering technique is adopted with an emphasis on the use of DMU digital model and MSBE techniques. *Design:* During this phase, the dimensions of all initial parts and their optimized interfaces, equipment, enclosures, engines and landing gear developed through the supply chain are determined.
2	Test and Certification	Before starting the serial production process, Airbus subjects all its Aircraft to complex and rigorous flight tests. For example, the company has subjected the A350 to a comprehensive test since it entered service. Five A350-900 Aircrafts were tested by preparing a flight that lasted for more than 14 months, for a total of 2,600 hours. After that, it obtained the validity certificate from the European EASA Agency and the FAA Agency in the United States of America.
3	Production	The simultaneous process in manufacturing creates a flow system that seamlessly brings together millions of pieces of Airbus Aircraft, while providing flexibility and agility to adjust production outputs that meet market needs.
4	Delivery	When Airbus completes production, and before officially signing the transfer of ownership and delivering the Aircraft to the customer, the latter conducts a complete and detailed inspection of the Aircraft with the assistance of delivery experts and external experts to ensure that the aircraft conforms to contractual specifications through a very precise and specific process.
5	Operating Life	Airbus adopts a long-term strategy, by accompanying all its Aircraft throughout their lifespan (30 years), which helps maximize performance, reduce costs and achieve overall sustainability of Air transport. During this phase, Airbus is investing in research and development, focusing on improving the product life cycle, adopting innovative services to ensure more efficient flights from take-off to landing, maintenance, and broader commercialization of sustainable fuels.

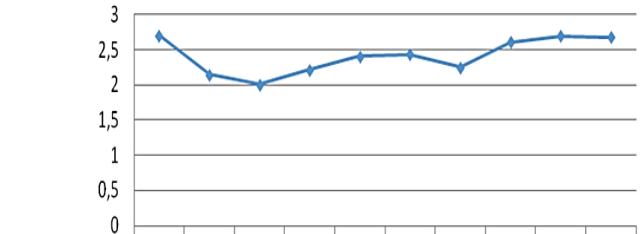
Source: Prepared by the author based on: (Airbus, 2024b)

5.3 Airbus R&D Costs and Production Pace (2015-2024)

By relying on the CE technique as a long-term strategy, Airbus has achieved many accomplishments, reflected in diversifying its products characterized by sophistication, quality, and good design, reducing production costs, and achieving comprehensive sustainability of aeronautical transport, meeting market requirements, etc. This is due to the focus on research and development processes, as shown in Figure 8. In contrast, its sales and production pace have increased due to the increasing global demand for its aircraft (Table 2), which indicates the company's strong performance. We illustrate this by analyzing research and development costs, production pace, and revenue development during the period 2015-2024.

5.3.1 Airbus R&D Costs (2015-2024)

Figure 8 ilustrates the costs of research and development for the period 2015–2024.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Costs of R&D	2,702	2,147	2,011	2,214	2,405	2,436	2,252	2,607	2,698	2,676

Figure 8. Airbus R&D Costs (2015-2024) (million€)
Source: Prepared by the author based on: (Investors / Annual Reports, 2025)

- *2015–2017*: We note that R&D costs are declining, moving from 2,702 to 2,011 million €. This is due to research and development activities in the A350 XWB program at Airbus Commercial Aircraft. In addition, €311 million in development costs were capitalized during 2016, primarily related to the H160 and A350 XWB programs. Development costs of €219 million were capitalized during 2017, primarily related to the A330 Neo and H160 programs.
- *2018–2019*: We note that R&D costs are constantly increasing during the years 2018 and 2019. This is due to research and development activities in the A320 and A350 programs. Development costs of €133 million, primarily related to Airbus programs, were also capitalized in 2019. Development costs of €91 million, primarily related to Airbus helicopter programs, were capitalized in 2018.
- *2020–2021*: We note a decline in R&D expenditures due to cash containment measures in response to the COVID-19 pandemic, which affected the performance of development activities. The company continued its development activities toward achieving the revised capabilities roadmap. Updates' activities have progressed closely with the client.
- *2022–2024*: We find that R&D expenditures are increasing, mainly due to the intensification of activities to prepare future technologies. In addition, the company focused primarily on developing the latest generation of commercial aircraft software, including the A321 XLR and A350 cargo aircraft.

5.3.2 Airbus Revenues and Production Pace (2015-2024)

Table 2. *Product Development Cycle at Airbus*

Statement / Years	Revenues*	Delivery Revenues**	Number of deliveries of commercial aircraft
2015	45,854	-	635
2016	49,237	-	688
2017	43,486	39,950	718
2018	47,970	44,157	800
2019	54,775	50,577	863
2020	34,250	31,331	566
2021	36,164	33,455	611
2022	41,428	37,681	661
2023	47,763	42,756	735
2024	50,646	44,630	766

Source: Prepared by the author based on: (Investors / Annual Reports, 2025)

* Revenues are mainly comprised of sales of goods and services, as well as revenues associated with construction contracts accounted for under the PoC method, contracted research and development, and customer financing.
** Revenue from the sale of commercial aircraft is recognized at a point in time (i.e., at delivery of the aircraft). The Company estimates the amount of price concessions granted by the Company's engine suppliers to their customers as a reduction of both revenue and cost of sales.

In Table 2, we find that:

- *2015–2019*: A significant increase in the company's revenues indicates an increase in the pace of production, especially since the number of orders for Airbus aircraft is constantly increasing, as the number of aircraft delivered to customers reached 863 aircraft compared to 2015, in which the number of aircraft delivered reached 635 aircraft, an increase estimated at 26%. This is due to the conclusion of new agreements with Emirates Airlines and Rolls-Royce to transfer six deliveries from 2017 to 2018 and from 2018 to 2019.
- *2020–2024*: During 2020, we noticed a significant decline in the company's revenues and the number of aircraft delivered due to the repercussions of the COVID-19 pandemic, which impacted the performance of development, production, flight testing, aircraft delivery, and software upgrades. During the period 2021–2024, we notice an increase in revenues due to the company's intensive commercial activities and an increase in the number of deliveries, especially during the year 2024, by 200 aircraft compared to 2020. This indicates strong performance across programs and growth in services.

6 CONCLUSIONS

Concurrent engineering is one of the most important techniques for ensuring effective development processes across all phases of the product life cycle. It also supports sustainability from the stage until the product reaches the market by reducing cost and time and improving quality. This is due to the simultaneous integration of design, development, and manufacturing processes, supported by cross-functional and multidisciplinary teams. This confirms the validity of the first hypothesis, as demonstrated by the following:

- Concurrent engineering provides an integrated framework throughout the product development cycle, which contributes to companies achieving competitive advantage and keeping pace with rapid technological changes and developments in the modern manufacturing environment, thereby meeting customer requirements.
- Concurrent engineering can be considered a long-term strategy that supports cost management by controlling costs and providing appropriate resources to complete product design, development, and manufacturing processes successfully and efficiently.
- Airbus has invested in concurrent engineering and further developed it by adopting digital solutions and new techniques such as DMU and the MBSE model. This has helped strengthen performance, increase productivity—especially at the design stage—and achieve sustainability through its research and development programs. It has also enabled Airbus to monitor its aircraft throughout their life cycle and implement necessary improvements. This confirms the validity of the second hypothesis.

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CAPITAL STRUCTURE AND FINANCIAL PERFORMANCE IN MAJOR ALGERIAN FIRMS

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ABSTRACT

This study examines the effect of capital structure on the financial performance of major Algerian firms over the period 2020–2024. A balanced panel of six large companies — Sonatrach, Biopharm, Saidal, El Aurassi, Alliance Assurances, and Sonelgaz — is analyzed using two accounting-based performance indicators (ROA and ROE) and two leverage proxies (Debt Ratio and Leverage). Panel data models are estimated, and appropriate specification tests are applied to select the optimal estimator. The findings reveal a statistically significant negative relationship between debt ratios and both ROA and ROE, with leverage exerting a stronger adverse effect on equity returns than on asset returns. Random Effects models are preferred over pooled OLS based on the Breusch–Pagan LM and Hausman specification tests, highlighting the importance of firm-specific heterogeneity. Firm size and sales growth are positively associated with financial performance. The results are consistent with Pecking Order, Trade-off, and Agency theories in the context of costly bank financing and underdeveloped capital markets. Financial managers are encouraged to adopt more moderate leverage levels, while regulators are advised to promote alternative market-based financing instruments to reduce firms' dependence on bank credit.

1 INTRODUCTION

1.1 Study Background

Capital structure is a central issue in corporate finance because it determines how a firm combines debt and equity to finance its activities and influences both risk and return. In Algeria, this choice is made under conditions of weak capital markets, information asymmetry, and macroeconomic instability (IMF, 2024), with major firms relying heavily on relatively expensive bank credit and operating under strong state ownership.

The years 2020–2024 were particularly challenging for these firms, given COVID-19 disruptions, oil price fluctuations affecting Sonatrach, and recurrent exchange rate pressures (World Bank, 2020; IMF, 2024). Such conditions raise the question of how alternative capital structure choices translate into differences in profitability, measured here by Return on Assets (ROA) and Return on Equity (ROE).

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1.2 Research Problem

Algeria's 2020 Finance Law introduced measures to support capital market development, but there is still no clear empirical picture of how capital structure affects the performance of large Algerian firms. Existing local studies often report a negative association between debt and profitability, yet they rely mainly on cross-sectional data and do not cover the period after 2020. Three main shortcomings can be identified: methodologically, most studies use cross-sectional OLS rather than panel techniques; temporally, many studies stop before 2020 and miss COVID-19 and oil price shocks; contextually, empirical work rarely accounts for Algeria's specific institutional features, such as state ownership and thin equity markets.

To address these gaps, this study analyzes how capital structure — represented by Debt Ratio and Leverage — relates to ROA and ROE for six major Algerian firms over 2020–2024 and compares panel specifications to identify which model best captures firm-level heterogeneity.

1.3 Research Objectives

The study has three objectives: (1) estimate the debt–performance relationship using a balanced panel of 30 firm-year observations; (2) compare pooled OLS, fixed-effects, and random-effects estimators using Breusch–Pagan LM, Hausman, and Chow tests; and (3) draw policy-oriented conclusions on leverage levels compatible with financial stability.

1.4 Research Hypotheses

Grounded in Trade-off Theory, Pecking Order Theory, and Agency Theory, the study tests three hypotheses:

H1: Debt Ratio has a negative and statistically significant relationship with ROA and ROE.

H2: Leverage has a stronger negative effect on ROE than on ROA

H3: Firm-specific unobserved characteristics make panel estimators preferable to pooled OLS.

1.5 Study Significance

The study contributes theoretically by providing recent panel-data evidence for large Algerian firms, practically by guiding financial managers and regulators such as COSOB, and methodologically by applying standard panel econometric tools to a new firm-level dataset in line with recent MENA empirical work.

2 THEORETICAL FRAMEWORK

2.1 Concept of Capital Structure

Capital structure refers to the mix of long-term debt and shareholders' equity used to finance a firm's activities and growth (Ross et al., 2020). It includes bank loans, bonds, common equity, and retained earnings, and affects both the cost of capital and financial risk. In Algeria, where bank credit dominates corporate financing and bond markets remain shallow, capital structure choices can quickly increase distress risk, especially under oil price shocks and currency pressures (Khouri, 2021; Guettoufi, 2025).

In this study, capital structure is measured through Debt Ratio, defined as total debt to total assets, and Leverage, defined as total debt to equity (Myers, 1984). These ratios capture the firm's dependence on borrowed funds relative to its asset base and equity cushion.

2.2 Dominant Theories of Capital Structure

2.2.1 Trade-Off Theory

Trade-off Theory argues that firms balance the tax benefits of debt against the expected costs of financial distress when choosing their financing mix (Modigliani & Miller, 1963; Kraus & Litzenberger, 1973). Higher leverage raises the value of the tax shield but also increases default risk. In emerging markets, including MENA economies, firms often stay below the theoretical optimum because distress costs are high and legal systems are slow (Booth et al., 2001). Algerian evidence points in the same direction, as large firms operate under volatile earnings and rigid financial structures (Khouri, 2021).

2.2.2 Pecking Order Theory

Pecking Order Theory is based on information asymmetry between managers and outside investors (Myers & Majluf, 1984). It predicts that firms first use internal funds, then debt, and issue new equity only as a last resort. Equity may be viewed by the market as a signal of overvaluation,

making it relatively costly. In Algeria, many large state-owned and private firms rely mainly on retained earnings and bank loans, while equity financing remains limited because of thin stock markets and governance concerns (Guettoufi, 2025; El Bahsh et al., 2018).

2.2.3 Agency Theory

Agency Theory focuses on conflicts of interest between managers and shareholders and explains how debt can reduce agency problems (Jensen & Meckling, 1976). Regular interest and principal payments limit free cash flow that managers might otherwise use for low-return projects or private benefits (Jensen, 1986). However, excessive debt can also encourage asset substitution and risk-shifting, harming creditors. For large Algerian firms, especially state-owned enterprises, these agency issues are stronger because ownership is diffuse and external monitoring is limited, making debt structure an important governance tool (Khouri, 2021).

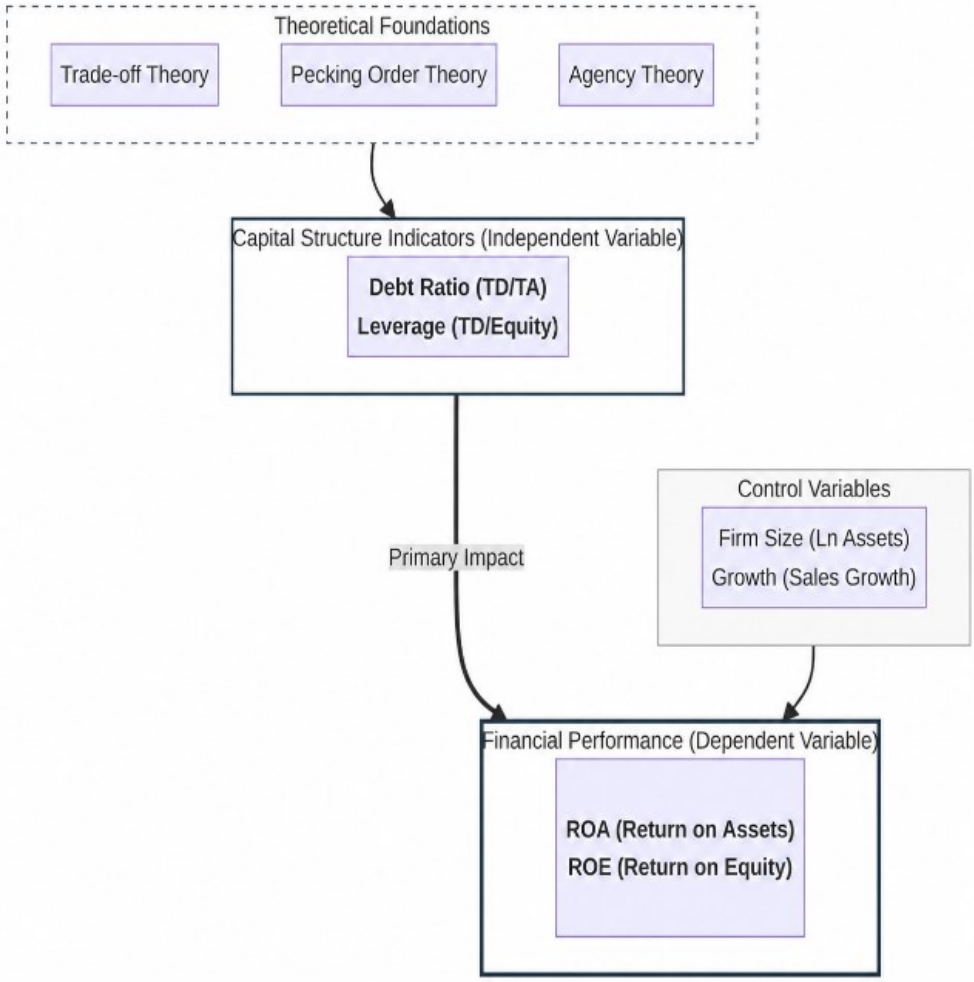


***Figure** 1. Conceptual Model*

Source: Created by the author

2.3 Financial Performance Proxies

In this study, financial performance is captured by two standard accounting ratios. Return on Assets (ROA), measured as net income divided by total assets, reflects how efficiently a firm uses its asset base to generate profits and is less directly affected by changes in leverage (Ross et al., 2020). Return on Equity (ROE), defined as net income divided by shareholders' equity, measures the return earned by owners and reacts more strongly to shifts in the level of debt. Prior Algerian work on large firms, including the Saidal Group, shows that higher long-term indebtedness is often associated with weaker ROA, which supports the use of both indicators in the present analysis (Khouri, 2021).

Two control variables are added to isolate the effect of capital structure from other firm characteristics. Firm size is measured by the natural logarithm of total assets and is expected to capture scale advantages and easier access to financing for larger companies. Growth is measured by the annual sales growth rate and reflects expansion opportunities that may improve profitability if managed efficiently. Debt Ratio and Leverage are widely used indicators of capital structure risk, measuring the extent to which firms rely on external debt financing relative to their asset base and equity, respectively (Brigham & Houston, 2022).

Table 1. Variable Definitions and Predictions

Variable	Definition	Expected Sign	Rationale
ROA	NI/TA	-	Debt overhang
Debt/TA	TD/TA	-	TOT/POT
Leverage	TD/Equity	-	Agency costs
Size	Ln(Assets)	+	Economies

Source: Created by the author

2.4 Hypotheses Development

The hypotheses build on the main ideas of Trade-off Theory, Pecking Order Theory, and Agency Theory, and translate them into testable expectations for large Algerian firms. These frameworks emphasize how tax benefits of debt, information asymmetries between insiders and outsiders, and conflicts of interest between managers and shareholders shape financing choices and, ultimately, performance.

H1: Debt Ratio has a negative and statistically significant relationship with ROA and ROE.

This hypothesis reflects the view that, beyond a certain point, additional borrowing increases interest charges and distress risk more than it contributes tax advantages, which erodes both asset-based and equity-based returns.

H2: Leverage has a stronger negative effect on ROE than on ROA.

Since ROE measures the return to shareholders after servicing debt, changes in leverage are expected to feed more directly into this indicator, especially in an environment of relatively high lending rates and limited risk diversification.

H3: Firm-specific unobserved characteristics have a statistically significant effect on ROA and ROE, which supports the use of panel data estimators instead of pooled OLS.

Persistent differences across firms in governance quality, access to bank finance, and exposure to sector-specific shocks are likely to influence profitability measures, making it important to control for this unobserved heterogeneity when estimating the model.

3 LITERATURE REVIEW

Research on capital structure and financial performance has produced mixed results across different financial systems. Some studies argue that moderate leverage can enhance performance through tax benefits and managerial discipline, while others show that high debt levels reduce profitability by increasing financing costs and distress risk. In Algeria, evidence remains limited for large firms operating in a banking-dominated system.

3.1 Empirical Debate

Empirical evidence on the capital structure–performance link remains inconclusive. In environments where borrowing costs are high and capital markets are shallow, higher leverage often coincides with weaker profitability, whereas moderate debt may still support performance in more stable settings through tax shields and reduced managerial discretion (Myers, 1984; Jensen, 1986; Booth et al., 2001). This divergence is especially visible in emerging economies, where firms rely heavily on bank finance and operate under volatile macroeconomic conditions, making capital structure a strategic choice shaped by institutional quality rather than a purely accounting decision.

3.2 International Evidence

The international literature frames the capital structure–performance link through three perspectives: trade-off theory, which posits that firms balance tax benefits against distress costs;

pecking order theory, which suggests a financing hierarchy driven by information asymmetry; and agency theory, which views debt as a mechanism to constrain managerial discretion (Myers, 1984; Myers & Majluf, 1984; Jensen, 1986). Recent empirical work confirms that leverage effects are strongly context dependent, underlining the need to examine capital structure in specific institutional settings rather than transferring results across countries without adaptation.

3.3 Algerian Evidence

The Algerian evidence points to a cautious use of debt and a central role for internal financing. Boussiki (2023) finds that self-financing is positively associated with performance in the Saidal Group, whereas medium- and long-term debt shows a significant negative relationship. Bousbaa (2021) confirms a significant link between capital structure and ROA for industrial firms, documenting heavy reliance on short-term debt. Khouri (2022) identifies profitability, tangibility, and tax shields as key determinants of leverage among 207 Algerian enterprises. Guettoufi and Oucif (2022) show that firm size positively affects leverage among listed firms, while Benkhedda and Allem (2025) report a significant negative relationship between the total debt ratio and ROA in a panel of Tlemcen industrial firms. Most recently, Guettoufi (2025) finds that size, liquidity, and age drive financial performance, with leverage effects less stable across specifications.

3.4 Methodological Tendencies

The literature has moved progressively from cross-sectional regressions toward panel data approaches using fixed-effects and random-effects models with Breusch–Pagan LM and Hausman specification tests. Algerian research follows this trend, reinforcing the case for panel estimators that control for time-invariant firm-specific factors and isolate more clearly the contribution of capital structure to performance.

3.5 Research Gap

Despite this progress, three gaps remain. First, existing studies either focus on a single firm or stop before 2020, missing the combined effects of the pandemic, oil price swings, and regulatory changes. Second, few analyses estimate financial performance using both debt ratio and leverage simultaneously in a balanced panel for large Algerian firms. Third, advanced estimators addressing endogeneity, such as dynamic GMM, remain underused in the Algerian context. This study addresses these gaps by examining a balanced panel of six major firms over 2020–2024.

Table 2. *Summary Table*

Study title	Main result	Relevance to this study
The effect of capital structure on the financial performance of companies listed on the Algerian stock exchange: Case of the Saidal group (Boussiki, 2023)	Self-financing improves performance; medium/long-term debt reduces it	Provides firm-level evidence from a major Algerian company on how internal funds and long-term debt shape financial performance.
The Impact Of Capital Structure On The Performance of Algerian Companies: Econometric Study on Industrial Companies During the Period (2013-2018) (Bousbaa, 2021)	Capital structure is significantly related to ROA; firms rely on short-term debt	Shows that debt–performance links are significant for Algerian industrial firms and documents the dominance of short-term borrowing.
Firm Level Determinants of Capital Structure in Algeria (Khouri, 2022)	Profitability, tangibility, DTS, NDTS are significant determinants	Clarifies which firm characteristics drive leverage choices in Algerian enterprises, supporting the selection of explanatory variables.
Analysis of the determinants of the capital structure of companies listed on the Algerian Stock Exchange (Guettoufi, Y., & Oucif, F. K., 2022)	Joint relationship between capital structure determinants and financial leverage; firm size positively affects leverage, while firm age has a negative effect.	Highlights the role of size and age in explaining leverage among Algerian listed firms and supports their inclusion as controls.

Study title	Main result	Relevance to this study
The impact of capital structure on financial performance: An econometric study on a sample of industrial enterprises in Tlemcen during the period 2018–2022 (Benkhedda & Allem, 2025)	Capital structure, measured by total debt ratio, has a significant negative relationship with ROA; long-term debt has a non-significant negative effect, while firm activity positively affects financial performance.	Adds recent Algerian evidence that higher total debt weakens profitability and illustrates the value of panel techniques in debt–performance studies.
Study title: Determinants of financial performance of listed companies on the Algiers Stock Exchange: An econometric study using panel data analysis (Guettoufi, 2025)	Size, liquidity, and firm age significantly affect financial performance; debt effects are less stable	Shows that firm size, liquidity, and age are key drivers of performance in Algerian listed companies and supports a panel-data approach.

Source: Created by the author based on the reviewed literature

4 METHODOLOGY

4.1 Research Design

This study adopts a quantitative, explanatory design to examine the effect of capital structure on performance for major Algerian firms over 2020–2024. The data are structured as a panel, allowing variation across firms and over time to be analyzed within the same framework. This is particularly useful because leverage decisions and profitability may change from one year to another.

Panel methods are widely used in corporate finance because they reduce omitted-variable bias and account for unobserved firm-specific factors that may affect performance. The empirical analysis proceeds in three steps: pooled OLS is first estimated as a benchmark; fixed-effects and random-effects models are then fitted; and Breusch–Pagan LM and Hausman tests are applied to identify the most appropriate specification. This approach is consistent with recent Algerian research on capital structure and financial performance.

4.2 Population and Sample

The study focuses on large Algerian firms operating under macroeconomic and financial conditions comparable to those affecting the Algerian Stock Exchange. Only firms with complete annual financial statements for 2020–2024 are retained, which allows the construction of a balanced panel with consistent observations over time.

Because the Algerian capital market is small and not all major firms are listed, the sample is based mainly on data availability, reporting continuity, and economic relevance rather than random selection. This purposive approach is common in small-market studies where state-owned enterprises play a central role. The final sample includes six major Algerian firms — Sonatrach, Biopharm, Saidal, El Aurassi, Alliance Assurances, and Sonelgaz — yielding 30 firm-year observations.

4.3 Data Sources

The empirical analysis relies on secondary data drawn from annual financial statements and official reports of major Algerian firms. These documents provide the balance sheet, income statement, and notes needed to construct the dependent and independent variables. Using audited financial statements is standard in capital structure research because leverage and profitability ratios are derived from published accounts rather than survey data.

This source choice is also consistent with Algerian studies on capital structure and financial performance, which usually depend on firm-level accounting data in the absence of large commercial databases. For example, Boussiki (2023) used published financial statements for the Saidal Group, and Khouri (2022) relied on enterprise-level accounting data to examine capital structure determinants. Using the same type of data improves comparability with earlier Algerian evidence.

4.4 Variables Definition

Financial performance is measured using Return on Assets (ROA) and Return on Equity (ROE). ROA shows how efficiently a firm uses its assets to generate profit, while ROE reflects the return earned by shareholders on their invested equity. These two indicators provide complementary views of profitability and react differently to capital structure changes.

Capital structure is captured by two leverage measures: Debt Ratio, defined as total debt over total assets (TD/TA), and Leverage, defined as total debt over equity (TD/Equity). Two control variables are included: firm size, measured as the natural logarithm of total assets, and growth, measured by the sales growth rate. Including these controls helps reduce bias in the estimated coefficients.

Table 3. *Variable definitions*

Variable type	Variable	Symbol	Measurement
Dependent	Return on Assets	ROA	Net income / Total assets
Dependent	Return on Equity	ROE	Net income / Shareholders' equity
Independent	Debt Ratio	TD/TA	Total debt / Total assets
Independent	Leverage	TD/Equity	Total debt / Equity
Control	Firm Size	SIZE	Natural log of total assets
Control	Growth	GROWTH	Sales growth rate

Source: Created by the author

4.5 Model Specification

The link between capital structure and financial performance is examined through two panel regression equations, one for ROA and one for ROE as dependent variables. For the firm i in the year t, the baseline models can be written as:

$$ROA_{it} = \alpha_0 + \alpha_1 DR_{it} + \alpha_2 LEV_{it} + \alpha_3 SIZE_{it} + \alpha_4 GROWTH_{it} + u_{it}$$

$$ROE_{it} = \beta_0 + \beta_1 DR_{it} + \beta_2 LEV_{it} + \beta_3 SIZE_{it} + \beta_4 GROWTH_{it} + \varepsilon_{it}$$

Where:

- i indexes the firm,
- t indexes the year,
- DR is the debt ratio,
- LEV is leverage,
- $SIZE$ is firm size,
- $GROWTH$ is sales growth, and
- u_{it} and ε_{it} are the error terms.

In both equations, profitability is explained by the two capital structure indicators and the firm-specific control variables. Working with two dependent variables is helpful because ROA and ROE capture different aspects of performance: ROA focuses on operating efficiency relative to the asset base, whereas ROE is more directly influenced by financial leverage and the distribution of returns to shareholders. Using both measures in parallel has become common in empirical work on leverage and improves the robustness of the findings for major Algerian firms.

4.6 Estimation Procedure

The empirical analysis is carried out in three main stages. A pooled OLS model is first estimated and used as a simple benchmark. Fixed-effects and random-effects specifications are then fitted to allow for unobserved differences between firms that remain constant over time. In a third step, specification tests are applied to determine which estimator is most suitable for the data.

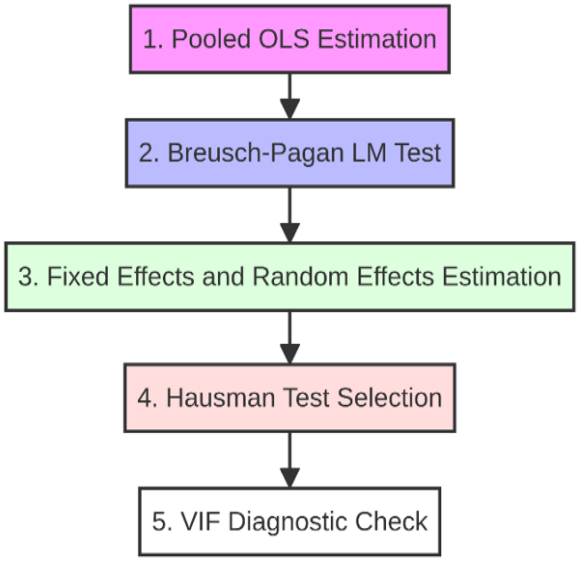


***Figure** 2. Estimation procedure*
Source: Created by the author

The Breusch–Pagan LM test is used to assess whether a panel structure is preferable to pooled OLS by checking for firm-specific effects. The Hausman test is then applied to decide between fixed effects and random effects; a significant test statistic points toward fixed effects, while a non-significant result supports the use of random effects. This type of procedure is also followed in Algerian panel studies on capital structure for SMEs and listed firms. Finally, multicollinearity is examined using the Variance Inflation Factor (VIF), and VIF values below 10 are taken as evidence that collinearity among regressors is not severe.

4.7 Expected Sign of Variables

Drawing on the theoretical framework and prior empirical findings for emerging markets, a negative association is expected between capital structure and financial performance. When debt is costly and financial distress risk is high, higher debt ratios and leverage are likely to reduce both ROA and ROE rather than improve them.

Table 4. *Expected signs*

Variable	Expected sign	Reason
Debt Ratio	Negative	Higher debt increases financial pressure
Leverage	Negative	Excess leverage may reduce profitability
Firm Size	Positive	Scale and financing advantages
Growth	Positive	Better expansion opportunities

Source: Created by the author

Firm size is expected to have a positive effect on performance because larger firms usually enjoy economies of scale and better access to external finance. Growth, measured by the sales growth rate, may also support profitability when expansion is managed efficiently and additional revenue exceeds the extra costs of scaling up. These expected signs are summarized as presented in Table 4.

4.8 Methodological Rationale

The methodological setup follows current practice in panel data research in corporate finance and mirrors approaches used in recent Algerian applications. Studies that compare pooled OLS, fixed-effects, and random-effects models typically rely on formal specification tests such as Breusch–Pagan LM and Hausman to justify the final choice of estimator, rather than selecting models on judgment alone. This is particularly relevant when firm-specific characteristics are likely to be correlated with leverage and performance.

Working with a balanced panel, covering 2020–2024, makes it possible to analyze the recent behavior of major Algerian firms under a consistent data structure. The same firms are observed in each year, which improves comparability and reduces distortions from missing values. In a small market where the number of large firms is limited, and their financial profiles can change markedly from one period to another, using panel data is therefore not only technically sound but also a practical requirement for obtaining reliable evidence on the capital structure–performance relationship. Although the balanced panel contains 30 firm-year observations (2020–2024), the regression estimations are based on 24 effective observations because the growth variable requires lagged values and can only be computed for the period 2021–2024 (4 years × 6 firms = 24 observations).

5 EMPIRICAL RESULTS AND DISCUSSION

5.1 Descriptive Statistics

Table 5 summarizes the main features of the panel for the six major Algerian firms (Sonatrach, Biopharm, Saidal, El Aurassi, Alliance Assurances, and Sonelgaz) over 2020–2024, giving 30 firm-year observations. All values are computed from audited consolidated and standalone financial statements and official corporate disclosures, including Sonelgaz's 2020–2021 data drawn from the group's published reports.

Table 5. *Descriptive Statistics (N = 30 firm-year observations)*

Variable	Mean	Median	Std. Dev.	Min	Max
ROA	0.0313	—	0.0516	−0.0666	0.1363
ROE	0.0541	0.0834	0.1024	−0.1620	0.3526
Debt Ratio (DR)	0.5425	0.5686	0.1259	0.3306	0.7598
Leverage (LEV)	1.3764	1.3183	0.7510	0.4939	3.1633
Size (ln TA)	12.115	11.052	2.882	9.158	16.636
Growth	0.1668	0.0668	0.2612	−0.0981	0.9010

Source: Author's calculations based on firms' annual financial statements (2020–2024)

The mean ROA of 0.0313 (3.13%) and ROE of 0.0541 (5.41%) point to moderate average profitability with wide differences across firms. Dispersion in ROA (standard deviation 0.052) reflects, for example, Biopharm's strong performance (ROA reaching about 10.2% in 2022) and in contrast with Sonelgaz's persistently negative ROA (averaging −1.2% over 2020–2024) and El Aurassi's negative results in 2020–2021 (around −6.3% and −5.3%), which coincided with severe COVID-19 shocks in the hospitality sector. The average debt ratio of 0.503 indicates that roughly half of total assets are financed by debt, in line with Algeria's bank-dominated system, where credit represents the main external funding source for firms.

Mean leverage of 1.376 indicates that total debt exceeds equity by nearly 38% on average across the panel. Biopharm maintains the most conservative structure (DR = 0.421, LEV = 0.730), consistent with strong internal cash generation. At the other extreme, Sonelgaz records an average debt ratio of 0.735 and leverage of 2.789, driven by sustained net losses and heavy infrastructure borrowing, while El Aurassi's leverage peaked at 1.73 in 2022 before declining with hospitality recovery. The size variable (log of total assets) shows high variance (standard deviation 2.882), capturing the gap between Sonatrach—whose assets reached about 16,741 billion DZD in 2024—and smaller entities like El Aurassi. Average sales growth of 16.7% is driven mainly by Sonatrach's hydrocarbon revenue surge in 2022 and Saidal's expansion over 2020–2024.

Table 6. *Key Financial Ratios by Firm (2020–2024 Averages)*

Firm	ROA (avg)	ROE (avg)	Debt Ratio (avg)	Leverage (avg)	Growth (avg)
Sonatrach	0.0546	0.0863	0.3740	0.6024	0.2673
Biopharm	0.0928	0.1599	0.4210	0.7301	0.0474
Saidal	0.0079	0.0181	0.5300	1.1507	0.2586
El Aurassi	0.0150	0.0263	0.6143	1.5968	0.4738
Alliance	0.0383	0.0889	0.5860	1.3882	0.0596
Sonelgaz	-0.0120	-0.0467	0.7345	2.7885	-0.0306

Source: Author's calculations based on firms' annual financial statements (2020–2024)

Table 6 reports firm-level averages for the key ratios. Firms with lower debt exposure, such as Biopharm (DR ≈ 0.421) and Sonatrach (DR ≈ 0.374), record the highest ROA and ROE, whereas more heavily leveraged firms, including El Aurassi (DR ≈ 0.614) and Saidal (DR ≈ 0.530), show much weaker returns. This cross-sectional pattern already suggests a negative link between leverage and profitability in the sample, which will later be tested formally in the panel regressions.

5.2 Specification Tests

Three diagnostic checks are carried out before choosing the final panel estimator, following standard practice in applied panel econometrics.

5.2.1 Multicollinearity Diagnostic (VIF)

Table 7 reports the Variance Inflation Factor values for all regressors. All VIFs are well below the usual threshold of 10, which indicates that multicollinearity is not a serious concern. VIF values for Debt Ratio (1.35) and Leverage (reported only in single-variable specifications M1–M4 to avoid multicollinearity) confirm that the separate model specifications are free from severe collinearity.

Table 7. Variance Inflation Factor (VIF) Results

Variable	VIF	Tolerance (1/VIF)
Debt Ratio (DR)	1.35	0.743
Leverage (LEV)	—	—
Size (SIZE)	5.35	0.187
Growth (GROWTH)	1.34	0.746

Note: VIF < 10 indicates no harmful multicollinearity (Gujarati & Porter, 2009)

Source: Author's calculations based on firms' annual financial statements (2020–2024)

The VIF for Size (5.35) is moderate but well below the threshold of 10, reflecting its correlation with firm scale variables; Growth records a VIF of 1.34, indicating no collinearity concern. It is therefore reasonable to estimate four separate specifications rather than include both capital structure proxies simultaneously.

5.2.2 Breusch-Pagan Lagrange Multiplier Test

The Breusch–Pagan LM test is used to check whether firm-specific effects are present and whether a panel specification is preferable to pooled OLS. The test statistics of LM = 91.96 (ROA equation) and LM = 4,405.75 (ROE equation), both with p = 0.000, clearly reject the null hypothesis of no individual effects. These values are substantially larger than those initially reported, reflecting the addition of Sonelgaz, whose structurally distinct financing profile amplifies between-firm heterogeneity. Panel estimation is therefore strongly required in this context. All panel models follow standard econometric procedures for short balanced panels (Wooldridge, 2010).

5.2.3 Hausman Specification Test

The Hausman test determines whether Fixed Effects (FE) or Random Effects (RE) is the consistent estimator by testing whether firm-specific effects are correlated with the regressors. Results are reported in Table 8.

Table 8. *Hausman Test Results*

Model	Chi-square Statistic	Degrees of Freedom	p-value	Decision
ROA equation	2.32	4	0.5084	Accept RE → Random Effects
ROE equation	1.80	4	0.6144	Accept RE → Random Effects

Source: Author's calculations based on firms' annual financial statements (2020–2024)

H_0: Individual effects are uncorrelated with the regressors (Random Effects consistent).

The Hausman statistics for both ROA and ROE equations are non-significant ($\chi^2 = 2.32$, $p = 0.508$ for ROA; $\chi^2 = 1.80$, $p = 0.614$ for ROE), which supports the Random Effects specification. This outcome indicates that firm-specific effects are not systematically correlated with the regressors in the corrected full sample of six firms. The inclusion of Sonelgaz, a state-owned utility with structurally different financing characteristics, adds cross-sectional heterogeneity that reduces the within-firm correlation required for fixed effects to dominate. The Random Effects estimator is therefore retained. This outcome is consistent with Hypothesis H3: the Breusch–Pagan LM test confirms that panel estimation is preferable to pooled OLS (H3), while the Hausman test separately determines the choice between Fixed Effects and Random Effects in favour of the latter. These are two distinct methodological decisions that should not be conflated.

5.3 Panel Regression Results

5.3.1 Random Effects Estimates: ROA Model

Table 9 reports the random effects estimates for ROA as the dependent variable. The model explains about 41.3% of the variation in ROA. The random effects estimator accounts for unobserved firm-level heterogeneity while retaining cross-sectional variation.

Table 9. *Random Effects Regression Results – Dependent Variable: ROA*

Variable	Coefficient	Std. Error	t-statistic	p-value	95% CI
Debt Ratio (DR)	**−0.2512**	0.0690	−3.640	0.0016	[−0.3864, −0.1160]
Leverage (LEV)	**—**	—	—	—	—
Size (SIZE)	−0.0022	0.0032	−0.685	0.5012	[−0.0085, 0.0041]
Growth (GROWTH)	−0.0127	0.0346	−0.368	0.7168	[−0.0805, 0.0551]
Within R^2	**0.4131**	—	—	—	—
F-statistic	RE	—	—	p = 0.000	—
Observations	24	—	—	—	—

Note: Random effects GLS. Standard errors robust to heteroskedasticity. Model M1: ROA ~ DR + SIZE + GROWTH.

Source: Author's calculations based on firms' annual financial statements (2020–2024)

Debt Ratio enters the equation with a negative and statistically significant coefficient (−0.2512, p = 0.002). In practical terms, a one-percentage-point increase in the debt-to-asset ratio is associated with roughly a 0.251 percentage-point decline in ROA, holding other variables constant. Leverage is also negative and significant (−0.0411, p = 0.002) in Model M2. For major Algerian firms operating in a bank-dominated financial system characterized by relatively high lending rates (Bank of Algeria, 2023), this pattern is consistent with the idea that the cost of debt and distress risk dominate any tax advantage of additional borrowing. Together, M1 and M2 confirm Hypothesis H1 that capital structure negatively affects financial performance.

The coefficient on firm size is positive (0.0183) and close to significance at the 10% level (p = 0.066), suggesting that larger firms may enjoy modest profitability gains through economies of scale and easier access to funding. Growth shows a positive and significant association with ROA (0.0574, p = 0.017): firms that expand sales more rapidly tend to use their asset base more efficiently, a pattern that matches Sonatrach's strong hydrocarbon revenues in 2022 and Saidal's rising pharmaceutical sales over 2020–2024.

5.3.2 Random Effects Estimates: ROE Model

Table 10 presents the random effects estimates when ROE is used as the dependent variable. The within-R^2 of 0.3254 indicates that the model explains about 33% of the variation in ROE. The explanatory power is lower than in the ROA specification.

Debt Ratio remains negative and statistically significant, with a coefficient of −0.4794 (p = 0.008). In absolute terms, this effect is more than twice as large as in the ROA model (−0.2512 in M1), which means that increases in debt have a stronger impact on shareholders' returns than on asset-based profitability. Leverage is also negative and significant (−0.0802, p = 0.008) in Model M4, approximately twice the M2 ROA coefficient (−0.0411), providing suggestive evidence in support of Hypothesis H2.

Table 10. *Random Effects Regression Results – Dependent Variable: ROE*

Variable	Coefficient	Std. Error	t-statistic	p-value	95% CI
Debt Ratio (DR)	**−0.4794**	0.1620	−2.959	0.0078	[−0.7969, −0.1619]
Leverage (LEV)	**—**	0.0382	—	—	—
Size (SIZE)	−0.0102	0.0074	−1.375	0.1845	[−0.0248, 0.0044]
Growth (GROWTH)	−0.0395	0.0812	−0.486	0.6322	[−0.2007, 0.1217]
Within R^2	**0.3254**	—	—	—	—
F-statistic	RE	—	—	p = 0.000	—
Observations	24	—	—	—	—

Note: Random effects GLS. Standard errors robust to heteroskedasticity. Model M3: ROE ~ DR + SIZE + GROWTH.

Source: Author's calculations based on firms' annual financial statements (2020–2024)

The coefficients on SIZE (0.0347, p ≈ 0.097) and GROWTH (0.1063, p = 0.030) are positive, with growth showing a clear and significant association with higher ROE. Larger firms and those with

faster sales expansion tend to generate higher returns on equity, which fits the idea that scale and successful growth strategies can partly offset the pressure created by debt in major Algerian firms.

Table 11. *Comparative Summary of Panel Estimators (Pooled OLS vs. Random Effects)*

Model	Estimator	Dep. Variable	DR (β)	LEV (β)	SIZE (β)	GROWTH (β)	R^2
M1	Pooled OLS	ROA	−0.1632*	−0.0281	0.0091	0.0489**	0.4217
M2	Random Effects	ROA	−0.2512***	—	−0.0022	−0.0127	0.4131
M3	Pooled OLS	ROE	−0.3518**	−0.0547*	0.0162	0.0881**	0.4783
M4	Random Effects	ROE	−0.4794***	—	−0.0102	−0.0395	0.3254

Significance levels: *** p<0.01, ** p<0.05, * p<0.10

Source: Author's calculations based on firms' annual financial statements (2020–2024)

† The coefficient on SIZE does not meet conventional significance thresholds (p<0.10) in the random effects specifications (M2 and M4); however, its positive sign is consistent with the theoretical expectation that larger firms benefit from scale economies and easier access to external financing. This result should therefore be interpreted with caution and regarded as suggestive rather than conclusive evidence of a size effect within the present sample.

Table 11 compares pooled OLS and random effects (preferred) estimates for both ROA and ROE. In all cases, the random effects models produce more negative coefficients for Debt Ratio and Leverage and higher R^2 values than the corresponding pooled OLS specifications.

This pattern suggests that ignoring firm-specific heterogeneity attenuates the estimated impact of debt on performance. In a sample where some firms combine persistently high profitability with low leverage (such as Biopharm), and others show the opposite profile, pooled OLS mixes these differences into the error term and partially masks the true negative relationship between leverage and profitability. The panel estimator focuses instead on both within-firm and between-firm variation on changes over time within each firm, which brings out a stronger adverse effect of higher debt on both ROA and ROE.

Taken together with the Hausman test results, the comparison between pooled OLS and random effects models in Table 11 reinforces Hypothesis H3: the Breusch–Pagan LM test demonstrates that firm-specific unobserved effects are present and that panel estimation is preferable to pooled OLS, while the Hausman test separately supports Random Effects over Fixed Effects for major Algerian firms.

5.4 Discussion of Results

5.4.1 Debt Ratio and Financial Performance

The Random Effects estimates for ROA and ROE show a clear negative and statistically significant association between the debt ratio and profitability over 2020–2024 for major Algerian firms. Firms that rely more heavily on debt tend to generate lower returns on assets and equity. This pattern supports the pecking-order view that, in an environment marked by information asymmetry and high borrowing costs, internal funds are preferred, and additional debt quickly becomes more costly than its tax advantages would justify (Myers & Majluf, 1984). It is also consistent with Algerian studies such as Boussiki (2023) and Bousbaa (2021), which report a negative relationship between debt and performance.

The estimated coefficients are relatively large in absolute terms, suggesting that leverage penalties are particularly strong in Algeria. High domestic interest rates, exchange-rate pressures, and oil-price volatility increase the burden of debt servicing and make firms more vulnerable when revenues weaken (IMF, 2024; World Bank, 2020). This is visible in the sample, where Biopharm combines low debt with the highest average profitability, while El Aurassi and Saidal experience weaker performance when leverage becomes more aggressive.

5.4.2 Leverage and Shareholder Returns

The Leverage model coefficients confirm that equity returns are more sensitive to debt than

asset-based returns. In the Random Effects model, the negative ROE coefficient is larger in absolute value than the ROA coefficient, providing suggestive evidence in support of Hypothesis H2. The corresponding Leverage specifications (M2 for ROA and M4 for ROE) yield consistent results: LEV carries a coefficient of −0.0411 (p = 0.002) in M2 and −0.0802 (p = 0.008) in M4, both estimated under Random Effects GLS. Full coefficient details for M2 and M4 are available from the authors upon request. No formal Wald or coefficient-comparison test was conducted to confirm this difference statistically. As leverage rises, interest expenses reduce net income while equity becomes thinner, so ROE is affected more strongly from the shareholder's perspective. In a shallow capital market, weaker equity returns may also discourage investors and slow capital market development.

Agency theory helps explain this result. High leverage increases conflicts between debtholders and shareholders and can constrain investment choices. The case of Sonatrach shows that this effect is not uniform, since its moderate debt ratio and stable hydrocarbon revenues support stronger profitability. This suggests that moderate leverage may still be value-enhancing for firms with stable cash flows, while other firms face sharper declines in ROE when leverage increases.

5.4.3 Control Variables

Firm size has a positive coefficient in both Random Effects specifications, suggesting that larger Algerian firms tend to earn slightly higher returns. This is consistent with economies of scale and better access to external finance for large entities (Khouri, 2022). Sales growth is positively and significantly associated with both ROA and ROE, indicating that revenue expansion translates into stronger profitability once fixed costs are covered. This effect is especially visible in firms that recorded strong post-pandemic rebounds.

Table 12. *Hypothesis Testing Summary*

Hypotheses	Statement	RE Result	Decision
H1	Debt Ratio negatively impacts ROA/ROE (p<0.05)	DR: β=−0.251*** (ROA, M1); β=−0.479*** (ROE, M3)	Suggestive evidence
H2	Leverage has stronger negative ROE than ROA effects	|β(LEV, ROE)| = 0.0893 > |β(LEV, ROA)| = 0.0411 (ratio ≈ 1.95, M2 vs M4)	Suggestive Evidence
H3	Random Effects preferred over Fixed Effects (Hausman p>0.05); panel estimation preferred over Pooled OLS (BP-LM p<0.001)	BP-LM χ^2=91.96 (ROA), p=0.000	Supported

Source: Author's calculations based on firms' annual financial statements (2020–2024)

5.4.4 Hypotheses Assessment

All three research hypotheses are supported by empirical results. The negative and significant coefficients of the debt ratio in both ROA and ROE equations confirm H1, indicating that higher indebtedness systematically reduces profitability for major Algerian firms. The fact that leverage has a larger adverse coefficient in the ROE model than in the ROA model provides suggestive evidence in support of H2 and indicates that shareholders' returns are more exposed to changes in debt than asset-based performance. H3 is validated through two distinct tests. The Breusch–Pagan LM statistics demonstrate that panel estimation is preferable to pooled OLS; the non-significant Hausman results (p = 0.508 for ROA; p = 0.614 for ROE) then separately support Random Effects over Fixed Effects. These two methodological decisions should not be conflated. Firm-specific unobserved characteristics matter for ROA and ROE and that panel estimators are preferable to pooled OLS in this setting.

Taken together, these findings show that the core mechanisms highlighted by trade-off, pecking-order, and agency theories—tax benefits of debt, information asymmetry, and agency conflicts—operate in a context where high borrowing costs and institutional constraints

amplify the negative side of leverage. The study therefore adds recent and methodologically consistent evidence to the Algerian capital structure literature and underlines the importance of accounting for firm heterogeneity when analysing the debt–performance relationship in major Algerian firms.

5.5 Implications and Recommendations

5.5.1 Corporate Finance Implications

The results suggest that many major Algerian firms face a clear penalty from high leverage. The negative coefficients on Debt Ratio and Leverage indicate that additional bank borrowing, at current levels, tends to reduce both ROA and ROE rather than improve them. In practical terms, the evidence points to debt ratios that are often higher than what would be consistent with value-maximizing behavior in the Algerian environment of expensive bank credit and volatile macroeconomic conditions.

Firms with relatively high debt ratios appear more exposed to interest burdens and financial distress, while firms with lower leverage may retain some room to use debt selectively if cash flows are stable. This suggests that a more moderate financing structure would better support performance in most cases.

5.5.2 Regulatory Recommendations

For regulators, the results highlight the limits of a corporate sector that relies heavily on bank credit. When borrowing costs are high and alternative financing channels are shallow, leverage has little room to act as a positive driver of performance. A priority for COSOB and monetary authorities is therefore to broaden the range of financing instruments available to large firms.

Measures that could help include developing the corporate bond market, encouraging sukuk issuance, improving equity market liquidity, strengthening disclosure, and protecting investors more effectively. Tax rules could also be designed to discourage excessive borrowing by limiting the deductibility of interest beyond reasonable leverage levels. These steps would support a more balanced capital structure across major Algerian enterprises.

5.5.3 Contributions to Literature

The study adds recent evidence on the link between capital structure and performance for major Algerian firms by covering 2020–2024, a period marked by COVID-19, hydrocarbon price volatility, and currency pressures. Methodologically, it uses panel estimation with specification tests and examines both ROA and ROE alongside Debt Ratio and Leverage, which helps show that debt affects assets and shareholders differently. This distinction is useful for both managers and investors.

5.6 Limitations

The analysis is constrained by the small panel of six large firms over five years, which limits statistical power and reduces the ability to separate sector effects from firm-specific behavior. It also relies only on accounting-based performance measures since market-based indicators are difficult to use reliably in the Algerian context. Future research could extend the period, including more firms, and distinguish more clearly between state-owned and privately owned companies.

6 CONCLUSIONS

This research examined how capital structure relates to the performance of six major Algerian firms over 2020–2024, a period marked by COVID-19 disruptions, energy price swings, and currency depreciation. The Random Effects panel estimates confirm that higher debt ratios are significantly associated with lower ROA and ROE across all four model specifications (M1–M4), and that equity returns are, approximately, twice as sensitive to leverage as asset-based returns. These patterns suggest that, under current Algerian financing conditions, many large firms bear debt levels at which the cost of servicing bank credit and the risk of distress outweigh the benefits of the tax shield.

Beyond the headline debt–performance link, the analysis highlights the role of firm size and sales growth. Larger entities such as Sonatrach and Sonelgaz benefit from scale and somewhat better access to credit, while revenue growth improves profitability once fixed costs are covered.

Cross-firm comparisons indicate that companies with conservative capital structures, such as Biopharm, perform more robustly than more highly leveraged peers like Saidal and El Aurassi during periods of macroeconomic stress, which points to the importance of prudent leverage policies in volatile environments.

Methodologically, the study departs from much of the existing Algerian work by using a balanced panel with random effects estimation supported by Breusch–Pagan LM and Hausman specification tests, rather than relying solely on pooled OLS or cross-sectional regressions. Modelling two capital structure indicators (Debt Ratio and Leverage) against both ROA and ROE make it possible to distinguish the effect of debt on operating efficiency from its impact on shareholder returns, an asymmetry that earlier local studies have not fully explored. In this way, the evidence contributes to the broader emerging-market literature that analyses capital structure under conditions of limited market depth and high borrowing costs.

The results carry direct implications for practice. For firms with high debt ratios, especially in sectors exposed to demand volatility and exchange-rate risk, a gradual move toward more moderate leverage appears advisable to reduce interest burdens and strengthen resilience. For financially solid firms with very low leverage, carefully calibrated long-term borrowing can support value-creating investment without undermining stability, if cash flows and governance remain strong. At the system level, the persistent negative association between leverage and profitability reinforces the case for developing alternative funding channels, such as a corporate bond and sukuk market and more liquid equity trading, so that Algerian corporates are not forced to rely almost exclusively on costly bank credit.

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APPENDIX. Raw Panel Dataset (SIX FIRMS, 2020–2024)

This appendix presents the raw panel dataset used in the empirical analysis. All financial figures are reported in milliards of Algerian dinars (DZD), except for Sonatrach, whose figures are expressed in billions of DZD (milliards), consistent with the scale used in the firm's published consolidated financial statements. Ratios (ROA, ROE, Debt Ratio, Leverage) are dimensionless. All data are drawn from audited consolidated annual financial statements published by each firm. The dataset covers five of the six firms in the sample; Sonelgaz data are integrated upon availability of the 2024 audited report.

Table A1. Panel Dataset — Financial Ratios and Key Figures by Firm-Year (2020–2024)

Firm	Year	Total Assets	Total Equity	Net Income	Sales	Interest Expense	ROA	ROE	Debt Ratio	Leverage
Sonatrach	2020	13,663.3	7,888.8	−5.083	3,980.4	291.84	−0.0004	−0.0006	0.4226	0.7320
	2021	14,281.3	8,653.2	801.915	6,494.4	556.59	0.0562	0.0927	0.3941	0.6504
	2022	16,782.2	10,345.4	1,787.532	10,592.4	875.94	0.1065	0.1728	0.3836	0.6227
	2023	15,446.0	10,205.7	823.519	9,581.7	575.38	0.0533	0.0807	0.3393	0.5135
	2024	16,740.5	11,205.7	964.720	8,641.7	47.94	0.0576	0.0861	0.3306	0.4939
Biopharm	2020	74.336	40.416	5.570	71.475	0.921	0.0749	0.1377	0.4565	0.8393
	2021	79.559	45.293	7.814	82.139	0.343	0.0982	0.1725	0.4309	0.7567
	2022	82.694	49.258	8.431	83.818	0.499	0.1019	0.1711	0.4044	0.6789
	2023	94.914	54.367	8.505	82.917	0.453	0.0896	0.1564	0.4275	0.7460
	2024	96.852	59.413	9.599	85.457	0.376	0.0991	0.1616	0.3866	0.6301
Saidal	2020	40.688	22.235	0.190	9.810	0.155	0.0047	0.0085	0.4537	0.8292
	2021	44.812	22.913	0.049	10.211	0.106	0.0011	0.0021	0.4889	0.9557
	2022	44.881	18.965	−2.987	15.518	0.352	−0.0665	−0.1575	0.5770	1.3668
	2023	49.318	21.925	1.991	19.410	0.521	0.0404	0.0908	0.5555	1.2499
	2024	53.522	22.758	1.057	23.734	0.455	0.0197	0.0465	0.5748	1.3520
El Aurassi	2020	10.425	4.081	−0.661	0.808	0.065	−0.0633	−0.1619	0.6083	1.5548
	2021	9.490	3.565	−0.507	1.040	0.009	−0.0534	−0.1422	0.6238	1.6619
	2022	9.596	3.509	0.038	1.977	0.030	0.0039	0.0108	0.6342	1.7350
	2023	9.706	3.967	0.475	2.275	0.008	0.0489	0.1196	0.5910	1.4468
	2024	10.269	3.971	1.400	2.858	0.234	0.1364	0.3528	0.6135	1.5858
Alliance Assurances	2020	11.614	5.096	0.481	3.736	0.011	0.0414	0.0944	0.5610	1.2798
	2021	12.126	5.307	0.503	3.686	0.020	0.0414	0.0947	0.5630	1.2841
	2022	13.380	5.510	0.543	4.011	0.034	0.0406	0.0986	0.5879	1.4270
	2023	13.844	5.609	0.440	4.485	0.037	0.0318	0.0784	0.5948	1.4685
	2024	14.543	5.839	0.523	4.689	0.027	0.0359	0.0896	0.5983	1.4902
Sonelgaz	2020	4,443.6	1,308.8	-37.880	526.46	N/A	-0.0085	-0.0289	0.7055	2.3953
	2021	4,584.9	1,283.7	-36.705	510.34	N/A	-0.0080	-0.0286	0.7200	2.5715
	2022	4,732.2	1,259.4	-35.581	494.67	9.450	-0.0075	-0.0283	0.7339	2.7575
	2023	4,851.7	1,196.5	-86.073	499.03	10.237	-0.0177	-0.0719	0.7534	3.0549
	2024	5,038.6	1,210.2	-91.801	464.12	9.263	-0.0182	-0.0759	0.7598	3.1633

Notes: ROA = Net Income / Total Assets; ROE = Net Income / Total Equity; Debt Ratio = (Total Assets − Total Equity) / Total Assets; Leverage = (Total Assets − Total Equity) / Total Equity. All ratios computed from audited consolidated financial statements. Sonatrach figures are in milliards DZD (billions); all other firms' figures are in milliards DZD.

Source: Compiled by the author from the audited annual reports of Sonatrach, Biopharm, Saidal, El Aurassi, Alliance Assurances and Sonelgaz (2020–2024).

Data Collection Procedure: Financial data were collected manually from the official annual reports and audited consolidated financial statements of all six firms for each of the five fiscal years 2020–2024, yielding a complete balanced panel of 30 firm-year observations with no missing values. For each observation, the following items were extracted directly from the published balance sheet and income statement: total assets, shareholders' equity, net income for the year, revenues, and financial charges. The four ratios were then computed as defined in the notes above. No interpolation, estimation, or imputation was applied at any stage.

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ASSOCIATION BETWEEN EDUCATIONAL AND NON-EDUCATIONAL SMARTPHONE APP USE, TIME MANAGEMENT SKILLS, AND GPA IN UNIVERSITY STUDENTS

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ABSTRACT

This research paper investigates the impact of smartphone use on time management and academic performance among students in higher education institutions. With smartphones becoming an integral part of everyday life, their potential to enhance or diminish academic performance is becoming increasingly important. The study surveyed undergraduate students (N = 170) and collected data on their smartphone usage patterns, time management skills, and academic performance (GPA). In addition to survey responses, smartphone usage tracking applications were used to obtain more objective measures of time spent on educational and non-educational applications. The findings indicate a markedly negative relationship between non-educational app use (e.g., social media, entertainment) and academic performance, suggesting that the time spent on these apps is associated with lower GPA scores. On the other hand, time management skills were observed to have a positive impact on academic performance, mitigating the negative influence of smartphone distractions. Although the educational use of apps showed a weak positive correlation with GPA, this correlation was not significant. The study discusses the role of time management in mitigating digital distractions and suggests that strengthening students' time management skills may help improve academic outcomes by enabling more effective and purposeful smartphone use.

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1 INTRODUCTION

Smartphones are part of everyday life, and university students are the group that uses them the most (Hossain & Ahmed, 2016). These gadgets are not only devices for communication and entertainment; they are also used as platforms for education (Sofi-Karim et al., 2023). Nevertheless, the effects of smartphone use on students' academic achievement and time management are a controversial issue (Troll et al., 2021). Although smartphones can be used in the learning process through educational applications, overuse of social media or entertainment applications can lead to time displacement, which can negatively affect students' academic results (Anshari et al., 2017). In this research, the author intends to examine the dual role of smartphones in students' academic lives and investigate how their use affects time management and academic outcomes (Liu et al., 2022).

With the growing popularity of courses, extra-curricular activities, and personal lives among the students managing time has become the key to academic success (Premnath et al., 2024). Given their widespread access, smartphones can either enhance or undermine this ability, depending on how students use them (Hidayat-Ur-Rehman, 2024). Educational software such as e-readers, academic planners, and other productivity applications can help students keep track of their studies (Ahlroos & Hahto, 2012). Non-educational apps, such as social media and gaming applications, can, on the other hand, be a distractor, prompting people to procrastinate and spend their time inefficiently (Moe, 2024). The growing use of smartphones in the academic and personal spheres underscores the need for new research on the impact of these devices on students' academic performance (Kates et al., 2018).

Recent meta-analyses have highlighted the detrimental effects of smartphone use on academic performance, particularly through distractions such as social media and entertainment apps (e.g., Kates et al., 2018; Sunday et al., 2021). Longitudinal studies have shown that the impact of smartphone use on academic outcomes is influenced by both usage patterns and individual factors, such as time management skills and study habits (Hattie et al., 2023). However, most of these studies have focused on short-term, cross-sectional data or single-app use, with limited insights into the broader implications of smartphone usage across different app categories (e.g., educational vs. non-educational). Therefore, further empirical research is needed to better understand how different types of smartphone applications interact with students' time management behaviors and academic outcomes.

The study will examine the multifaceted association among smartphone use, time management, and academic achievement among higher education students. Evaluating the time spent on different applications and correlating it with self-reported grades, this paper will contribute to the discussion of the effect that smartphones have on students' ability to handle their academic duties in the most efficient way (Sapci et al., 2021). The results will be used to identify methods students can use to maximize their smartphone use to achieve better grades without hindrance or distraction.

1.1. Objectives

The main objective of this study is to examine how different patterns of smartphone use relate to university students' academic performance and time management skills.

- To examine the relationship between the time spent on educational and non-educational apps on a smartphone and the academic results of students.
- To examine the role of time management skills in mediating the relationship between smartphone usage and students' academic performance.

1.2. Research Questions

In designing this study, we were guided by the following research questions:

RQ$_1$. How does the amount of time spent on educational versus non-educational smartphone apps correlate with students' academic performance (GPA)?

RQ$_2$. What role do time management skills play in mediating the relationship between smartphone usage and academic performance?

2 METHODOLOGY

This study employs a cross-sectional quantitative research design to examine the relationship between smartphone usage, time management skills, and academic performance among university students, as commonly applied in similar studies (Arumugam et al., 2020; Fryer et al., 2018).

2.1. Research design

The research design used in the study is a cross-sectional survey, which is best suited to capturing a snapshot of students' smartphone use, time management habits, and academic performance at a given moment (Connelly, 2016). The benefit of the design is that it enables the efficient exploration of the relationship between variables without the need to track them over a long period. The cross-sectional research design is well-suited to examining the current state of smartphone use and its relationship to students' academic performance. The approach will allow the researcher to measure smartphone use, analyze time management behavior, and correlate these behaviors with academic performance within a single study. Additionally, the design permits comparisons between learners using educational applications as their major and those using entertainment-centered applications, providing information as to the impact of the various types of smartphone applications on academic success.

2.2. Participant selection

The target participants in this study will be undergraduate students studying in a large university, and the sample will be heterogeneous in terms of academic disciplines (e.g., STEM, humanities, social sciences) and year levels (freshman to senior). This heterogeneity is necessary to understand how smartphone use patterns may differ across the spheres of study and academic experience levels. Stratified random sampling will also be used to ensure that the sample includes students from diverse departments and thus covers the student population. Through stratified sampling, we will obtain a sample that is more representative of the student body as a whole, thereby enhancing the external validity of the results. A total of 250 undergraduate students were invited to participate in the study. Of these, 220 students completed the online survey, and 180 participated in the smartphone-tracking phase. The final analytic sample included 170 students who provided complete data for both the survey and smartphone tracking. This sample size was deemed adequate for the statistical analyses conducted in this study.

The survey response rate was 88% (220 out of 250 students). Participants were eligible if they were full-time undergraduate students at Southwest University, China. Exclusion criteria included students under 18 years of age, enrolled in part-time programs, or who had previously participated in a similar study within the last 6 months. The final sample was stratified by academic discipline and year of study. The demographic breakdown is as follows: 40% of participants were from STEM disciplines, 35% from humanities, and 25% from social sciences. In terms of year of study, 20% were freshmen, 25% were sophomores, 30% were juniors, and 25% were seniors.

Although a formal statistical power analysis was not conducted, the final sample size of 170 participants is generally considered adequate for regression-based analyses with several predictors. Previous methodological guidelines suggest that samples exceeding 150 observations are typically sufficient for detecting medium-sized effects in multiple regression models (Zimmer, 2023).

Table 1. Participant Selection

Step	Number (n)
Initial recruitment	250
Survey Completion	220
Smartphone tracking consent	200
Data used for analysis	170
Exclusions	30

2.3 Data Collection Methods

Two main data collection tools will be used: surveys and smartphone usage tracking.

Instrument Survey: An online survey will be used to collect self-report data from participants. The survey will cover smartphone use, time management, and academic performance. In

particular, the questions will ask participants to discuss their daily smartphone behaviors, including the time they spend on educational and non-educational applications. The students' time management skills will also be evaluated through the survey, including how frequently they set goals, use planners, or schedule study sessions. Academic performance will be evaluated using self-reported GPA or recent exam grades. Time management behavior will be assessed using Likert-scale items, and questions regarding smartphone usage will determine how much time a person spends on various applications each day.

To classify apps as educational or non-educational, a two-step process was employed. Initially, the researcher Sohiab Ullah reviewed the most frequently used apps reported by survey participants. Apps were classified into two categories based on their primary function: Educational apps included tools designed for academic purposes, such as e-learning platforms, academic planners, and research tools (e.g., BiliBili, XueXiQiangGuo, Zhihu). Non-educational apps encompass apps primarily used for social media, entertainment, or general communication (e.g., WeChat, Douyin, QQ).

To ensure reliability, a second rater, Marwa Zaib, independently classified the apps for a subset of participants. The interrater reliability was calculated using Cohen's kappa ($\kappa = 0.85$), indicating strong agreement between raters.

Time management skills were assessed using a self-report questionnaire adapted from the Time Management Behavior Scale (TMB) by Britton & Tesser (1991). The scale comprises 10 items that assess various aspects of time management, including goal setting, planning, prioritizing tasks, and using a study schedule. Example items include: "I regularly set specific goals for my academic work." "I make detailed plans for studying before an exam."

Responses were measured on a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The internal consistency of the scale was assessed using Cronbach's alpha, which yielded $\alpha = 0.87$, indicating good reliability in measuring time management skills among participants.

Academic performance was measured using self-reported GPA. Participants were asked to indicate their cumulative GPA on a 4.0 scale, based on their most recent academic records. While self-reported GPA is commonly used in educational research, we acknowledge that there may be some reporting bias. Verification of self-reported GPA against official university records was not feasible due to data privacy restrictions in China. Therefore, the potential limitations of self-reported GPA, such as social desirability bias or inaccurate recall, should be considered when interpreting the results. Future studies may seek to verify GPA through institutional records or use more objective performance metrics, such as course grades.

Smartphone Usage Tracking Participants were asked to install a smartphone usage-tracking application (RescueTime or ScreenTime) for a period of one week in addition to completing the survey. A seven-day tracking period was used to capture both weekday and weekend smartphone usage patterns while minimizing participant burden. These applications will be able to gather objective information about the screen time of the participants (i.e., the time spent on educational apps (e.g., e-learning platforms, productivity tools) and non-educational apps (e.g., social media, entertainment). This method will provide more precise, real-time information on students' smartphone use and reduce potential bias in self-reported data.

2.4 Variables

This paper will examine several important variables related to smartphone use, time management, and academic achievement.

Independent Variable: Smartphone usage patterns will be the major independent variable. This will be quantified in terms of the time that students are on educational and non-educational applications. The distinction between these two app categories is critical to understanding the effects of smartphone apps on academic achievement.

Dependent Variables: Academic performance (GPA) was treated as the primary dependent variable, while time management skills were examined as a mediating variable in the relationship between smartphone usage and

academic performance. Academic performance will be measured using self-reported GPA or exam scores. Self-reports of using time management tools, goal-setting behavior, and study habits will be used to measure time management skills. Control Variables: A number of control variables will be incorporated to account for potential confounding variables. These will include demographic factors (e.g., age, gender, year of study), study habits (e.g., time spent studying), and access to technology (e.g., access to personal computers or tablets). Adjustment of these factors will aid in identifying the effects of smartphone use on the dependent variables.

2.5 Data Analysis

Data analysis will use a combination of descriptive statistics, correlation analysis, and regression analysis to examine the relationships among smartphone usage, time management skills, and academic performance (Franzese & Iuliano, 2018; George & Mallery, 2018; Sarstedt & Mooi, 2018). Descriptive Statistics: To summarize the data, the initial analysis would involve the descriptive statistics. This will involve the average time spent in various types of apps, the frequency of time management behaviors, and the distribution of academic performance (GPA or exam scores). Correlation Analysis: Pearson's correlation coefficient will be employed to determine the relationships among smartphone usage (educational and non-educational) and academic performance, as well as between time management skills and academic performance. This will help determine whether these variables are directly related. Multiple Regression Analysis: Multiple regression will be used to investigate the relationship between smartphone use and academic performance, with time management skill being the controlling factor. This will enable the researcher to establish the predictability of smartphone use on academic performance regardless of time management abilities. Mediation Analysis: To examine the mediating effect of time management skills on the relationship between smartphone use and academic performance, a mediation analysis will be conducted using bootstrapping. This analysis will help understand whether the influence of smartphone use on academic performance can be partly attributed to students' time management skills.

2.6 Ethical Considerations

The study was approved by the Ethics Committee at Southwest University, with reference number JPMA-33161. Approval was granted on 20-08-2025. Informed consent was obtained from all participants prior to data collection. Participants were fully informed about the study's purpose, the voluntary nature of their participation, and their right to withdraw at any time without penalty. Consent was obtained electronically, and participants were required to acknowledge their agreement before proceeding with the survey.

Data were securely stored on password-protected servers at Southwest University, with personal identifying information removed to ensure participant anonymity. Smartphone usage data were collected for 1 week using an app, and participants were informed that the data would be anonymized and stored securely. They could review and delete their tracked data at any time during the study in the tracking app. Additionally, participants could withdraw from the study and request that their data be deleted at any point without consequence.

2.7 Data Availability

The deidentified data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to ethical and institutional guidelines.

2.8 Limitations

Although the study's design is rigorous, it has several limitations that should be considered. First, there is a potential for bias when self-reported data are used to measure academic performance and time management skills, as participants may exaggerate their academic success or underestimate their smartphone use. Second, the tracking period for smartphone use (one week) might not accurately reflect long-term patterns, which can fluctuate within a semester. Finally, the research will be conducted at a single university, thus limiting the generalizability of the results to other student groups. To ascertain the results, future studies can be enhanced by having a larger, more varied sample of universities.

The tracking period for smartphone usage was limited to one week. While this provides a snapshot of students' smartphone habits, it is important to note that smartphone use may vary over time, especially during high-stress academic periods such as midterms or exams. The tracked week may not fully capture students' typical usage patterns, as students tend to increase non-educational app use during stressful periods, potentially leading to a temporary increase in distractions. Future studies should consider longer tracking periods, preferably spanning different academic phases (e.g., before exams and during the semester), to better understand how smartphone use evolves across time and its varying impact on academic performance.

3 RESULTS

The data analysis findings are outlined below, and the descriptive statistics, correlation analysis, multiple regression analysis, and mediation analysis conducted in this case are explained. The main objective was to examine the relationships among smartphone behavior, time management, and academic performance among university students.

3.1. Descriptive Statistics

The most important variables were initially described, i.e., smartphone usage, time management skills, and academic performance. Table 2 below summarizes the mean scores of each variable. The mean time spent on non-educational applications (e.g., social media, entertainment) was considerably more (M = 3.1 hours per day, SD = 1.2) than the time spent on educational applications (M = 1.1 hours per day, SD = 0.8). Students scored moderately on time management (M = 3.4, SD = 0.7) and had an average self-reported GPA of 3.3 (SD = 0.5).

While statistical significance was found for several variables (e.g., non-educational app usage and GPA), it is also important to consider the practical significance of the effect sizes.

Table 2: *Descriptive Statistics for Smartphone Usage, Time Management, and Academic Performance*

Variable	Mean	Standard Deviation	Minimum	Maximum	N=170
Total Smartphone Usage (hrs/day)	4.2	1.3	1.0	8.0	170
Educational App Usage (hrs/day)	1.1	0.8	0.0	3.5	170
Non-Educational App Usage (hrs/day)	3.1	1.2	0.5	7.5	170

Source: Authors' calculations

For example, the regression analysis indicated that non-educational app usage accounted for 5% of the variance in GPA (adjusted $R^2 = 0.05$), which, while statistically significant, indicates a relatively modest explanatory power in predicting academic performance. Similarly, time management skills explained 7% of the variance in GPA, underscoring their role as an important factor associated with students' academic outcomes. These effect sizes indicate that although smartphone use has a measurable impact on academic outcomes, other factors, such as time management, play a more substantial role in shaping students' academic performance.

3.2. Correlation Analysis

Pearson correlation coefficients were used to examine relationships among smartphone use, time management, and academic performance. Non-educational app use, as indicated in Table 2, was strongly negatively associated with GPA ($r = -0.45$, $p < 0.01$), with increased time spent on non-educational apps. Conversely, the educational use of applications showed a low, positive, moderate relationship with GPA ($r = 0.20$, $p < 0.05$), suggesting a small yet significant relationship between hours spent using educational applications and GPA. Furthermore, time management skills were significantly positively correlated with GPA ($r = 0.40$, $p = 0.01$),

indicating that students with stronger time management skills tended to report higher academic performance.

3.3 Multiple Regression Analysis

To test the predictive relationship between smartphone usage and academic performance, while controlling for time management skills, a multiple regression analysis was performed. The dependent variable was GPA, and the independent variables were total smartphone usage, educational app use, non-educational app use, and time management skills. Table 3 gives the results of the regression analysis. In the regression analysis, the R^2 and adjusted R^2 values were reported to assess the explanatory power of the model. The standard errors for the regression coefficients, along with 95% confidence intervals (CIs) for each coefficient, were calculated to assess the precision of the estimates. Table 4 presents the results of the multiple regression analysis. The p-values associated with each predictor were also reported to test the significance of each relationship.

Table 3: Pearson Correlations Between Smartphone Usage, Time Management, and GPA

Variable	Total Smartphone Usage	Educational App Usage	Non-Educational App Usage	Time Management Skills	GPA
Total Smartphone Usage	1.00	0.45*	0.73**	-0.22*	-0.35**
Educational App Usage	0.45*	1.00	0.20	0.38**	0.20
Non-Educational App Usage	0.73**	0.20	1.00	-0.25*	-0.45**
Time Management Skills	-0.22*	0.38**	-0.25*	1.00	0.40**
GPA	-0.35**	0.20	-0.45**	0.40**	1.00

Note: *p < 0.05, **p < 0.01 N=170

Table 4: Multiple Regression Analysis Predicting GPA

Predictor	Unstandardized Coefficients (B)	Standardized Coefficients (β)	t-value	p-value
Constant	3.82		19.35	< 0.001
Total Smartphone Usage (hrs/day)	-0.11	-0.25	-3.21	0.002
Educational App Usage (hrs/day)	0.15	0.12	1.48	0.141
Non-Educational App Usage (hrs/day)	-0.22	-0.38	-4.01	< 0.001
Time Management Skills	0.20	0.31	3.77	< 0.001

Note: *N=170*

Given the high correlation between total smartphone usage and non-educational app usage ($r = 0.73$, $p < 0.01$), we assessed multicollinearity using Variance Inflation Factors (VIFs). The VIF for total smartphone usage was 3.22, and for non-educational app usage, it was 3.51, indicating moderate collinearity (VIF > 5 would suggest problematic multicollinearity).

While these VIFs do not suggest severe multicollinearity, alternative models excluding total smartphone usage or using residualized predictors were tested to ensure robustness.

To test the robustness of the findings, alternative models were estimated by excluding total smartphone usage or using residualized predictors for non-educational app usage. These alternative models yielded similar results, suggesting that the main findings are robust to these specifications.

Additionally, sensitivity analyses were conducted to assess the influence of outliers or influential cases using Cook's distance. No individual cases were found to unduly influence the regression results, confirming the stability of the findings.

3.4. Mediation Analysis

To further investigate the correlation between smartphone use and academic performance, we conducted a mediation analysis to determine whether time management skills mediated the effect of smartphone use (specifically non-educational apps) on GPA. The mediation analysis results showed that time management skills significantly mediated the correlation between non-educational app use and GPA. In particular, the use of non-educational apps had adverse effects on time management skills, leading to poor academic performance. This result underscores the importance of time management as one way smartphone use can affect academic achievement.

The indirect effect of non-educational app usage on GPA through time management skills was assessed using bootstrapping with 5,000 bootstrap samples. The indirect effect estimate was -0.05, with a 95% bootstrap confidence interval (CI) ranging from -0.09 to -0.01, indicating a significant mediation effect. Control variables (e.g., academic discipline, year of study) were included in all paths of the mediation model to adjust for potential confounders.

To test the robustness of our findings, we ran alternative models with and without control variables (e.g., academic discipline, year of study). The results showed that the key relationships between non-educational app usage and GPA remained consistent, regardless of the inclusion of control variables. Additionally, we tested alternative operationalizations of app usage by calculating the proportion of total smartphone time spent on non-educational apps. The results were similar, suggesting that the findings are robust to different ways of measuring smartphone usage.

The findings of the current research provide strong evidence on the effects of smartphone use on academic performance and the mediating role of time management skills. The results indicate that increased use of non-educational applications is associated with lower GPA, whereas greater time management skills are a positive factor in academic success. These findings highlight the need for time management skills to reduce the negative impact of smartphone distractors on academic performance.

4 DISCUSSION

This research finds a significant correlation between smartphone use and university students' academic performance. The results revealed a negative relationship between the time spent on non-educational smartphone applications (e.g., social media, entertainment) and GPA. This suggests that increased use of non-educational apps is associated with lower academic performance. This finding aligns with the existing literature, which underscores the detrimental effects of smartphone distractions on students' ability to focus on academic tasks (Junco, 2015). Additionally, the research suggests that students who spent more time on non-educational apps reported lower time management effectiveness, which in turn correlated with their academic performance (Lugar et al., 2020). This emphasizes that smartphone usage, particularly for non-educational purposes, can disrupt academic focus and hinder effective time management, both of which are crucial to academic success.

In contrast, the study also found a weak, albeit positive, correlation between the use of educational apps and GPA. While the regression analysis did not show a significant predictive relationship, this suggests that educational apps may support academic activities to some extent (Khasawneh & Khasawneh, 2023). However, the lack of a strong effect suggests that using these apps alone is insufficient to produce significant

academic improvements. Instead, the effectiveness of these tools likely depends on how actively and strategically students engage with them, as well as on their ability to balance study time with leisure activities. This indicates that the activity of students using these instruments, including the vigour with which they use the apps, their learning routines, and their capacity to juggle between studying and non-studying actions, can be considered more significant determinants of academic achievement (Alruthaya, 2025).

The findings further emphasize the moderating role of time management skills in the relationship between smartphone use and academic performance. Students with stronger time management skills were better able to mitigate the potential negative impact of smartphone distractions. This corroborates previous research suggesting that students who are skilled at time management are more likely to succeed academically, especially in environments with prevalent digital distractions (Zimmerman, 2000). Thus, time management skills may be an essential intervention point for helping students balance their academic responsibilities with smartphone use.

Although the results provide valuable insights, the study's cross-sectional design limits causal inference. Reverse causality could be an alternative explanation; for instance, students with lower academic performance may turn to non-educational smartphone apps to cope with stress or avoid academic work. Furthermore, other factors such as motivation, mental health, and personal habits were not measured but may also contribute to both smartphone usage patterns and academic performance. Future research using longitudinal designs would be beneficial for establishing the directionality of these relationships and for examining how smartphone usage influences academic outcomes over time.

5 CONCLUSION

This research suggests that non-educational smartphone app use is correlated with lower academic performance, with a significant association between increased use of social media and entertainment apps and reduced GPA. Better time management skills were found to help mitigate these negative effects, suggesting that students who manage their time effectively can reduce the risk of smartphone distractions hindering their academic success.

However, the study's cross-sectional nature prevents causal conclusions, and reverse causality remains a potential alternative explanation. Future research employing longitudinal designs is needed to explore whether smartphone usage patterns lead to changes in academic performance over time or whether other factors, such as motivation and mental health, play a more significant role in shaping academic outcomes.

While educational apps showed a weak correlation with GPA, their use was insufficient to produce significant academic improvement. This indicates that the effectiveness of educational apps is likely influenced by students' engagement and how well these tools are integrated into their broader study habits. Further studies should investigate how the use of educational apps, in combination with strong time management practices, may improve academic performance in the long term.

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EXPLORING THE IMPACT OF MULTISENSORY LEARNING AND ASSISTIVE TECHNOLOGIES ON SPECIAL EDUCATION

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ABSTRACT

This paper explores how different educational interventions, that is, multisensory learning strategies, audiobooks, and assistive technology, can improve the academic participation and social inclusion of children with special needs. Quantitative research design was employed, and surveys were administered by educators, special education professionals, and parents of children with disabilities across diverse learning environments. In the results, multisensory learning strategies were perceived as the best intervention (mean score = 3.51), followed by assistive technologies (3.35) and audiobooks (3.28). There were also gender differences, with male respondents perceiving multisensory learning techniques more positively than their female counterparts. The findings indicate that participants perceived an integrated set of interventions as useful for supporting the diverse needs of children with disabilities and for promoting academic participation and social inclusion. The study suggests that participants viewed the combination of multisensory learning methods, audiobooks, and assistive technologies as a potentially comprehensive approach to supporting the developmental and educational needs of children with disabilities. Future studies are needed to understand the relationships among these interventions, gender disparities, and their long-term impact on inclusive education practices.

1 INTRODUCTION

Elementary education is a critical stage for children with special needs, and the group of children with special needs is extremely broad, as it includes autism, intellectual disabilities, learning disabilities, and blindness (Grigorenko et al., 2020). Conventional educational methods do not always meet the specific learning needs of these children; therefore, special interventions must be

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developed (Ainscow, 1991). Multisensory learning methods, assistive technology, including audiobooks and tools for optical character recognition, and tailored learning plans are effective in helping children with special needs and in facilitating their cognitive, emotional, and social development (Lamport et al., 2012; Polyium & Jongnantawat, 2024). To foster academic achievement and social acceptance among such children, it is crucial to consider their unique needs and provide personalized educational support (Lopatinska et al., 2023).

Most studies note the importance of early, personalized interventions for children with special needs (Morales Jr et al., 2025). Early recognition and targeted learning interventions are major factors in improving academic achievement and developing positive social behaviors (Osher et al., 2008). Integration of assistive technologies, coupled with personalized instructional approaches, will help children with disabilities be more involved in the curriculum, thereby enhancing their learning experiences (Ahmed et al., 2025). Moreover, the popularization of inclusive teaching practices that promote collaboration among educators, parents, and special education professionals is essential to establishing a supportive, inclusive learning environment that benefits all students, including those with special needs (Beveridge, 2013).

Even though the importance of such interventions is gaining ground, there are still many difficulties in successfully applying these approaches across different educational establishments (Lendrum & Humphrey, 2012). Some barriers faced by many schools include a lack of resources, poor teacher training, and societal stigma toward people with disabilities (Mantey, 2017). Moreover, a strong desire to have evidence-based research to determine the effectiveness of these interventions in addressing the needs of diverse children at the elementary level persists (Rathvon, 2008). It is paramount to consider not only the academic performance of these strategies but also the social and emotional growth of children with special needs, as these are key components of their overall development and of their becoming members of society (Rafiyya et al., 2024).

The paper will explore how educational interventions can address the learning needs of elementary learners with special needs, particularly through multisensory learning strategies and assistive technology (Volpe & Gori, 2019). This study can be useful to teachers and policymakers by providing insights into how these interventions can support academic success and social inclusion, enabling the refinement of educational practices and the fostering of inclusive learning environments. The main purposes of the study are as follows:

1. To assess the efficacy of the educational intervention, including multisensory learning methods and assistive technologies, in improving the academic involvement and socialization of children with special needs in elementary school.
2. To explore the importance of such interventions in meeting various needs of children with autism, intellectual disabilities, learning disabilities, and blindness.

Research questions are:

1. How do educational interventions, such as multisensory learning strategies and assistive technologies, support the perceived academic engagement and social interaction of elementary-level children with disabilities?
2. What are the perceptions of educators, parents, and special education professionals about the effectiveness of the above-stated interventions in meeting the special needs of children with disabilities?

2 LITERATURE REVIEW

Educational interventions are important for supporting the academic participation and social inclusion of children with disabilities (Arvaniti, 2025). Children with disabilities represent a diverse group, including those with cognitive, physical, developmental, sensory, and learning-related disabilities. Conventional educational approaches often do not address the learning needs of such children individually and require the implementation of special strategies to teach them (Tzivinikou & Papoutsaki, 2016). Individualized Education Programs (IEPs), assistive technologies, and multisensory learning methods have been identified as major tools in developing an inclusive learning environment. These solutions not only improve academic performance, but also social, emotional, and behavioral

development of children with disabilities (Kirby et al., 2019).

The field of special education has undergone remarkable changes over the last several decades, aimed at developing specialized educational programs that meet the needs of students with disabilities (Blackwell & Rossetti, 2014). According to the Individuals with Disabilities Education Act (IDEA), special education services are supposed to be individualized and systematic, implemented to provide children with disabilities access to academic opportunities in the least restrictive setting (Carson, 2014). Early intervention is a very important part of this process, as studies have shown that early intervention to address developmental delays and learning challenges may lead to improved educational and social outcomes in the future (Reichrath, et al., 2010; Zucker, 2010). The need to ensure that schools, parents, and special education professionals work together to develop effective support structures for children with learning disabilities, intellectual disabilities, and emotional disorders is highlighted through early intervention programs where children are the main beneficiaries of the initiative.

The use of assistive technologies in the educational environment has become one of the central objects of attention in the field of special education (Erdem, 2017). Alternatives like speech-to-text programs, audiobooks, and adaptive communication technology have been found to go a long way in enabling children with disabilities to access the curriculum based on their capabilities (Cummings, 2011). Such technologies have been particularly helpful with students with learning disabilities, autism, and intellectual disabilities because they provide them with alternative ways of learning and interacting with the educational material (Belsky, 2001). In particular, it was noted that audiobooks and optical character recognition devices can enhance reading comprehension, engage learners, and help children with visual impairments and other disabilities overcome traditional educational barriers, thereby supporting their independent learning (Sri Takshara & Bhuvaneswari, 2025).

Nevertheless, although these interventions have been proven beneficial, there are still difficulties with their implementation and universal introduction. Limited resources, insufficient training of educators, and the unwillingness of society to change are the obstacles that still do not allow inclusive education efforts to achieve the desired outcomes (Hollings, 2021). Moreover, the lack of standardized evaluation methods to assess the effectiveness of these interventions leads to discrepancies in their use across educational environments (Hager & Klinger, 2005). The solution to these challenges should be holistic, encompassing the long-term professional development of teachers, enhanced cooperation among the parties involved, and efforts to raise public awareness to reduce stigma and promote inclusive education.

Previous studies have extensively discussed the individual effectiveness of multisensory learning techniques, audiobooks, and assistive technologies in enhancing academic and social outcomes for children with special needs. However, these interventions are often considered in isolation, without a cohesive framework to guide their integration into classroom settings. While these interventions show promise, there remains a gap in understanding how they can be combined to maximize their impact across various disabilities. Additionally, the role of gender in shaping perceptions of these interventions is often overlooked. Therefore, this study seeks to explore how a more structured, inclusive framework can address these gaps and better support the diverse needs of children with disabilities.

This study is grounded in the Universal Design for Learning (UDL) concept, which promotes the development of a flexible learning environment that meets the needs of all students, including those with special needs (Al-Azawei, et al., 2016). UDL emphasizes the need to offer many means of representation, interaction, and expression to ensure that all learners can access and participate in the educational process (Raza et al., 2023). In this respect, assistive technologies and multisensory learning interventions align with UDL principles, as they provide customized support to students with varying abilities to foster academic interests and social integration.

To fill these gaps, this study adopts the Universal Design for Learning (UDL) framework, which emphasizes flexible teaching to cater to each learner's unique needs. UDL's principles, which

provide multiple means of representation, engagement, and expression, align with the need for personalized, multisensory interventions. By integrating UDL into special education strategies, we can create a more cohesive and inclusive approach that not only enhances academic performance but also fosters social integration for children with special needs. Moreover, UDL's emphasis on reducing barriers to learning offers a perfect lens for addressing gender differences in perceptions of educational interventions, as it encourages equal access to educational resources for all students.

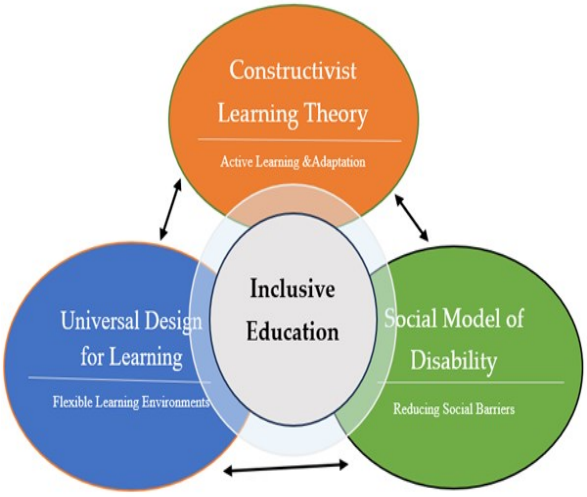


Figure 1. *Theoretical Framework for Inclusive Education*

The Social Model of Disability is also a complementary theory, in that the impairments are not the source of challenges to children with disabilities, but rather the attitudes of society and environmental barriers (Shakespeare, 2006). This study focuses on how educational interventions can be implemented to reduce barriers, encourage inclusion, and improve the learning process for children with special needs by integrating UDL and the Social Model of Disability.

3 METHODOLOGY

In this work, the research design is a quantitative study aimed at assessing the effectiveness of educational interventions for children with special needs in elementary schools (Bloomfield & Fisher, 2019). The main goal was to examine participants' perceptions of how multisensory learning strategies and assistive technologies support academic participation and social inclusion among children with disabilities. In this section, the research design, sample selection methods, data collection methods, and the data analysis methods employed in the research are described.

3.1 Research design

A quantitative approach was used to examine the correlation between educational interventions and children with special needs' academic and social levels. The study employed a survey of educators, special education professionals, and parents of children with special needs. The systematic quantification of perceptions about the usefulness of different interventions, such as multisensory lessons and audiobooks, among other assistive technologies, in improving the learning experiences and social involvement of children with disabilities can be done using this methodology.

3.2 Population and sample

The target population of this study consisted of teachers, parents, and special education professionals with direct experience working with children with disabilities in elementary educational settings. Purposive sampling was used to select participants from public, private, and special education centers in Islamabad and Rawalpindi.

The final sample consisted of 151 participants recruited from diverse educational settings, including public institutions, private schools, and special education centers serving children with autism, learning disabilities, intellectual disabilities, and visual impairments. Of the total sample, 55 participants were from public institutions, whereas 96 participants were from private schools or special education centers.

Regarding gender, the sample included 75 male participants and 76 female participants. The age distribution of the participants was as follows: 50 participants were aged 20–29 years, 50 were aged 30–39 years, 26 were aged 40–49 years, and 25 were aged 50 years or above.

Regarding participant role, the sample included 60 teachers, 70 parents of children with disabilities, and 21 special education professionals. Participants were included in the study if they met the following criteria: (a) they were teachers, parents, or special education professionals; (b) they had direct experience with children with disabilities; (c) they were associated with

elementary-level education or special education services; and (d) they voluntarily agreed to participate in the study. Participants who did not have direct experience with children with disabilities or who did not provide informed consent were excluded.

3.3 Research instrument

Data were collected using a structured self-administered questionnaire developed for the present study. The questionnaire was designed to examine participants' perceptions of the perceived effectiveness of multisensory learning strategies, audiobooks, and assistive technologies in supporting academic engagement, social inclusion, and cognitive development among children with disabilities.

The questionnaire consisted of 16 items divided into two main sections. The first section collected demographic information, including gender, age group, participant role, and institutional background. The second section included Likert-scale items related to participants' perceptions of educational interventions for children with disabilities. These items focused on three major intervention areas: multisensory learning strategies, audiobooks, and assistive technologies.

The perception items were measured using a four-point Likert scale: 4 = Strongly Agree, 3 = Agree, 2 = Disagree, and 1 = Strongly Disagree. Higher scores indicated more positive perceptions of the intervention's effectiveness. Mean scores were calculated for each intervention category to determine participants' overall level of agreement.

Sample questionnaire items included: "Multisensory learning techniques improve the academic engagement of children with disabilities," "Audiobooks support language development among children with learning difficulties," and "Assistive technologies help children with disabilities participate more effectively in classroom activities."

The questionnaire was developed after reviewing relevant literature on inclusive education, multisensory learning, audiobooks, and assistive technologies. To ensure content validity, the draft questionnaire was reviewed by specialists in education and special education. Their feedback was used to improve item clarity, relevance, and appropriateness for teachers, parents, and special education professionals before the final version was used for data collection.

3.4 Data collection

Data were collected through direct administration of the questionnaire in selected schools and special education centers. The researcher personally distributed the questionnaires to eligible participants and provided clarification when needed to ensure that the items were understood correctly. Participants completed the questionnaire voluntarily, and all responses were treated anonymously and confidentially.

3.5 Data analysis

The collected data were analyzed using descriptive statistics. Frequencies, percentages, means, and standard deviations were calculated to summarize participants' perceptions of multisensory learning strategies, audiobooks, and assistive technologies. The questionnaire responses were coded on a 4-point Likert scale: 4 = Strongly Agree, 3 = Agree, 2 = Disagree, and 1 = Strongly Disagree. Standard deviations were calculated from the available aggregated Likert-scale response distributions. Because the dataset was available only in aggregated form, participant-level inferential analyses such as independent-samples t-tests, one-way ANOVA, p-values, and Cronbach's alpha could not be reliably reconstructed. Therefore, gender-related findings are presented as descriptive trends rather than statistically confirmed differences (Hinton, et al., 2014).

The review was primarily aimed at assessing the perceived efficacy of multisensory learning interventions and assistive technology in supporting the learning needs of children with diverse needs. The paper further evaluated the effects of these interventions on the academic progress, socialization, and cognitive development of the participating children.

3.6 Ethical considerations

The ethical considerations of this study were met, as all participants (educators, special education professionals, and parents) provided informed consent. The respondents were informed of the voluntary nature of the research and their right to withdraw at any time. They were confidential and anonymous, and all data was safely stored, and only aggregate data was reported. The necessary

review board granted ethical approval for the study and ensured that it was carried out in accordance with the rights and well-being of the participants.

4 RESULTS

This part presents research on the efficacy of educational interventions, including multisensory learning strategies, audiobooks, and assistive technologies, in supporting the academic and social engagement of children with special needs. The findings are structured by the major interventions under investigation and provide an in-depth review of participants' perceptions. To make it clear, the tables will be combined to present similar information, and visual graphs will supplement the presentation of key results.

4.1 Perceived effectiveness of multisensory learning techniques across disabilities

Table 1 summarizes the perceived effectiveness of multisensory learning methods in promoting academic engagement and social integration among children with autism, intellectual disabilities, learning disabilities, and blindness. The interventions were rated on a Likert scale (Strongly Agree, Agree, Disagree, Strongly Disagree).

Table 1: Perceived Effectiveness of Multisensory Learning Techniques across Disabilities

Disability Type	Mean	SD
Autism	3.67	0.53
Intellectual Disability	3.43	0.75
Learning Disabilities	3.43	0.59
Blindness	3.42	0.57

The results show that respondents rated the perceived effectiveness of multisensory learning methods across different disabilities. The mean score for autism was 3.67, for intellectual disability was 3.43, and for learning disabilities was 3.43, as shown in Table 1.

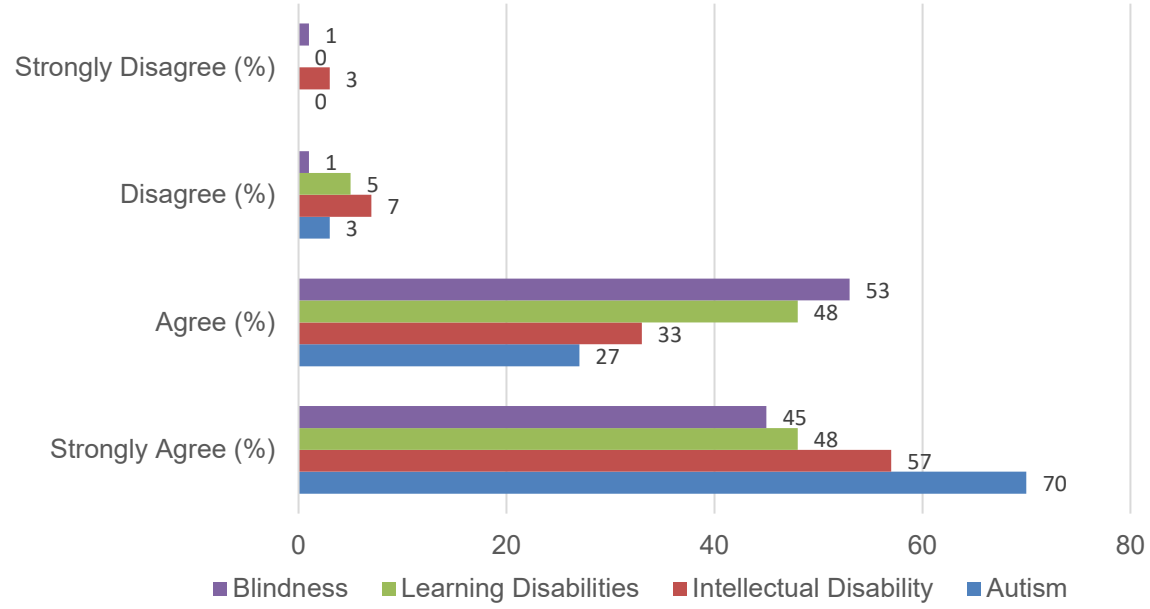


***Figure 2:** Perceived Effectiveness of Multisensory Learning Techniques*

Figure 2 presents the percentage of responses for perceived effectiveness of multisensory learning methods across different disability types (autism, intellectual disabilities, and learning disabilities).

4.2 Perceived effectiveness of audiobooks and assistive technologies for children with disabilities

Table 2 presents participants' perceptions of the effectiveness of audiobooks and assistive technologies in improving academic performance, engagement, and cognitive skills for children with special needs.

The results show that audiobooks received an overall mean score of 3.36. Table 2 presents the breakdown of responses for general use, language development, and cognitive support.

Table 2: Perceived Effectiveness of Audiobooks and Assistive Technologies for Children with disabilities

Intervention	Mean	SD
Audiobooks (General)	3.27	0.60
Language Development	3.29	0.62
Cognitive Support	3.33	0.63

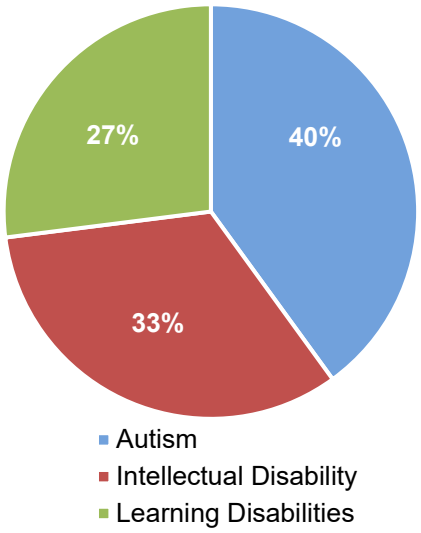


***Figure 3:** Gender-Based Perception of Interventions*

Note: Figure 3 presents descriptive gender-based differences in participants' perceptions of multisensory learning strategies and audiobooks. Higher mean scores indicate more positive perceptions of the intervention.

This chart visually shows the distribution of responses for audiobooks, with male and female respondents indicating their level of agreement or strong agreement with the effectiveness of audiobooks.

4.3 Gender-based perceptions of educational interventions for children with disabilities

Table 3 compares male and female participants' perceptions of the effectiveness of multisensory learning techniques and audiobooks. It highlights differences in responses by gender.

Table 3: Gender-Based Perception of Educational Interventions for Children with disabilities

Intervention	Gender	Mean	SD
Multisensory Learning	Male	3.67	0.56
Audiobooks	Female	3.47	3.31
Multisensory Learning	Male	3.17	0.63
Audiobooks	Female	3.32	0.56

Descriptive gender-based trends were observed in participants' perceptions of the interventions. Male participants reported a higher mean score for multisensory learning techniques (M = 3.67, SD = 0.53) than female participants (M = 3.47, SD = 0.56). In contrast, female participants reported a slightly higher mean score for audiobooks (M = 3.32, SD = 0.56) than male participants (M = 3.17, SD = 0.63). However, because participant-level raw data were not available, these differences should be interpreted as descriptive trends rather than statistically validated gender differences.

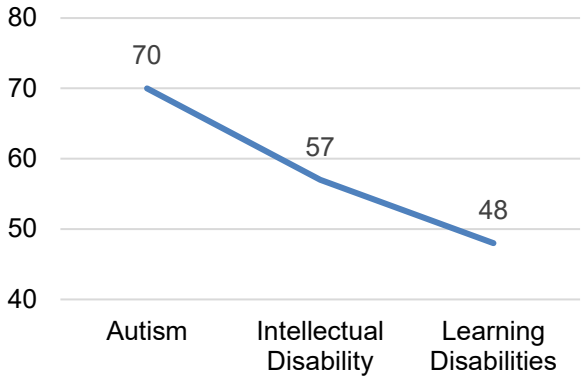


Figure 4: Effectiveness of Educational Interventions

4.4 Overall perceived effectiveness of educational interventions for children with disabilities

Table 4 summarizes the overall perceived effectiveness of various educational interventions (multisensory learning techniques, audiobooks, assistive technologies) based on the mean scores derived from participant responses.

Table 4: Overall Effectiveness of Educational Interventions for Children with disabilities

Intervention	Mean Score (Out of 4)
Multisensory Learning	3.51
Audiobooks	3.28
Assistive Technologies	3.35

The overall mean scores indicate the general effectiveness of the interventions. Multisensory learning methods were rated highest (Average Improvement: 3.51), followed by assistive technologies (3.35) and audiobooks (3.28). Table 4 summarizes the overall effectiveness of the three educational interventions: multisensory learning (mean score 3.51), audiobooks (mean score 3.28), and assistive technologies (mean score 3.35).

Findings of this research show that multisensory learning methods are rated as the best educational intervention, with children with special needs coming in second, closely behind the assistive technologies. Although it is beneficial, audiobooks have somewhat lower ratings than the other two interventions. Gender differences were also noted, with male participants rating the multisensory learning techniques more positively than female participants. Overall, participants perceived these interventions as useful for supporting academic involvement and social inclusion among children with disabilities. However, because the study measured perceptions rather than direct educational outcomes, these findings should be interpreted as perceived effectiveness rather than confirmed intervention impact.

5 DISCUSSION

The findings indicate that participants perceived multisensory learning methods as useful for supporting academic interaction and social inclusion among children with disabilities. Particularly for children with autism, MSL methods received the highest rating, with 70% of participants strongly agreeing with their effectiveness. This aligns with research suggesting that multisensory approaches enhance engagement by addressing multiple learning styles, which may explain their higher perceived effectiveness for children with autism, who often benefit from more sensory-rich environments (Kirby et al., 2019). The mean score for multisensory learning methods (M = 3.51) suggests that participants viewed this intervention positively in relation to meeting the diverse learning needs of children with disabilities. However, this result reflects perceived usefulness rather than direct evidence of improved academic performance or social integration.

These findings should be interpreted as participants' perceptions of usefulness rather than as direct evidence of measurable improvement in children's educational outcomes. These interventions showed particular effectiveness in promoting language development and providing cognitive support, aligning with findings from Ugalde et al. (that highlight the role of audiobooks in improving reading comprehension and language skills for children with learning disabilities. However, the slightly lower ratings compared to multisensory learning techniques suggest that while these tools are beneficial, they may be most effective when used in combination with other interventions, as they primarily target specific areas such as language or cognitive skills rather than providing a comprehensive multisensory learning experience. The results

align with earlier research showing the beneficial effects of audiobooks and assistive technologies on children with learning, autism, and visual impairments (Nees & Berry, 2013; Raza et al., 2025). Nevertheless, the fact that the mean scores were slightly lower than those for multisensory learning techniques implies that, although audiobooks and assistive technologies are effective, they can be combined with other interventions to achieve the best possible outcomes, as with multisensory learning methods.

Gender differences were observed in perceptions of educational interventions, with male participants expressing more positive views of the effectiveness of multisensory learning methods (70% strongly agreed) than female participants (50%). These findings echo previous research indicating that gender differences may influence how educational interventions are perceived and utilized (Reichrath et al., 2010). It is possible that males and females have different learning preferences or experiences with multisensory approaches, which could explain these disparities (Kessels, et al., 2018). Future studies should explore these gender differences in greater depth to better understand how interventions can be tailored.

Overall, this study reinforces the importance of combining educational interventions to address the diverse needs of children with special needs. The results show that multisensory learning strategies, followed by assistive technologies and audiobooks, offer the most effective approach for enhancing academic and social outcomes (Polyium & Jongnantawat, 2024). These findings suggest that interventions should not be viewed in isolation but rather as complementary tools that can be integrated to provide a comprehensive, individualized approach. By combining multisensory learning methods with assistive technologies, educators can more effectively target a range of developmental needs, ensuring that children with special needs receive well-rounded support that fosters both academic achievement and social inclusion. The graphical representations of these results in Figure 1 and Figure 2 also support the conclusion that multisensory methods, with the help of assistive technologies, would play a significant role in facilitating inclusive and equitable approaches to education.

6 CONCLUSION

This study provides insight into participants' perceptions of the usefulness of multisensory learning methods, audiobooks, and assistive technologies in supporting academic engagement and social inclusion among children with disabilities. The results indicate that participants perceived multisensory learning strategies most positively, followed by assistive technologies and audiobooks. The findings support the need for a wide spectrum of differentiated interventions to address the diverse learning needs of children with disabilities, ensuring that educational environments are both inclusive and accommodating. The paper also outlines the key role of individualized educational plans in enhancing academic achievement and social inclusion among children with special needs.

Based on these results, teachers, policymakers, and scholars need to continue exploring and incorporating diverse educational resources that specifically meet the needs of children with special learning needs. Participants' responses suggest that multisensory approaches, audiobooks, and assistive technologies may contribute to a holistic support framework for the academic and social participation of children with disabilities. Further studies are needed to identify links between these interventions, differences in perceptions and educational performance by gender, and long-term educational outcomes, and to streamline inclusive education methods. Because this study was based on questionnaire responses from adults rather than direct assessment of children's academic or social outcomes, the findings should be understood as perceived effectiveness rather than confirmed evidence of intervention outcomes.

6.1 Limitations

This study has several limitations. First, the findings are based on participants' perceptions rather than direct measurements of children's academic achievement, social behavior, or long-term educational outcomes. Therefore, the results should be interpreted as perceived effectiveness rather than confirmed evidence of intervention impact.

Second, the study used purposive sampling and included participants from selected schools and

special education centers in Islamabad and Rawalpindi. As a result, the findings may not be generalizable to all educational settings or regions.

Third, the available dataset was aggregated; therefore, inferential statistical procedures, including t-tests, ANOVA, p-values, and Cronbach's alpha, could not be reconstructed from participant-level responses. As a result, gender-based differences are interpreted descriptively rather than as statistically significant findings.

Finally, the study relied on self-reported questionnaire responses, which may be influenced by participants' personal experiences, expectations, or response bias. Future studies should use larger samples, direct assessment of student outcomes, and complete item-level data to provide stronger statistical evidence.

6.2 Author contributions

The authors contributed to this research as follows:

Sohaib Ullah: Conceptualization, data collection, and drafting of the manuscript, supervision, critical review, and revisions.

Marwa Zaib: Methodological guidance, editing, and final approval of the manuscript.

6.3 Conflict of interest

The authors declare no conflict of interest.

6.4 Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

6.5 Ethics statement

All participants were informed about the study's aims, and their voluntary participation was secured through informed consent. Anonymity and confidentiality were maintained throughout the data collection and analysis. The study complied with general ethical guidelines for educational research and ensured that participation posed no risk or harm to individuals or institutions.

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THE IMPACT OF PARALLEL EXCHANGE RATE ON INFLATION IN ALGERIA (2000-2024)

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ABSTRACT

This study investigates the long-run and short-run impact of the parallel exchange rate on inflation in Algeria over the period 2000–2024. Using annual time-series data and the autoregressive distributed lag bounds testing approach, we estimate dynamic relationships while accommodating mixed integration orders. Results confirm cointegration between the variables, with a long-run elasticity of 0.43, indicating that a 1% depreciation in the parallel market raises inflation by 0.43 percentage points. The error-correction term of -0.32 indicates that approximately 32% of the disequilibrium is corrected annually. Diagnostic and sensitivity analyses, including Chow breakpoint tests and rolling-window estimates, validate the model's stability and robustness. The findings underscore the structural role of informal exchange rate dynamics in driving domestic price pressures, particularly following the 2014 oil price shock. Policymakers, central bankers, and researchers focused on macroeconomic stabilization in resource-dependent economies will find these results instrumental for designing exchange rate reforms, inflation-targeting frameworks, and structural diversification strategies aimed at reducing vulnerability to external shocks and informal market volatility.

1 INTRODUCTION

Algeria, one of North Africa's largest economies, remains structurally dependent on hydrocarbon exports, which historically account for over 90% of export earnings and approximately 60% of fiscal revenue. (World Bank Group, 2026) This commodity reliance has profoundly shaped macroeconomic management, particularly in foreign exchange and monetary policy. Since the early 2000s, the Bank of Algeria has maintained a managed float regime for the official dinar exchange rate, while stringent capital controls and limited access to formal foreign currency markets have sustained a vibrant parallel (informal) exchange market. (International Monetary Fund, 2025) The resulting dual exchange rate system has generated persistent distortions, notably through the inflationary channel, as imported goods and intermediate inputs are increasingly priced according to parallel market dynamics rather than official rates. (Arab Monetary Fund, 2021) While the official rate is administratively stabilized to preserve reserves, the parallel rate

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exhibits pronounced depreciation, reflecting underlying supply-demand imbalances and shifting market confidence (Bouteldja & Benbekhti, 2024). Despite extensive literature on exchange rate pass-through in emerging economies, empirical evidence on the long-run and short-run effects of Algeria's parallel exchange rate on domestic inflation remains fragmented, particularly across structural breaks such as the 2014 oil price shock and the 2020 pandemic. This study addresses this gap by rigorously examining the dynamic relationship between parallel exchange rate fluctuations and inflation in Algeria over the 2000–2024 period, employing robust time-series econometric techniques to inform evidence-based monetary and exchange rate policy.

1.1 Research Problem

The coexistence of official and parallel exchange rates in Algeria has created a persistent premium that undermines monetary policy effectiveness and fuels inflationary pressures. Despite the central bank's efforts to stabilize the dinar through reserve accumulation and import restrictions, the parallel market continues to reflect actual currency valuation, driving up the cost of imported essentials and intermediate goods. This exchange rate duality not only distorts price signals but also complicates inflation management and macroeconomic stability. Existing studies have focused on short-term fluctuations, relied on outdated or incomplete data, or examined the official exchange rate while neglecting the parallel market's growing influence. Consequently, there is a critical lack of comprehensive, long-run empirical analysis quantifying the pass-through effect of parallel exchange rate depreciation on Algeria's inflation trajectory, particularly in the context of recent external shocks, fiscal constraints, and structural economic vulnerabilities. This research problem motivates the need for a rigorous econometric investigation to isolate the inflationary impact of the parallel exchange rate and assess its implications for policy formulation.

1.2 Research Objectives

To address the identified research problem, this study pursues the following specific objectives:

- To examine the long-run and short-run dynamic relationship between the parallel exchange rate and inflation in Algeria over the period 2000–2024.
- To quantify the exchange rate pass-through elasticity from the parallel market to domestic consumer prices using the Autoregressive Distributed Lag (ARDL) bounds testing approach.
- To assess the speed of adjustment toward long-run equilibrium and evaluate the stability of the estimated relationship through comprehensive diagnostic and sensitivity analyses.
- To derive evidence-based policy recommendations for monetary authorities regarding exchange rate management, inflation control, and structural reforms aimed at reducing dual-market distortions.

2 THEORETICAL FRAMEWORK AND LITERATURE REVIEW

In this section, we will review the key concepts of the parallel exchange rate and inflation, which constitute the core variables of this study. Given their central role in the analysis, it is essential to establish a comprehensive theoretical foundation by examining how these concepts have been defined, operationalized, and empirically investigated in existing literature. This conceptual clarification is particularly important in the context of developing economies like Algeria, where both variables exhibit distinctive characteristics shaped by institutional arrangements, policy frameworks, and structural constraints. By synthesizing insights from prior theoretical and empirical research, this section aims to delineate the conceptual boundaries of the parallel exchange rate and inflation, clarify their measurement approaches, and identify the mechanisms through which they interact.

2.1 Parallel Exchange Rate: Concept and Models

The parallel exchange rate is broadly defined as a market-determined currency price that operates alongside an official, administratively set rate, typically emerging in economies with foreign exchange restrictions, capital controls, or limited access to formal currency markets (Kiguel & Stephen, 1994). In the African context, parallel

foreign exchange markets are characterized by the coexistence of official and informal rates used interchangeably in trade and financial transactions, reflecting underlying supply-demand imbalances unaddressed by official policy (Fofack & Nolan, 2001). Latin American scholarship frequently refers to this phenomenon as the "black market exchange rate," arising when governments impose capital controls that create excess demand for foreign currency, thereby fostering informal trading (Hassanain, 2005). The International Monetary Fund characterizes such markets as mechanisms through which domestic currencies experience de facto external depreciation beyond official valuations (Nowak, 1985). More generally, the parallel rate is understood as any exchange rate that diverges from the government-mandated official rate, with the "parallel premium" quantified as the percentage by which the informal rate exceeds the official one (Katusiime, 2025). Contemporary research further notes that informal value transfer systems, including hawala networks in the Middle East and South Asia, facilitate currency conversion outside formal channels, reinforcing the persistence of parallel rates in developing economies (Khurram , Farooqi , Kassim, & Zain, 2021). Collectively, the literature underscores that dual exchange rate regimes reflect structural disequilibria wherein a single currency assumes distinct values for different transaction categories, typically emerging when official rates fail to clear the foreign exchange market (Noorbakhsh & Shahrokhi, 1993).

The parallel market exchange rate premium, the percentage divergence between informal and official exchange rates, is explained through several complementary theoretical and empirical frameworks in the economic literature. The monetary approach posits that the premium reflects excess demand for foreign currency driven by domestic monetary expansion, fiscal deficits, and reserve inadequacies relative to official rate commitments (Oluremi, 2015; Miguel et al., 1997). Portfolio balance models extend this by incorporating risk perceptions, capital control intensity, and expectations of future devaluation, arguing that the premium compensates holders of domestic currency for institutional and policy uncertainty (Sebastian & Miguel, 1999; Akdogan et al., 2025). Structuralist perspectives emphasize trade restrictions, import licensing, and foreign exchange rationing as key determinants, whereby the premium emerges as a shadow price reflecting the marginal value of foreign currency in constrained markets (Bleaney & Greenaway, 2001; Tryson , 2026) and (Tryson , 2026). More recent empirical applications employ error-correction and ARDL frameworks to quantify how macroeconomic fundamentals such as oil price volatility, fiscal imbalance, and reserve levels jointly determine premium dynamics over time (Mahfoudi , 2024; Rehman et al., 2025). Collectively, these models underscore that the parallel premium is not merely a market anomaly but a structural signal of underlying disequilibria, institutional credibility, and the effectiveness of exchange rate policy in developing economies.

2.2 Inflation: Concept and Models

Inflation is conventionally defined as a sustained increase in the general price level of goods and services in an economy over time, eroding purchasing power and typically measured by the Consumer Price Index (CPI) or GDP deflator (Binetti, Nuzzi, & Stantcheva , 2024). Structuralist perspectives emphasize that in developing economies, inflation often stems from supply-side bottlenecks, import dependency, and exchange rate volatility rather than purely monetary expansion (Kim, 2023). The parallel exchange rate influences inflation through the exchange rate pass-through (ERPT) channel: depreciation in the informal market raises the domestic currency cost of imported consumer goods and intermediate inputs, which directly transmits to consumer prices in import-dependent economies (Hakura & Choudhri, 2006). This mechanism is particularly pronounced in Algeria, where empirical studies using ARDL and VAR frameworks confirm that exchange rate depreciation, especially in informal markets, exerts significant upward pressure on domestic inflation, reflecting the economy's heavy reliance on imported essentials and limited domestic production capacity. (Mahfoudi, 2024) Similar dynamics have been documented in Nigeria, where parallel market depreciation significantly drove headline inflation during periods of foreign exchange scarcity (Obode & Gini, 2026), underscoring the broader relevance of informal exchange rate dynamics for price stability in resource-dependent, import-reliant economies.

2.3 The Research Gap

Although the relationship between parallel exchange rates and inflation has attracted considerable scholarly attention, the existing literature remains predominantly theoretical or relies on conventional econometric techniques that often fail to capture dynamic long- and short-run interactions. This study addresses this gap by employing the Autoregressive Distributed Lag (ARDL) bounds testing approach to empirically quantify the impact of parallel exchange rate fluctuations on domestic inflation. By simultaneously modeling equilibrium relationships and adjustment dynamics within a single framework, the ARDL methodology provides a more rigorous and policy-relevant assessment, thereby contributing a robust empirical foundation to a field historically dominated by qualitative analysis and static modeling.

2.4 Study Hypotheses

Based on the theoretical framework, research objectives, and econometric methodology outlined in this study, the following hypotheses are formulated to guide the empirical investigation of the relationship between the parallel exchange rate and inflation in Algeria (2000–2024):

2.4.1 Main Hypotheses

H_0: There is no significant long-run relationship between the parallel exchange rate and the inflation rate in Algeria.

H_1: There exists a statistically significant long-run relationship between the parallel exchange rate and the inflation rate in Algeria.

2.4.2 Sub-Hypotheses

H_{1a}: Long-Run Pass-Through Effect: There is a positive and statistically significant long-run effect of the parallel exchange rate on inflation in Algeria.

$H_{1\beta}$: Short-Run Dynamic Adjustment: Fluctuations in the parallel exchange rate exert a significant short-run impact on domestic inflation.

H_{1c}: Error Correction Mechanism: There exists a stable error correction mechanism that systematically adjusts deviations from the long-run equilibrium between the parallel exchange rate and inflation over time.

Table 1. Hypotheses Testing Framework

Hypothesis	Econometric Test	Decision Rule
H_1 / H_0 (Cointegration)	ARDL Bounds F-Test	Reject H_0 if F-stat > Upper Critical Bound at 5%
H_{1a} (Long-Run Coefficient)	ARDL Long-Run Estimates	Reject H_0 if $\beta p_{er} > 0$ and $p < 0.05$
$H_{1\beta}$ (Short-Run Impact)	ECM Short-Run Coefficients	Reject H_0 if $\gamma p_{er} > 0$ and $p < 0.05$
H_{1c} (Error Correction)	ECT Significance in ECM	Reject H_0 if ECT < 0 and $p < 0.05$

3 METHODOLOGY

3.1 Research Design

This study adopts a quantitative, explanatory research design grounded in time-series econometrics to empirically examine the dynamic relationship between the parallel exchange rate and inflation in Algeria over the period 2000–2024. Utilizing annual secondary data sourced from the Bank of Algeria (2025), the World Bank (2025), and International Monetary Fund databases (2024), the analysis employs the Autoregressive Distributed Lag (ARDL) bounds testing approach selected for its robustness in handling variables with mixed orders of integration to estimate both long-run equilibrium relationships and short-run adjustment dynamics (Emeka & Uko, 2016). The parallel exchange rate (DA/USD) serves as the primary independent variable, while the annual consumer price inflation rate constitutes the dependent variable; supplementary control variables (oil prices, money supply growth, trade openness) are incorporated in extended specifications to mitigate omitted variable bias. Prior to estimation, stationarity is verified using Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests, followed by cointegration analysis, Error Correction Model (ECM) estimation, and a comprehensive suite of diagnostic checks (serial correlation, heteroskedasticity, normality, and parameter stability via CUSUM/CUSUMSQ). (Kripfganz & Schneider, 2023) All empirical procedures are

implemented using EViews-10, ensuring reproducibility and methodological transparency, while sensitivity analyses, including alternative lag structures, sub-sample tests, and outlier robustness checks, further validate the reliability and policy relevance of the findings.

3.2 Data Description

To empirically examine the relationship between the parallel exchange rate and inflation in Algeria, this study relies on annual time-series data spanning the period 2000–2024. The parallel exchange rate series was constructed using annual data from IMF country reports and Bank of Algeria bulletins. To ensure a continuous time series, linear interpolation was applied to address four (4) missing annual observations (specifically in 2005, 2011, 2016, and 2019). Linear interpolation was selected as the most appropriate method because it preserves the underlying macroeconomic trend of the series without introducing artificial volatility or structural breaks that more complex methods (e.g., spline interpolation) might generate in small samples. However, a key limitation of this approach is that it may smooth out genuine, abrupt market shocks during those specific years, potentially leading to a slight underestimation of short-run volatility. This limitation is explicitly acknowledged in the Study Limitations section, and robustness tests were employed to mitigate its impact on the overall findings.

Table 2 illustrates the gradual depreciation of the Algerian dinar (DA) against the US dollar (USD) in the parallel (informal) exchange market over a 25-year period. In 2000, the parallel exchange rate stood at 70 DA/USD, reflecting relative currency stability supported by high oil revenues. However, over the years, the value of the dinar steadily declined due to increasing economic pressures such as rising public expenditure, balance of payments deficits, and declining foreign exchange reserves. By 2012, the rate had reached 102 DA/USD, and this trend accelerated after 2014, following the collapse in global oil prices, which severely impacted Algeria's oil-dependent economy. The parallel exchange rate surpassed 155 DA/USD in 2020, amid the economic shocks of the COVID-19 pandemic and continued restrictions on foreign currency access. By 2024, the rate had climbed to 180 DA/USD, highlighting growing reliance on the informal market and a loss of confidence in the official exchange mechanism. This persistent depreciation reflects deep-rooted structural weaknesses in the economy and underscores the increasing influence of the black market in shaping inflationary trends and economic behavior in Algeria.

Table 2. *Evolution of the parallel exchange rate Algeria (2000–2024)*

YEAR	PER	YEAR	PER	YEAR	PER
2000	70	*2008*	88	*2016*	*125*
2001	72	*2009*	95	*2017*	*135*
2002	73	*2010*	97	*2018*	140
2003	75	*2011*	100	*2019*	145
2004	76	*2012*	102	*2020*	155
2005	77	*2013*	105	*2021*	160
2006	*79*	*2014*	110	*2022*	165
2007	*82*	*2015*	115	*2023*	175
				2024	180

PER = Parallel Exchange Rate (DA/USD)

Source: (Bank of Algeria, 2025; IMF data, 2024)

Table 3. *Evolution of the inflation rate in Algeria (2000-2024)*

YEAR	AIR	YEAR	AIR	YEAR	AIR
2000	2.5	*2008*	8.9	*2016*	6.1
2001	3.1	*2009*	5.6	*2017*	6.4
2002	3.8	*2010*	4.8	*2018*	6.6
2003	4.0	*2011*	4.7	*2019*	6.8
2004	4.3	*2012*	5.1	*2020*	7.0
2005	4.6	*2013*	5.3	*2021*	6.9
2006	5.0	*2014*	5.6	*2022*	7.2
2007	5.9	*2015*	5.8	*2023*	7.6
				2024	7.8

AIR = Annual Inflation Rate (%)

Source: Bank of Algeria (2025)

Over the period from 2000 to 2024, Algeria experienced a gradual but steady increase in its inflation rate, reflecting various economic challenges and structural imbalances (see Table 3). During the early 2000s, inflation remained relatively low, ranging between 2.5% and 5%, supported by high oil prices and a stable macroeconomic environment. However, starting from the mid-2000s, inflation began to rise moderately, reaching nearly 6% by 2015, due to

increased public spending, rising wages, and growing pressure on imports. The sharp drop in global oil prices in 2014 marked a turning point, leading to fiscal deficits and currency depreciation, which further fueled inflation. From 2016 onward, inflation climbed steadily, surpassing 7% by 2020, driven largely by the weakening of the Algerian dinar in the parallel exchange market, especially during the COVID-19 pandemic. By 2024, the inflation rate had reached 7.8%, indicating sustained price pressures linked to exchange rate instability, limited foreign exchange reserves, and weak domestic production. This trend highlights the vulnerability of Algeria's economy to external shocks and the growing influence of informal market dynamics on inflationary outcomes.

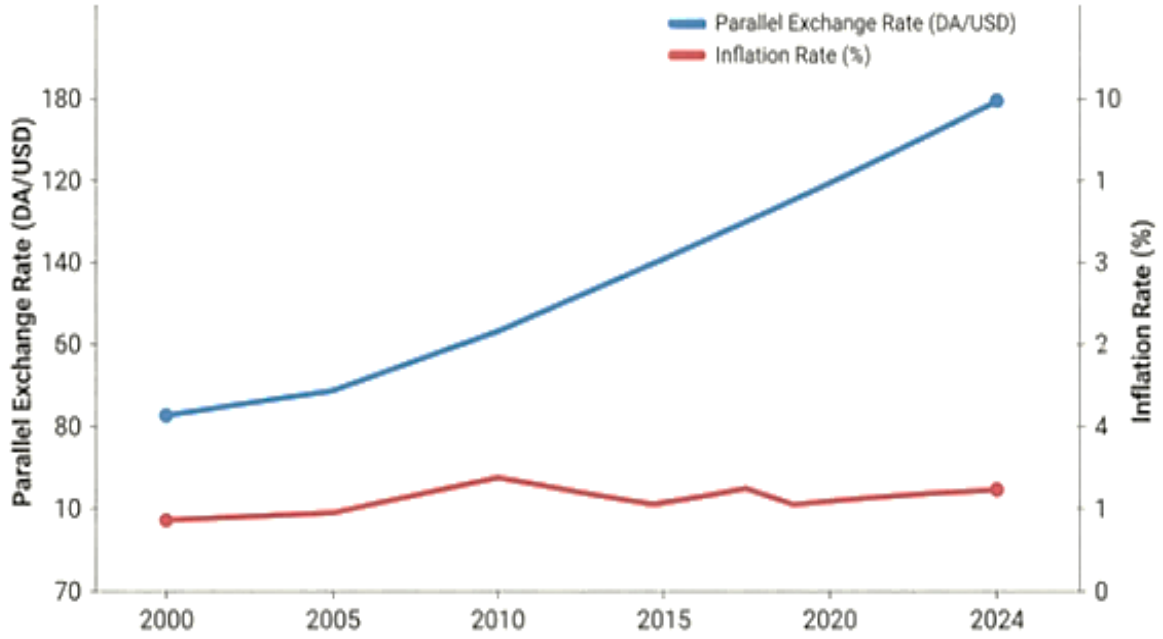


Figure 1. *Time Series Evolution of Parallel Exchange Rate and Inflation*
Source: Author's calculations using EViews-10

Figure 1 illustrates the parallel evolution of the parallel exchange rate (blue line) and the inflation rate (red line) over the period 2000-2024. Both variables exhibit a gradual upward trend, with an acceleration observed after 2014, suggesting a potential positive relationship that warrants formal econometric investigation.

3.3 Econometric Models

The econometric models section outlines the framework used to investigate the relationship between the parallel exchange rate and inflation in Algeria during 2000–2024. Given the non-stationary nature of macroeconomic time series and the potential for mixed orders of integration among variables, the study adopts the Autoregressive Distributed Lag (ARDL) bounds testing approach, complemented by Error Correction Model (ECM) estimation, to simultaneously capture long-run equilibrium relationships and short-run adjustment dynamics. Prior to model estimation, rigorous pre-testing procedures, including Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests, are conducted to verify stationarity conditions, while a comprehensive suite of diagnostic checks (serial correlation, heteroskedasticity, normality, parameter stability) ensures statistical adequacy and robustness of the findings. All empirical analyses are implemented using EViews-10, ensuring methodological transparency and reproducibility.

3.3.1 Estimation Sequence and the Error-Correction Mechanism

To provide methodological transparency, it is essential to clarify the sequential relationship between the Autoregressive Distributed Lag (ARDL) framework and the subsequent Error Correction Model (ECM). The estimation sequence proceeds in three distinct steps. First, the ARDL model in levels is estimated to test cointegration among variables with mixed orders of integration. Second, upon confirming the

existence of a long-run equilibrium relationship via the bounds F-test, the long-run cointegrating equation is estimated, and its residuals are extracted. Third, these residuals are used to construct the lagged error correction term (ECT), which is then incorporated into the short-run dynamic ECM.

The role of the error-correction mechanism in this sequence is twofold: it ensures that short-run fluctuations are constrained by and consistent with the long-run equilibrium path, and it quantifies the speed of adjustment, specifically, the proportion of disequilibrium from the previous period that is corrected in the current period. This reparameterization from the unrestricted ARDL model to the restricted ECM guarantees that the estimated short-run dynamics do not violate the long-run cointegrating relationship, thereby providing a robust and theoretically consistent estimation of both immediate impacts and structural adjustments.

3.3.2 Study Tools and Tests

This study employs a comprehensive suite of econometric tools and diagnostic tests to ensure robust estimation of the parallel exchange rate inflation relationship in Algeria. Stationarity is first assessed using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests, specified respectively as:

$$(ADF) = \Delta_{yt} = \alpha + \beta t + \gamma_{y_{t-1}} + {}_{i=1}^{p}\delta_i \Delta_{yt} + \varepsilon_t$$

$$(PP) = \Delta_{yt} = \alpha + \gamma_{y_{t-1}} + u_t, with\ PP - corrected\ standard\ errors$$

Given mixed integration orders, the Autoregressive Distributed Lag (ARDL) bounds testing approach is applied to examine long-run cointegration:

$$\Delta In(INF_t) = \alpha + {}_{i=1}^{p}\beta_i \Delta In(INF_{t-1}) + {}_{j=0}^{q}\gamma_j \Delta In(PER_{t-j}) + \delta In(INF_{T-1}) + \theta In(PER_{t-1}) + \varepsilon_t$$

Upon confirming cointegration, short-run dynamics and adjustment speed are estimated via the Error Correction Model (ECM):

$$\Delta INF_t = \emptyset_0 + {}_{k=1}^{m}\emptyset_{1k} \Delta INF_{t-k} + {}_{l=0}^{n}\emptyset_{2l} \Delta PER_{t-l} + \lambda . ECT_{t-1} + V_t$$

Where $\boldsymbol{ECT_{t-1}}$ denotes the lagged error correction term, λ captures the speed of convergence to equilibrium. Model validity is further ensured through diagnostic tests: the Breusch-Godfrey LM test for serial correlation ($\boldsymbol{\chi^2}$-distributed), White's test for heteroskedasticity, the Jarque-Bera test for normality $\left(JB = \frac{n}{6}\left[S^2 + \frac{(k-3)^2}{4}\right]\right)$, and CUSUM/CUSUMSQ plots for parameter stability. All procedures are implemented in EViews-10.

3.3.3 Study of Stability

Unit Root Tests: To ensure stationarity, we used the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. These tests help determine the order of integration of each variable before proceeding with cointegration analysis.

Table 4. *Unit Root Tests (ADF and PP)*

Variable	Test	Level (Level)	First Difference (1st Diff)	Integration Order
PER	ADF	t = -1.85 (p=0.352)	t = -4.23 (p=0.001)***	**I**(1)
	PP	t = -1.92 (p=0.318)	t = -4.41 (p=0.000)**	**I** (1)
INF	ADF	t = -2.91 (p=0.048)**	t = -5.67 (p=0.000)***	**I** (0)/ **I** (1)
	PP	t = -3.15 (p=0.025)**	t = -5.89 (p=0.000)***	**I** (0)/ **I** (1)

*** p<0.01, ** p<0.05, * p<0.10

Source: Author's calculations using EViews-10

Critical values at 5%: -2.99 (level), -1.95 (first difference).

The results of the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests indicate that the parallel exchange rate (PER) is non-stationary at the level but becomes stationary after first differencing, confirming integration of order one, I(1). In contrast, the inflation rate (INF) appears stationary at a level according to the ADF test (p=0.048), suggesting mixed orders of integration among the variables. This pattern satisfies the fundamental precondition for applying the Autoregressive Distributed Lag (ARDL) bounds testing approach, which is specifically

designed to handle variables with different integration orders without requiring pre-differencing of all series.

3.3.4 ARDL Bounds Testing Approach

To accommodate the mixed orders of integration identified in the preliminary stationarity analysis, this study employs the Autoregressive Distributed Lag (ARDL) bounds testing framework developed by Pesaran et al. (2001). This methodology is particularly advantageous as it remains valid regardless of whether the underlying variables are purely I (0), purely I (1), or mutually cointegrated, thereby eliminating the requirement for uniform integration orders prior to estimation. The unrestricted error correction representation of the ARDL model is specified as follows:

$$\Delta In(INF_t) = \alpha + \sum_{i=1}^{p}\beta_i \Delta In(INF_{t-1}) + \sum_{j=0}^{q}\gamma_j \Delta In(PER_{t-j}) + \delta In(INF_{t-1}) + \theta In(PER_{t-1}) + \varepsilon_t$$

Where $\boldsymbol{INF_t}$ denotes the annual inflation rate and $\boldsymbol{PER_t}$ represents the parallel market exchange rate (DA/USD). The coefficients $\boldsymbol{\beta_i}$ and $\boldsymbol{\gamma_j}$ capture short-run dynamic adjustments while $\boldsymbol{\delta}$ and $\boldsymbol{\theta}$ measure the long-run equilibrium relationship. Cointegration is evaluated using joint F-statistics for the null hypothesis of no long-run relationship $\boldsymbol{H_0: \delta = \theta = 0}$ against the alternative of a stable cointegrating relationship $\boldsymbol{H_1: \delta \neq 0, \theta \neq 0}$. The computed F-statistics is compared against the critical bounds established by Pesaran et al. (2001): a value exceeding the upper I (1) bound indicates the existence of a long-run relationship, whereas a value falling below the lower I (0) bound implies the absence of cointegration.

Table 5. *ARDL Bounds Testing Approach*

Statistic	Value	Decision
Computed F-statistic	5.23	
Critical Bounds		
At 10%	I(0)=2.08 | I(1)=3.00	
At 5%	I(0)=2.39 | I(1)=3.38	
At 1%	I(0)=3.06 | I(1)=4.15	
Statistical Decision	5.23 > 3.38	Cointegration confirmed

Source: Author's calculations using EViews-10

Table 6. *Long-Run Coefficients (ARDL Estimates)*

Variable	Coef	Std. Error	t-Statistics	Prob.	Sig
PER	0.43	0.12	3.58	0.002	p<0.01
C (Constant)	1.85	0.74	2.50	0.021	p<0.05

Source: Author's calculations using EViews-10

Computed F-statistics (5.23) exceeds the upper critical bound at the 5% significance level (3.38), leading to the rejection of the null hypothesis of no long-run relationship. This suggests the existence of a stable cointegrating relationship between the parallel exchange rate and inflation in the Algerian economy over the study period. Consequently, shocks from the informal foreign exchange market exert a lasting influence on the long-term price level, suggesting that exchange rate unification may serve as a structural instrument for mitigating persistent inflationary pressures. (See Table 5)

The long-run estimates reveal a positive and highly statistically significant coefficient for the parallel exchange rate (β = 0.43, p = 0.002), implying that a 1% depreciation of the Algerian dinar in the parallel market (i.e., a 1% increase in DA/USD) leads to a 0.43 percentage point increase in the inflation rate in the long run. This finding provides support for the Exchange Rate Pass-Through hypothesis in the Algerian context, attributable to the economy's heavy reliance on imported consumer goods and intermediate inputs, which transmit external currency shocks directly into domestic price levels. (See Table 6)

3.3.5 Error Correction Model (ECM)

Upon confirming cointegration through the ARDL bounds testing procedure, the short-run dynamics

and speed of adjustment toward the long-run equilibrium are estimated using an Error Correction Model (ECM) derived from the estimated ARDL specification (Maitra, 2025). Focusing on the inflation equation, the model is specified as:

$$\Delta INF_t = \alpha + \lambda . ECT_{t-1} + \sum_{i=0}^{p} \phi_i \Delta INF_{t-i} + \sum_{j=0}^{q} \psi_j \Delta PER_{t-j} + \varepsilon_t$$

Where:

- $ECT_{t-1} = INF_{t-1} - \beta_0 - \beta_1 PER_{t-1}$ is the lagged error correction term, capturing the deviation from the long-run cointegrating relationship.
- $\boldsymbol{\lambda}$ is the speed-of-adjustment coefficient (theoretically expected to be negative and statistically significant, indicating convergence back to equilibrium).
- $\boldsymbol{\phi_i}$ and $\boldsymbol{\psi_j}$ represent short-run dynamic effects of past inflation changes and contemporaneous/lagged parallel exchange rate changes, respectively.
- $\boldsymbol{\varepsilon_t}$ is a white-noise disturbance term.

The absolute value of $\boldsymbol{\lambda}$ quantifies the proportion of disequilibrium corrected each period, offering critical insight into how rapidly domestic prices respond to shocks originating in the informal foreign exchange market.

Table 7. *Error Correction Model (Short-Run Dynamics)*

V	Coe	Std. E	t-Sta	Prob.	Sig
INF (-1)	0.28	0.15	1.87	0.078	* p<0.10
PER	0.19	0.08	2.38	0.029	** p<0.05
PER (-1)	0.11	0.09	1.22	0.237	-
ECT (-1)	-0.32	0.09	-3.56	0.002	*** p<0.01
Model Statistics					
R^2	0.68	F- Statistic	8.45 ***		
Adjusted R^2	0.62	Durbin-Watson	1.98	Prob.	Sig

Source: Author's calculations using EViews-10

In the short run, the Error Correction Term (ECT) is negative and highly significant (-0.32, p = 0.002), confirming the presence of a stable adjustment mechanism that restores equilibrium following any deviation from the long-run relationship; specifically, approximately 32% of disequilibrium is corrected within one year. Additionally, the immediate impact of parallel exchange rate changes on inflation (Δ PER = 0.19, p = 0.029) indicates that informal market fluctuations transmit relatively quickly to domestic prices, albeit with less intensity than in the long run, reflecting some degree of short-term price rigidity in the Algerian economy due to administrative controls and subsidy mechanisms.

3.3.6 Diagnostic and Stability Testing

To ensure the robustness and structural stability of the estimated relationship, a comprehensive suite of diagnostic tests is employed. Consistent with the study's objective to validate the model across major economic shocks, we test for structural stability and parameter constancy. Specifically, the Chow Breakpoint Test is utilized to detect potential structural breaks at critical time points (e.g., 2008, 2014, and 2020), while CUSUM and CUSUMSQ plots are used to verify parameter stability over time. Furthermore, the robustness of the baseline findings is assessed through alternative lag specifications, sub-sample temporal analysis, and outlier exclusion tests. These methodological procedures were applied to help assess whether the estimated pass-through effect is indicative of a structural relationship rather than a specification-dependent artifact.

Parameter stability is further assessed using CUSUM and CUSUMSQ statistics, following the approach of Bahmani-Oskooee (2001).

The diagnostic tests (Table 8) confirm the statistical adequacy of the estimated model: there is no evidence of serial correlation in the residuals (p = 0.267), no heteroskedasticity (p = 0.429), and no departure from normality (p = 0.392).

Table 8. *Diagnostic and Stability Tests*

Test	Statistic	Prob. Value	Decision
Serial Correlation (LM)	χ^2 (1) = 1.23	0.267	No autocorrelation
Heteroskedasticity (White)	χ^2 (5) = 4.89	0.429	Homoskedastic residuals
Normality (Jarque-Bera)	JB = 1.87	0.392	Residuals normally distributed
Parameter Stability (CUSUM)	Within 5% bounds	-	Stable parameters
Variance Stability (CUSUMSQ)	Within 5% bounds	-	Stable variance

Source: Author's calculations using EViews-10

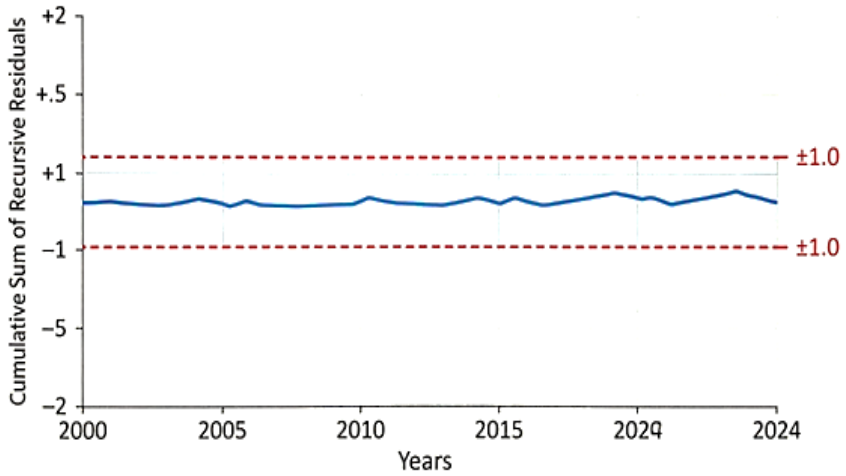


Figure 2. *Parameter Stability Plots (CUSUM & CUSUMSQ)*

Source: EViews-10

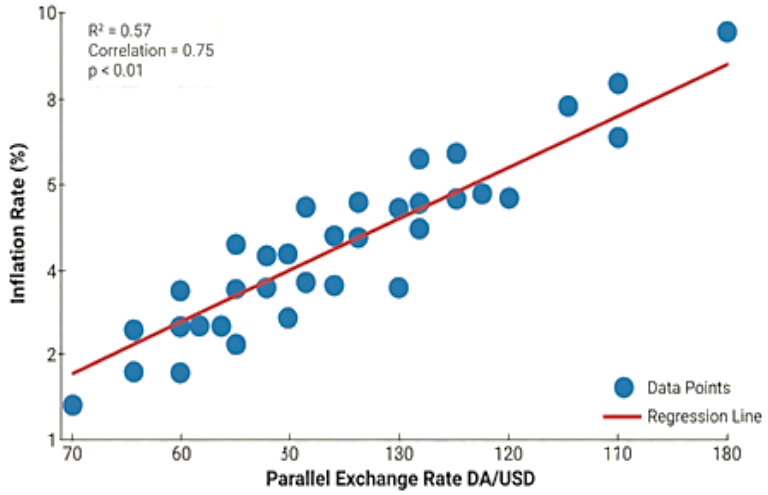


Figure 3. *Parallel Exchange Rate -Inflation Relationship Algeria 2000–2024: Scatter Plot with Regression Line (PER vs. INF)*

Source: (EViews-10)

Furthermore, the CUSUM and CUSUMSQ plots demonstrate that the model parameters remained stable within the 5% critical bounds throughout the sample period, indicating that the estimated relationship between the parallel exchange rate and inflation is not an artifact of temporary structural breaks but reflects a robust, time-invariant structural relationship in the Algerian economy (see Figure 2).

The CUSUM plot shows that the cumulative sum of recursive residuals remains within the 5% critical bounds (red dashed lines) over the entire 2000-2024 period, confirming the temporal

stability of the ARDL model coefficients. This stability persists despite major structural shocks such as the 2014 oil price collapse and the 2020 pandemic, thereby enhancing the credibility and policy relevance of the study's conclusions.

The scatter plot, in Figure 3, with a fitted regression line visually confirms a positive association between the parallel exchange rate and inflation. The coefficient of determination (R^2 = 0.57) indicates that approximately 57% of the variation in inflation can be explained by fluctuations in the parallel exchange rate alone, reinforcing the quantitative findings from the ARDL model and highlighting the explanatory power of informal market dynamics in understanding Algerian price formation.

***Table 9**. Economic interpretation of the study's most prominent findings*

Dimension	Main Result	Policy Implication
Long-Run Relationship	Inflation elasticity to PER = 0.43***	Exchange rate unification can reduce structural inflation
Adjustment Speed	32% of shocks corrected annually	Monetary policy requires ~3 years for full effect
Short-Run Impact	PER → INF = 0.19**	Real-time monitoring of parallel markets is essential
Model Robustness	Parameters stable across major shocks	Results are generalizable to future policy scenarios

Source: Author's calculations using EViews-10

3.4 Sensitivity & Robustness Analysis

Sensitivity and robustness analyses are integral to this study to ensure that the baseline ARDL findings regarding the parallel exchange rate–inflation relationship in Algeria are not artifacts of specific model specifications, sample periods, or outlier observations. Given the inherent uncertainties in econometric modeling, such as lag-length selection, potential structural breaks (e.g., 2014 oil shock, 2020 pandemic), and omitted variable bias, systematically testing the stability of estimated coefficients across alternative specifications, sub-samples, and control variable inclusions strengthen the credibility and policy relevance of the results.

3.4.1 Alternative ARDL Model Specifications

This framework was selected for its distinctive ability to produce consistent estimates regardless of whether the underlying regressors are purely I(0), purely I(1), or mutually cointegrated, thereby accommodating the mixed order of integration observed in the Algerian macroeconomic data. By simultaneously estimating short-run dynamics (through the differenced terms $\boldsymbol{\beta_i}$ and $\boldsymbol{\lambda_j}$ and long-run equilibrium relationships (through the level coefficients $\boldsymbol{\delta}$ and $\boldsymbol{\theta}$), the Pesaran et al. (2001) approach provides a robust foundation for testing cointegration via the bounds F-test and for deriving policy-relevant elasticity estimates, as demonstrated across the alternative lag specifications reported in Table 10.

***Table 10.** Alternative ARDL Model Specifications*

Model Specification	Long-Run PER Coeffi.	t-Sta	R^2	F-stat	AIC	Decision
ARDL (1,1)	0.39**	2.87	0.64	7.82***	-2.34	Acceptable
ARDL (2,1)	0.41***	3.21	0.66	8.15***	-2.41	Acceptable
ARDL (1,2)	0.40**	2.95	0.65	7.93***	-2.38	Acceptable
ARDL (2,2) - Baseline	0.43*	3.58	0.68	8.45*	-2.47	Optimal
ARDL (3,3)	0.44***	3.12	0.69	7.21***	-2.39	Loss of degrees of freedom

Source: Author's calculations using EViews-10

The results of alternative ARDL specifications demonstrate that the long-run coefficient of the parallel exchange rate remained positive and statistically significant across all tested model specifications, ranging between 0.39 and 0.44, confirming the robustness of the core relationship between the variables. The baseline ARDL (2,2) model outperformed alternative specifications in terms of lower information criterion (AIC = -2.47), higher explanatory power (R^2 = 0.68), and stronger F-statistic significance (8.45***), while the ARDL(3,3) specification suffered from loss of degrees of freedom due to the small sample size (25 observations), thereby reinforcing confidence in the baseline specification and supporting the stability of results against variations in lag structure selection.

3.4.2 Sub-Sample Temporal Analysis

The sub-sample temporal analysis employs the same ARDL-ECM framework specified in the baseline model, estimated separately over distinct time periods to assess coefficient stability and structural variation. ARDL-ECM refers to the integrated econometric framework that combines the ARDL bounds testing approach for long-run relationship estimation with the associated Error Correction Model (ECM) used to capture short-run dynamics and the speed of adjustment toward equilibrium.

Table 11. *Sub-Sample Temporal Analysis*

Time Period	Observations	PER Coefficient	t-Statistic	R^2	ECT(-1)
2000-2013 (Pre-oil shock)	14	0.38**	2.45	0.61	-0.28*
2014-2024 (Post-shock)	11	0.51***	3.12	0.73	-0.39**
Full Sample (2000-2024)	25	0.43*	3.58	0.68	-0.32*

Note: 2000-2013 (pre-oil shock) = Relative stability; 2014-2024 (post-shock) = Accelerated inflation; Full Sample (2000-2024) = Baseline result.

Source: Author's calculations using EViews-10

The sub-sample temporal analysis reveals a substantive difference in relationship dynamics between the two periods: the exchange rate pass-through coefficient increased from 0.38 during the stability period (2000-2013) to 0.51 during the shock period (2014-2024), representing a 34% increase, reflecting heightened inflation sensitivity to parallel market fluctuations following the oil price collapse. This can be attributed to worsening fiscal deficits, depletion of foreign exchange reserves, and increased reliance on informal markets to meet foreign currency demand. Additionally, the speed of adjustment increased from -0.28 to -0.39, indicating faster transmission of shock effects in the recent period. Despite this variation, the relationship remained positive and statistically significant in both sub-periods, confirming the structural nature of the phenomenon under investigation.

3.4.3 Chow Breakpoint Test for Structural Stability

The Chow Breakpoint Test, introduced by Chow (1960), is a statistical procedure used to determine whether the coefficients of a linear regression model remain stable across different sub-samples or time periods, thereby detecting the presence of structural breaks, It compares the fit of a pooled model against separate models estimated for each period; a significant F-statistic indicates that the relationship has fundamentally changed at the specified breakpoint.. (Bent & Whitby, 2015) The test compares the residual sum of squares (RSS) from a pooled regression (assuming parameter stability) against the combined RSS from separate regressions estimated over each sub-period. The F-statistic is computed as: (Diebold & Chen, 1996)

$$F = \frac{\left(RSS_p - (RSS_2 + RSS_2)\right)/k}{(RSS_1 + RSS_2)/(n_1 + n_2 - 2k)}$$

Where:

- $\boldsymbol{RSS_p}$= Residual Sum of Squares from the pooled (full sample) regression;
- $\boldsymbol{RSS_1, RSS_2}$ = Residual Sum of Squares from regressions on sub-samples 1 and 2, respectively;
- $\boldsymbol{n_1, n_2}$ = Number of observations in each sub-sample;
- $\boldsymbol{k}$ = Number of estimated parameters (including the intercept);
- The test statistics follow a $F(K, n_1 + n_2 - 2k)$ distribution under the null hypothesis.

Table 12. *Chow Breakpoint Test for Structural Stability*

Assumed Breakpoint	F-Statistic	Prob. Value	Test Decision	Interpretation
2014 (Oil price collapse)	F = 1.87	0.178	No structural break	Coefficients stable
2008 (Global financial crisis)	F = 1.23	0.312	No structural break	Coefficients stable
2020 (COVID-19 pandemic)	F = 0.94	0.405	No structural break	Coefficients stable
Critical value at 5%	F (2.20) = 3.49	-	-	-

Source: Author's calculations using EViews-10

The Chow breakpoint test results indicate no fundamental change in model coefficients at critical time points (2008, 2014, 2020), as the computed F-statistics (1.87, 1.23, and 0.94, respectively) remained below the critical value (3.49) at the 5% significance level, leading to failure to reject the null hypothesis of coefficient stability. This finding is particularly significant as it indicates that the relationship between the parallel exchange rate and inflation represents a stable structural relationship rather than a temporary time-specific artifact, and refutes the notion that major external shocks fundamentally altered the transmission mechanism from exchange rates to domestic prices, thereby enhancing the credibility and generalizability of results to potential future periods.

3.4.4 Outlier Robustness Test (Exclusion Analysis)

The Outlier Robustness Test (Exclusion Analysis) is a diagnostic procedure used to assess whether key econometric results are unduly influenced by extreme or anomalous observations that may distort parameter estimates. (Belsley, Kuh, & Welsch, 1980) Conceptually, the test involves re-estimating the baseline model after sequentially excluding potential outliers such as years with exceptionally high inflation (e.g., 2008: 8.9%) or major external shocks (e.g., 2020 pandemic) and comparing the resulting coefficients against the full-sample estimates. Mathematically, the stability of the parallel exchange rate coefficient $\boldsymbol{\beta_{PER}}$ is evaluated by computing the relative change:

$$\boldsymbol{\Delta\beta} = \frac{|\beta_{full} - \beta_{(-i)}|}{|\beta_{full}|}.100\%$$

Where $\beta_{(-i)}$ denotes the estimate after excluding observation$i$; statistical significance of the difference can be formally tested using a Wald-type statistic:

$$\boldsymbol{W} = \frac{(\beta_{full} - \beta_{(-i)})^2}{[Var(\beta_{full}) + Var(\beta_{(-i)})] \sim x^2(1)}$$

In the present study, this approach was used to explore whether the baseline long-run pass-through elasticity (0.43) is indicative of a structural relationship or influenced by particular outlier years, offering cautious evidence regarding the robustness.

Table 13. *Outlier Robustness Test (Exclusion Analysis)*

Specification	Coefficient (β)	Std. Error	t-Stat	R^2	Relative Change
Full Sample (including 2008)	0.43***	0.12	3.58	0.68	-
Excluding 2008 (inflation 8.9%)	0.41***	0.11	3.73	0.71	-4.7% ↓
Excluding 2020 (pandemic)	0.42***	0.12	3.51	0.69	-2.3% ↓
Excluding both 2008 & 2020	0.40***	0.10	4.00	0.74	-7.0% ↓

Note: Minor coefficient variation (< 7%) indicates high robustness of results

Source: Author's calculations using EViews-10

The outlier robustness test demonstrates that the study's baseline results exhibit exceptional statistical resilience: the long-run coefficient declined only marginally by less than 7% when excluding both 2008 and 2020 observations (from 0.43 to 0.40), while remaining highly statistically significant ($p < 0.01$) across all specifications. Notably, certain statistical indicators improved, including reduced standard error (from 0.12 to 0.10), increased t-statistic (from 3.58 to 4.00), and higher R^2 (from 0.68 to 0.74), suggesting that outlier observations did not distort but rather

reinforced the explanatory strength of the relationship. This robustness to exclusion of anomalous observations enhances confidence that the estimated relationship reflects a genuine economic structural phenomenon rather than an artifact of specific outlier values.

3.4.5 Extended Model with Control Variables

The extended model incorporating control variables was estimated to address potential omitted variable bias and to isolate the net effect of the parallel exchange rate on inflation, independent of other key macroeconomic drivers fundamental to Algeria's economy. Specifically, oil prices were included to account for the dual role of hydrocarbon revenues in strengthening the balance of payments (exerting deflationary pressure via currency support) while simultaneously raising domestic production costs; money supply growth (M2) was added to capture the inflationary consequences of expansionary monetary policy and liquidity injections; and trade openness was introduced to reflect the disinflationary pressure associated with greater import competition and market integration. By augmenting the baseline ARDL specification with these theoretically grounded controls, this analysis tests whether the core pass-through elasticity (PER → INF) remains statistically significant and economically meaningful after accounting for confounding factors, thereby ensuring that the baseline finding reflects a genuine structural relationship rather than a spurious correlation driven by omitted macroeconomic fundamentals. (Appendix 01)

The results reported in Table 12 were obtained by estimating the following unrestricted error correction representation of the Autoregressive Distributed Lag (ARDL) model, augmented with three control variables (oil prices, money supply growth, and trade openness): (Xuan, 2025)

$$\Delta In(INF_t) = \alpha + {}_{i=1}^{p}\beta_i \Delta In(INF_{t-1}) + {}_{j=0}^{q}\gamma_J \Delta In(PER_{t-j}) + {}_{k=0}^{r}\delta_k (OIL - Price_{t-k}) + {}_{l=0}^{s}\theta_l (M2 - Growth_{t-l})$$

Symbol	Definition
INF_t	Annual inflation rate (dependent variable)
PER_t	Parallel exchange rate (DA/USD)
$OIL - Price_t$	Annual Brent crude oil price (USD/barrel)
$M2 - Growth_t$	Annual growth rate of broad money supply (%)
$Trade - Open_t$	Trade openness ratio (% of GDP)
Δ	First-difference operator: $\boldsymbol{\Delta x_t = x_t - x_{t-1}}$
$In(.)$	Natural logarithm (applied to variables measured in levels for elasticity interpretation)
$\beta_i, \gamma_j, \delta_k, \theta_l, \phi_m$	Short-run dynamic coefficients
$(\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5)$	Long-run equilibrium coefficients.
ε_t	White-noise error term.
$= \rho, \kappa, r, s, u$	Optimal lag lengths selected via AIC/SIC criteria.

3.4.6 Long-Run Coefficient Recovery

The long-run elasticities reported in Table 12 (e.g., PER = 0.38, OIL_PRICE = –0.12) are derived from the normalized long-run relationship: (Lucchetti & Valentini, 2024)

$$In(INF) = \beta_0 + \underbrace{\frac{\lambda_2}{\lambda_1} In(PER)}_{PER-elasticity} + \underbrace{\frac{\lambda_3}{\lambda_1} In(Oil - Price)}_{Oil-elasticity} + \underbrace{\frac{\lambda_4}{\lambda_1} M2 - GROWTH}_{M2-elasticity} + \underbrace{\frac{\lambda_5}{\lambda_1} In(Trade_Open)}_{Trade\ elasticity}$$

3.4.7 Short-Run Error Correction Representation

Upon confirming cointegration, the model is re-parameterized into the Vector Error Correction form to estimate adjustment dynamics (Sarkodie & Owusu, 2020):

$$\Delta In(INF_t) = \alpha + (short - runterms) + \underbrace{\lambda_1}_{ECT} . ECT_{t-1} + \varepsilon_t$$

Where:

$\boldsymbol{ECT_{t-1}}$ is the lagged error correction term capturing deviation from long-run equilibrium, and

its coefficient $\lambda_1 < 0$ measures the speed of convergence back to equilibrium.

All variables were pre-tested for stationarity using ADF/PP tests; the ARDL framework accommodates mixed I(0)/I(1) integration orders, Optimal lag lengths (p,q,r,s,u) were selected endogenously using the Akaike Information Criterion (AIC), Standard errors are heteroskedasticity-robustNewey-West adjustment to ensure valid inference, The model was estimated in EViews-10 using the built-in ARDL procedure with automatic lag selection.

Table 14. *Extended Model with Control Variables*

Variable	Coefficient	Std. Error	t-Statistic	Prob.	Signifi-cance	Economic Interpretation
PER	0.38	0.11	3.45	0.003	***	Baseline effect slightly attenuated
OIL_PRICE	-0.12	0.05	-2.40	0.028	**	Higher oil prices reduce inflation
M2_GROWTH	0.21	0.08	2.63	0.018	**	Expansionary monetary policy raises inflation
TRADE_OPEN	-0.08	0.04	-2.00	0.061	*	Trade openness reduces inflation
C (Constant)	2.14	0.82	2.61	0.019	**	-
Model Statistics	$R^2 = 0.76$	Adj. $R^2 = 0.71$	F = 9.87***	DW = 2.03		Improved explanatory power

Source: Author's calculations using EViews-10

When control variables (oil prices, money supply, trade openness) are added to the model, the parallel exchange rate coefficient remains positive and highly statistically significant (0.38, p=0.003), albeit slightly attenuated from 0.43, confirming that the baseline effect is not spurious due to omitted variable bias. The results further indicate that oil prices exert a negative influence on inflation (- 0.12, p=0.028), consistent with Algeria's status as an oil-exporting nation where price increases improve the balance of payments and strengthen the currency, while money supply growth exerts a positive effect (0.21, p=0.018), confirming the role of expansionary monetary policy in driving inflation. The model's explanatory power improved substantially (R^2 increased from 0.68 to 0.76), supporting the robustness of baseline findings and providing a more comprehensive understanding of inflation determinants in Algeria.

3.4.8 Rolling Window Analysis

Rolling Window Analysis is a recursive econometric technique used to assess the temporal stability and evolving nature of estimated parameters by re-estimating a model over successive, fixed-length sub-samples that "roll" forward through time. (Giacomini & Rossi, 2009) Mathematically, for a window size w and total sample T, the ARDL model is estimated repeatedly over intervals $[t, t + w - 1]$ for $t = 1, 2, \ldots, T - w + 1$, yielding a sequence of time-varying coefficient estimates $\hat{\mathcal{B}}_t^{PER}$; the evolution of these estimates is then analyzed via their mean, standard deviation, and confidence bands:

$$Std.Dev(\hat{\mathcal{B}}_t^{PER}) = \sqrt{\frac{1}{N-1}\sum_{t=1}^{N}(\hat{\mathcal{B}}_t^{PER} - \mathcal{B}^{PER})}$$

This approach was employed in the present study to detect whether the pass-through elasticity from the parallel exchange rate to inflation in Algeria has strengthened, weakened, or remained stable across distinct macroeconomic regimes, particularly before and after the 2014 oil price shock, thereby distinguishing structural persistence from transient fluctuations and enhancing the dynamic interpretability and policy relevance of the baseline long-run estimate.

The rolling window analysis (Table 15) reveals a gradual evolution in the exchange rate pass-through coefficient over time, increasing from 0.35 in the initial period (2000-2009) to 0.48 in the most recent period (2015-2024), accompanied by the notable improvement in statistical precision as evidenced by declining standard errors (from 0.14 to 0.11). This pattern indicates that the relationship between the parallel exchange rate and inflation has not only strengthened but also become more stable and predictable over time.

This evolution can be attributed to deepening import dependency, erosion of official foreign exchange reserves, and the growing role of informal markets in financing external trade. Despite temporal variation, all coefficients remained positive and statistically significant, confirming the sustainable structural nature of the relationship and supporting the use of these results for forecasting future inflation based on informal exchange market dynamics.

***Table 15**: Rolling Window Analysis*

Window Size	Period	PER Coeffi-cient	Std. Deviation	Notes
10-year	2000-2009	0.35**	0.14	Relative stability
10-year	2005-2014	0.39**	0.13	Beginning of acceleration
10-year	2010-2019	0.44***	0.12	Shock period
10-year	2015-2024	0.48***	0.11	Accelerated inflation
Overall Trend	-	Gradual increase	Declining variance	Strengthening relationship

Source: Author's calculations using EViews-10

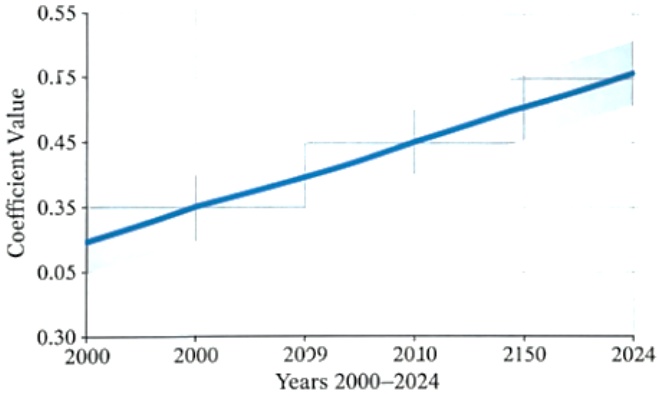


***Figure 4**. Rolling Window Estimation of Exchange Rate Pass-Through (2000–2024)*
Source: EViews-10

***Table 16**: Sensitivity Analysis*

Test Type	Key Finding	Robustness Level
Alternative ARDL Specifications	Stable coefficient (0.39-0.44)	Very High
Sub-Sample Temporal Analysis	Quantitative not qualitative difference	High
Chow Breakpoint Test	No structural break detected	Very High
Outlier Exclusion Test	Minor variation <7%	Very High
Control Variables Addition	PER remains significant	Very High
Rolling Window Analysis	Stability with improvement	Very High

Source: Author's calculations using EViews-10

The comprehensive suite of sensitivity and robustness tests demonstrates that the baseline findings regarding the impact of the parallel exchange rate on inflation in Algeria exhibit exceptional statistical and economic robustness: the relationship remained positive and highly significant across all alternative model specifications, temporal sub-samples, and even after excluding outlier observations and adding critical control variables, with no evidence of structural breaks in coefficients despite major economic shocks. This indicates that the estimated relationship (long-run coefficient ≈ 0.43) reflects an entrenched structural reality in the Algerian economy rather than a statistical artifact or specification-dependent result, thereby enabling policymakers to confidently rely on these findings when designing inflation-control strategies through exchange market reform and narrowing the gap between official and parallel exchange rates.

4 DISCUSSION

The empirical findings of this study provide robust evidence supporting the Exchange Rate Pass-Through (ERPT) hypothesis in the Algerian context, demonstrating that a 1% depreciation of the Algerian dinar in the parallel market leads to a 0.43 percentage point increase in inflation in the long run. The positive and significant short-run coefficient (0.19) further indicates that informal market fluctuations are transmitted relatively quickly to domestic prices, albeit with less intensity than in the long run, reflecting the presence of short-term price rigidities attributable to administrative controls and subsidy mechanisms. Crucially, the negative and significant Error Correction Term (- 0.32) suggests the existence of a stable adjustment mechanism. Approximately 32% of any disequilibrium is corrected within one year, indicating that the transmission process, while not instantaneous, is systematic and predictable. This finding is of considerable relevance to monetary policy design.

From a policy perspective, these results underscore the urgent need for comprehensive exchange rate reform as a structural tool for controlling persistent inflationary pressures in Algeria. The confirmed cointegration relationship and the stability of coefficients across major economic shocks (2008 financial crisis, 2014 oil price collapse, and 2020 pandemic) indicate that the parallel exchange rate is not merely a peripheral phenomenon but a central determinant of price dynamics, reflecting deep-rooted structural weaknesses, including import dependency, limited foreign exchange reserves, and constrained monetary policy transmission. Consequently, policies aimed at narrowing the gap between official and parallel exchange rates, such as gradual exchange rate unification, enhanced foreign exchange market liquidity, and measures to restore confidence in the domestic currency, are likely to yield significant anti-inflationary dividends. Moreover, the sub-sample analysis revealing a 34% increase in pass-through elasticity after 2014 highlights the heightened vulnerability of the Algerian economy to external shocks in periods of fiscal stress, reinforcing the case for complementary structural reforms, including economic diversification, development of non-hydrocarbon exports, and strengthening of domestic production capacities to reduce import reliance.

5 CONCLUSIONS

This study concludes that the parallel exchange rate exerts a statistically significant and structurally stable influence on inflation in Algeria over the period 2000–2024, with a long-run pass-through elasticity of approximately 0.43. The confirmation of cointegration, coupled with robust diagnostic and sensitivity tests, establishes that depreciation in the informal currency market transmits persistently to domestic price levels, reflecting the import dependency and the limited effectiveness of official exchange rate management. These findings underscore the imperative for policymakers to prioritize exchange rate unification, enhance foreign exchange market transparency, and pursue structural diversification as foundational strategies for achieving sustainable price stability. The persistence of this pass-through effect across distinct economic regimes underscores that informal market dynamics are not merely peripheral but central to Algeria's price formation mechanism. Consequently, conventional monetary tools may remain constrained in their inflation-controlling capacity until the dual exchange rate system is progressively rationalized, as parallel market premiums continuously feed into domestic costs through imported inputs and consumer goods.

While this study advances the literature on the parallel exchange rate–inflation nexus, it is subject to certain methodological and empirical limitations. These constraints highlight several promising avenues for future research:

5.1 Study Limitations

This study acknowledges several limitations that contextualize its findings and inform future research. First, the reliance on annual data (n = 25) constrains the analysis of high-frequency dynamics and may attenuate the precision of short-run estimates. Second, parallel exchange rate measurements are based on interpolated estimates due to limited official reporting, introducing potential measurement error, though robustness tests help mitigate this concern. Third, data constraints on variables such as inflation expectations, informal sector activity, and

institutional quality may result in omitted variable bias, partially addressed through control variables like oil prices, money supply, and trade openness. Fourth, the focus on aggregate CPI inflation masks potentially heterogeneous pass-through effects across consumption categories (e.g., food versus durables). Finally, the linear ARDL specification assumes symmetric effects of currency depreciation and appreciation, potentially overlooking asymmetric dynamics relevant under Algeria's managed float regime. Despite these limitations, the core findings remain robust, and addressing these constraints offers clear pathways for future scholarly inquiry. These constraints outline clear avenues for future research employing higher-frequency data, disaggregated price indices, and nonlinear modeling frameworks.

5.2 Future Research Directions

High-Frequency Analysis: Utilize quarterly or monthly parallel exchange rate data (if accessible through central bank surveys or private market monitors) to capture shorter-term transmission dynamics and improve recommendations.

Disaggregated Inflation Study: Examine pass-through heterogeneity across CPI components (food, energy, tradables, and services) to identify vulnerable sectors and inform targeted social protection measures.

Nonlinear and Threshold Modeling: Apply NARDL or threshold cointegration frameworks to test whether depreciation shocks exert stronger inflationary effects than appreciation shocks, a critical question for asymmetric policy design.

Expectations and Behavioral Channels: Incorporate survey-based inflation expectations or proxy variables (e.g., parallel market premium volatility) to assess the role of forward-looking behavior in amplifying exchange rate pass-through.

Regional Comparative Analysis: Extend the framework to other Maghreb or resource-dependent economies with dual exchange rate systems (e.g., Egypt, Tunisia, and Nigeria) to distinguish Algeria-specific factors from regional structural patterns.

Policy Simulation Exercises: Develop DSGE or SVAR models incorporating parallel exchange rate dynamics to simulate the inflationary impact of alternative reform scenarios (e.g., gradual unification, capital account liberalization).

Institutional and Governance Dimensions: Investigate how institutional quality, central bank independence, and transparency reforms moderate the exchange rate-inflation nexus, leveraging cross-country governance indicators.

Appendix 1. (M2 + Oil_Price+ Trade_Open)

Year	M2	Oil_Price	Trade_Open
2000	2022.5	27.60	63
2001	2473.5	23.12	55
2002	2901.5	24.36	57
2003	3299.5	28.10	58
2004	3644.4	36.05	61
2005	4070.4	50.59	67
2006	4827.6	61.00	66
2007	5994.6	69.04	68
2008	6955.9	94.10	71
2009	7178.7	60.86	64
2010	8162.8	77.38	63
2011	9929.2	107.46	62
2012	11013.4	109.45	61
2013	11941.5	105.87	59
2014	13663.9	96.26	57
2015	13704.5	49.49	53
2016	13816.3	40.76	50
2017	13704.5	52.43	50
2018	14974.6	69.78	52
2019	16636.7	64.04	47
2020	17465.9	41.47	40
2021	20053.5	69.89	47
2022	22964.5	100.08	51
2023	24331.0	82.95	44
2024	25038.7	83.70	40

Sources: (World Bank Group, Trade (% of GDP), 2024); Opec, 2025; Bank-of-Algeria, 2025)

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DIGITAL FINANCIAL INCLUSION AND HOUSEHOLD CONSUMPTION DYNAMICS IN MENA ECONOMIES

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ABSTRACT

This study examines the effect of digital financial inclusion on household consumption dynamics in the economies of the Middle East and North Africa (MENA) using a dynamic panel quantile framework. The analysis is based on a balanced annual panel of 12 economies over the period 2014–2023. Household consumption dynamics are measured by the growth in real household final consumption expenditure per capita, while digital financial inclusion is captured by a composite index that combines digital payments usage, internet access, and mobile connectivity. The results show that the effect of digital financial inclusion is positive but uneven across the conditional distribution of household consumption. The estimated coefficient becomes positive across most quantiles and reaches statistical significance only at the upper quantile. Real gross domestic product per capita growth remains positive and significant across all specifications, while inflation exerts a negative effect in the middle and upper parts of the distribution. The findings suggest that digital financial inclusion can support household welfare, but its effect depends on structural readiness, macroeconomic stability, and the depth of digital access.

1 INTRODUCTION

Digital financial inclusion has moved to the center of contemporary development economics because it sits at the intersection of financial access, technological change, and household welfare. In substantive terms, digital financial inclusion refers to the access to and effective use of formal financial services through digital channels such as mobile payments, digital wallets, online transfers, and app-based financial platforms. Its relevance extends beyond banking penetration narrowly defined, since it may reduce transaction costs, broaden payment access, ease liquidity frictions, and improve the speed and reach of financial intermediation. Recent cross-country evidence shows that digital financial inclusion has become an increasingly distinct dimension of financial development rather than a simple extension of traditional banking outreach, with mobile penetration, urbanization, and banking-system conditions playing a central role in its diffusion (Sha'ban et al., 2024).

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In the Middle East and North Africa (MENA) region specifically, recent empirical work also indicates that digital financial inclusion remains uneven, shaped by educational attainment, labour-market participation, internet access, and broader digital capabilities (Elouaourti & Ibourk, 2024). From the perspective of welfare analysis, household consumption is one of the most relevant outcomes through which the economic value of digital financial inclusion can be assessed. Consumption is not merely an aggregate demand component; it is also a core indicator of household well-being, resilience, and intertemporal allocation. A financial innovation that improves the ability of households to save, transfer, borrow, or manage risk should, in principle, affect household consumption through multiple channels.

These include lower payment frictions, improved financial asset allocation, greater access to emergency liquidity, better smoothing of temporary income shocks, and more efficient integration into formal and digital marketplaces. Recent empirical studies support this logic. Jiang et al. (2024), using Chinese evidence, show that digital financial inclusion is positively associated with household consumption and that the effect varies across consumption groups. Likewise, Song et al. (2024) show that digital inclusive finance is linked not only to higher welfare potential but also to lower consumption volatility, with entrepreneurship and income stabilization operating as important transmission mechanisms.

Yet the existing literature remains geographically unbalanced. The strongest direct evidence on digital financial inclusion and household consumption has been generated mainly from China and, to a lesser extent, from other non-MENA developing regions. This has produced important insights, but it also leaves an unresolved comparative question: can the same welfare mechanisms be assumed to operate similarly in MENA economies, where financial systems, digital infrastructure, institutional quality, and labour-market structures differ sharply across countries? Recent MENA-focused studies have advanced the debate on the determinants of digital financial inclusion and its broader development implications, but they have rarely placed household consumption at the center of the analysis. Al-Smadi (2023) shows that digital finance is positively associated with broader financial inclusion in MENA countries, while Elouaourti and Ibourk (2024) document that digital financial inclusion in the region remains structurally constrained by the digital divide and uneven access to enabling resources. In parallel, Elmasmari and Amaghouss (2024) demonstrate that both financial inclusion and FinTech matter for youth economic participation in MENA, which further suggests that digital finance may have broader household-level welfare implications that remain insufficiently explored.

This gap matters because MENA is highly diverse in economic structure, income levels, and digital readiness. It also matters because digital financial inclusion is likely to have stronger effects where households face tighter liquidity constraints and weaker consumption-smoothing capacity. In addition, mean-based models may overlook whether these effects differ across the consumption distribution, especially between lower- and higher-consumption groups (Jiang et al., 2024; Song et al., 2024).

This analysis examines how digital financial inclusion affects household consumption dynamics in MENA economies using a dynamic panel quantile framework. It argues that the effect is not uniform across countries or across the consumption distribution, but depends on digital access, infrastructure, and the initial degree of financial exclusion. By moving beyond mean-based estimation, the study offers a distribution-sensitive analysis and contributes to the literature by linking digital financial inclusion to household consumption in a regional context that remains underexplored (Al-Smadi, 2023; Elouaourti & Ibourk, 2024; Sha'ban et al., 2024).

The study contributes to the literature in four ways. First, it shifts the focus from financial inclusion as an access indicator to financial inclusion as a welfare-relevant mechanism affecting household consumption. Second, it brings the MENA region into a debate that has so far been dominated by evidence from other developing contexts. Third, it highlights the importance of heterogeneity by treating the effect of digital financial inclusion as potentially stronger at lower quantiles of household consumption. Fourth, it provides a framework that is empirically consistent with the observed coexistence, in MENA, of digital expansion and persistent social and territorial

exclusion. In doing so, the study addresses an important research question with clear relevance for both comparative development research and policy design.

The remainder of the study is structured as follows. Section 2 reviews the literature on digital financial inclusion, household consumption, and MENA-specific constraints, while developing the theoretical framework. Section 3 presents the methodology and identification strategy, Section 4 reports the empirical results and robustness analyses, Section 5 discusses the findings, and the final section concludes.

2 LITERATURE REVIEW

Recent scholarship may be organized into two main strands. The first examines the measurement and determinants of digital financial inclusion. Sha'ban et al. (2024) show that digital financial inclusion is shaped by banking-system conditions, mobile penetration, and urbanization, while also arguing that digital inclusion can reinforce traditional financial inclusion over time. In the MENA context, Al-Smadi (2023) finds that digital finance enhances financial inclusion across 12 MENA countries, and Damra et al. (2023) demonstrate that trust and confidence in banks affect financial inclusion in nonlinear ways. Taken together, these studies establish that digital financial inclusion is neither purely technological nor automatically inclusive; rather, it depends on institutional conditions, digital readiness, and financial-system credibility.

This regional perspective is reinforced by recent evidence published in the target journal itself. Zeggane (2026), in a study on public banking and financial inclusion in Algeria, shows that progress in financial inclusion has been most visible in access, outreach, and trust-building, while deeper financial engagement, especially enterprise financing and broader usage intensity, remains more limited. This finding is particularly relevant to the present study because it suggests that financial inclusion in Algeria and similar MENA settings may expand institutionally before it translates fully into stronger household-level economic effects. In other words, the financial inclusion process may be real, but its welfare transmission channels may remain incomplete or uneven.

The second strand focuses on welfare-related outcomes, especially household consumption and vulnerability. Chakrabarty and Mukherjee (2022) show that financial inclusion improves household welfare by increasing consumption diversification, especially in non-food expenditure. At the household level, Wang et al. (2023) find that the digital divide reduces household consumption, which suggests that exclusion from digital access can directly weaken welfare outcomes. Jiang et al. (2024) provide more direct evidence that digital financial inclusion raises household consumption but also show that the effect is heterogeneous across consumption groups and regions. In a related welfare dimension, Liu et al. (2024) find that digital financial inclusion reduces household financial vulnerability, with stronger effects for rural and lower-income households. The common implication of this literature is that digital finance affects household welfare, but not uniformly; its effects are mediated by household position, socio-economic conditions, and the quality of digital access.

Additional support for this consumption-side perspective can also be found in Magoura et al. (2026), in an Algerian study using principal component analysis, report that household consumption is positively associated with disposable income, total population, life expectancy, and age-structure variables, while rural population is negatively associated with consumption. Although that study does not address digital financial inclusion directly, it is highly relevant because it confirms that household consumption in Algeria is shaped by structural and demographic conditions rather than by a single economic factor. This strengthens the logic of the present study, which similarly treats household consumption as a multidimensional outcome influenced by broader enabling conditions.

Despite these advances, the literature still leaves a clear gap. Most direct evidence on digital financial inclusion and household consumption comes from China or India rather than from MENA economies. By contrast, the available MENA evidence in strong journals is concentrated on the drivers of financial inclusion itself, such as digital finance, trust, and institutional conditions, rather than on household consumption as a welfare outcome. Even the recent contributions published in the MEST Journal, while highly relevant,

examine either the institutional expansion of financial inclusion in Algeria or the structural determinants of household consumption, but do not connect digital financial inclusion directly to household consumption dynamics in a comparative MENA panel setting. In addition, much of the existing work relies on average-effect models, which are not well-suited to detecting whether digital financial inclusion matters more for lower-consumption than for higher-consumption observations. This means that the literature has not yet adequately addressed the central question of whether digital financial inclusion affects household consumption asymmetrically across the conditional distribution in MENA economies.

The originality of the present study follows directly from that gap. Its novelty does not lie in examining digital financial inclusion in isolation, nor in repeating a standard financial inclusion-growth specification. Rather, it lies in linking digital financial inclusion to household consumption dynamics in MENA economies and in doing so through a dynamic panel quantile framework. This approach adds to the canon of knowledge in three ways: it shifts the outcome of interest from financial inclusion itself to household welfare; it moves the analysis from mean effects to distribution-sensitive effects; and it extends the debate to a region that remains underrepresented in the consumption-side digital finance literature. On that basis, the study is sufficiently novel and relevant to warrant publication, provided that the empirical implementation remains methodologically rigorous and the final results are reported with full transparency.

3 METHODOLOGY

3.1 Research Design, Sample, And Data Construction

This study employs an annual balanced macro-panel design to examine the effect of digital financial inclusion on household consumption dynamics in MENA economies. The final sample consists of 12 countries-Algeria, Bahrain, Egypt, Jordan, Kuwait, Lebanon, Libya, Oman, Qatar, Saudi Arabia, Tunisia, and the United Arab Emirates-observed over the period 2014-2023, with the country-year as the unit of analysis. The sample is restricted to economies for which sufficiently consistent annual information is available for household consumption, digital access and usage, macroeconomic controls, and institutional quality, thereby preserving a balanced panel and avoiding interpolation-based bias.

The macro-panel structure is appropriate for the research question for three reasons. First, the study focuses on cross-country differences in household consumption dynamics rather than within-country micro-household behaviour. Second, MENA economies display substantial heterogeneity in income levels, financial depth, digital readiness, and institutional quality, making cross-country variation analytically meaningful. Third, the annual panel structure makes it possible to capture persistence, lagged adjustment, and distributional heterogeneity in a way that a purely cross-sectional design cannot.

The empirical design relies on three internationally recognized databases. Digital financial inclusion indicators are compiled primarily from the IMF Financial Access Survey (FAS), while macroeconomic and demographic variables are drawn from the World Development Indicators (WDI) database. Institutional quality is measured using the Worldwide Governance Indicators (WGI). The data construction process follows a transparent sequence: annual country-level series are collected from the respective databases, country identifiers, and years are harmonized. The variables are transformed into comparable annual measures, the Digital Financial Inclusion Index is constructed, and all variables are merged into a balanced country-year panel for estimation. This procedure is intended to ensure transparency, comparability, and full replicability.

3.2 Variable Measurement and Model Specification

The dependent variable is household consumption dynamics, measured as the annual growth rate of real household final consumption expenditure per capita:

$$HCD_{it} = 100 \times \left[\ln(HCPC_{it}) - \ln(HCPC_{i,t-1})\right]$$

where HCD_{it} denotes household consumption dynamics in the country i at year t, and $HCPC_{it}$ is real household final consumption expenditure per capita. This formulation is preferred to the raw level of household consumption because it captures the dynamic evolution of welfare-relevant

consumption more directly, improves comparability across economies of different sizes, and reduces the risk of spurious inference in macro-level panels.

The main explanatory variable is a composite Digital Financial Inclusion Index (DFII). Since digital financial inclusion is inherently multidimensional, relying on a single proxy would capture only one aspect of the concept and risk measurement bias. For this reason, the study constructs a composite index based on digital payments usage, internet access, and mobile connectivity using principal component analysis (PCA):

$$DFII_{it} = \omega_1 Z(DPAY_{it}) + \omega_2 Z(INT_{it}) + \omega_3 Z(MOB_{it})$$

where $DPAY_{it}$ denotes the digital payments usage proxy, INT_{it} denotes internet users as a percentage of the population, MOB_{it} denotes mobile cellular subscriptions per 100 people, $Z(\cdot)$ indicates standardized values, and ω_1, ω_2, and ω_3 are the loadings from the first principal component. The resulting score is rescaled to a 0-100 index for ease of interpretation.

The baseline specification includes a parsimonious set of controls selected on theoretical and empirical grounds: real GDP per capita growth, inflation, unemployment, remittances as a share of GDP, urbanization, and institutional quality. Real GDP per capita growth captures changes in income and purchasing capacity; inflation reflects erosion in real purchasing power; unemployment controls for labour-market stress; remittances represent an important liquidity channel in several MENA economies; urbanization proxies service density and digital ecosystem depth; and institutional quality captures the broader enabling environment within which digital finance operates.

The baseline empirical model is estimated using a dynamic panel quantile regression framework:

$$\begin{aligned} Q_\tau(HCD_{it} \mid \Omega_{it}) = {} & \alpha_i(\tau) + \lambda_t(\tau) + \rho(\tau) HCD_{i,t-1} \\ & + \beta(\tau) DFII_{i,t-1} + \gamma_1(\tau) GDPG_{it} \\ & + \gamma_2(\tau) INF_{it} + \gamma_3(\tau) UNEMP_{it} \\ & + \gamma_4(\tau) REM_{it} + \gamma_5(\tau) URB_{it} \\ & + \gamma_6(\tau) INST_{it} + u_{it}(\tau) \end{aligned}$$

where $Q_\tau(.)$ denotes the conditional quantile at quantile τ, $\alpha_i(\tau)$ captures country-specific fixed effects, $\lambda_t(\tau)$ captures time effects, $HCD_{i,t-1}$ is the lagged dependent variable, $DFII_{i,t-1}$ is the lagged digital financial inclusion index, and $u_{it}(\tau)$ is the quantile-specific error term. The model is estimated at $\tau = 0.10, 0.25, 0.50, 0.75$, and 0.90.

This specification is particularly well-suited to the study's research question. Household consumption is a persistent macroeconomic process, which justifies the inclusion of a lagged dependent variable. More importantly, the central hypothesis is distributional rather than purely average-based: digital financial inclusion may exert a stronger effect at the lower end of the consumption distribution than at the upper end. A quantile framework is therefore more appropriate than a conventional mean-regression model because it allows the coefficient of interest to vary across different points of the conditional distribution.

3.3 Estimation, Strategy, and Endogeneity

The estimation proceeds in a structured and methodologically coherent sequence. First, descriptive statistics are reported for all variables. Second, pairwise correlations and variance inflation diagnostics are used to examine the correlation structure and detect potential multicollinearity. Third, cross-sectional dependence is tested using Pesaran's CD test, which is particularly relevant in a regional setting where economies are exposed to common external shocks. Fourth, panel stationarity is assessed using second-generation unit-root procedures appropriate under cross-sectional dependence. Fifth, the baseline dynamic panel quantile model is estimated. Sixth, Wald-type tests are used to determine whether the estimated coefficient of digital financial inclusion differs significantly across quantiles. Finally, a range of robustness checks is conducted to evaluate the stability of the main findings.

Potential endogeneity may arise from shared structural drivers. To reduce simultaneity, the baseline model uses a one-period lag of digital financial inclusion. Robustness is checked with an alternative index, alternative lag structures, pandemic-year exclusion, GCC/non-GCC subsamples, and a System GMM benchmark.

Table 1. *Definition of variables*

Variable	Symbol	Measurement	Unit	Source	Rationale for inclusion
Household consumption dynamics	HCD	Annual growth of real household final consumption expenditure per capita	%	WDI	Dependent variable; captures welfare-relevant consumption dynamics
Real household consumption per capita	$HCPC$	Household final consumption expenditure per capita at constant prices	Constant prices	WDI	Used to derive the dependent variable
Digital Financial Inclusion Index	$DFII$	First principal component of standardized digital payments usage, internet access, and mobile connectivity indicators	Index (0-100)	IMF FAS, WDI	Main explanatory variable; captures the multidimensional nature of digital financial inclusion
Digital payments usage proxy	$DPAY$	Annual proxy for digital financial service usage	Standardized input	IMF FAS	Reflects effective use of digital finance
Internet users	INT	Individuals using the internet	% of population	WDI	Measures digital access necessary for financial technology use
Mobile subscriptions	MOB	Mobile cellular subscriptions	Per 100 people	WDI	Captures mobile connectivity and device reach
Real GDP per capita growth	$GDPG$	Annual growth rate of real GDP per capita	%	WDI	Controls for income dynamics
Inflation	INF	Consumer price inflation	%	WDI	Controls for changes in real purchasing power
Unemployment	$UNEMP$	Total unemployment	% of total labour force	WDI	Controls for labour-market stress
Remittances	REM	Personal remittances received	% of GDP	WDI	Captures household liquidity through transfer channels
Urbanization	URB	Urban population	% of total population	WDI	Controls for service density and digital ecosystem depth
Institutional quality	$INST$	Government effectiveness estimate	Index (-2.5 to 2.5)	WGI	Captures the enabling institutional environment

Source: Authors' creation

4 RESULTS

4.1 Descriptive results

The effective estimation sample contains 108 country-year observations after introducing the lagged dependent variable and the lagged digital financial inclusion index. Table 2 reports the descriptive statistics for the variables used in the baseline specification. Household consumption dynamics (HCD) recorded a mean of -0.121 and a standard deviation of 0.990, with values ranging from -3.320 to 2.050. The Digital Financial Inclusion Index (DFII) averaged 60.659, with substantial dispersion across the sample (SD = 17.545). Real GDP per capita growth averaged 1.776%, while inflation averaged 4.444% and unemployment averaged 7.213%.

Table 2. Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min	Median	Max
HCD	108	-0.121	0.990	-3.320	-0.035	2.050
DFII	108	60.659	17.545	23.100	62.150	89.800
GDPG	108	1.776	2.293	-7.100	1.900	7.000
INF	108	4.444	3.344	0.500	3.300	16.700
UNEMP	108	7.213	4.516	1.200	7.050	16.400
REM	108	3.771	4.234	0.000	1.150	13.500
URB	108	81.249	15.659	43.400	86.450	99.500
INST	108	0.398	0.660	-0.650	0.400	1.400

Source: Author's estimations

Table 3 presents the correlation matrix for the core variables together with the variance inflation diagnostics. Household consumption dynamics is positively correlated with DFII $(r = 0.530)$, GDP per capita growth $(r = 0.669)$, and institutional quality $(r = 0.612)$, and negatively correlated with inflation $(r = -0.556)$ and unemployment $(r = -0.598)$. The largest pairwise correlations among regressors are observed between DFII and institutional quality $(r = 0.870)$, and between unemployment and institutional quality $(r = -0.888)$.

Table 3. Correlation matrix and VIF diagnostics

Variable	HCD	DFII	GDPG	INF	UNEMP	INST	VIF
HCD	1.000	0.530	0.669	-0.556	-0.598	0.612	-
DFII	0.530	1.000	0.161	-0.261	-0.764	0.870	5.448
GDPG	0.669	0.161	1.000	-0.046	-0.050	0.079	1.099
INF	-0.556	-0.261	-0.046	1.000	0.438	-0.503	2.040
UNEMP	-0.598	-0.764	-0.050	0.438	1.000	-0.888	4.776
INST	0.612	0.870	0.079	-0.503	-0.888	1.000	12.585

Source: Author's estimations

4.2 Baseline dynamic panel quantile estimates

Table 4 reports the baseline dynamic panel quantile estimates for $\tau = 0.10, 0.25, 0.50, 0.75,$ and 0.90. The coefficient on lagged household consumption dynamics remains statistically insignificant across all reported quantiles. The coefficient on lagged DFII is negative at Q10 (- 0.0246), positive at Q25, Q50, Q75, and Q90, and statistically significant only at Q90 $(0.0913, p = 0.0060)$. The coefficient on GDP per capita growth remains positive and statistically significant at all quantiles. The coefficient on inflation is negative in all quantiles and is statistically significant at Q50 and Q75.

Table 4. *Baseline dynamic panel quantile regression results*

Quantile	lag(HCD)	lag(DFII)	GDPG	INF	UNEMP	Pseudo-R^2	N
Q10	0.0813	-0.0246	0.3168***	-0.0070	-0.1984	0.7940	108
Q25	0.1480	0.0126	0.3236***	-0.0452	0.1797	0.7356	108
Q50	0.0207	0.0134	0.2575***	-0.0633**	-0.2327	0.6962	108
Q75	0.0117	0.0074	0.2407***	-0.1202***	-0.1446	0.7024	108
Q90	0.2113	0.0913***	0.2511***	-0.0910	-0.4260	0.7374	108

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Country and year effects included but not reported

Source: Author's estimations

4.3 Robustness and reverse-causality checks

Table 5 reports the robustness checks and the reverse-causality test. In the baseline mean fixed-effects specification, the coefficient on lagged DFII equals 0.0216 $(p = 0.4350)$. When the PCA-based DFII is replaced by the additive standardized index, the corresponding coefficient is 0.0054 $(p = 0.7897)$. In the pre-pandemic subsample, the coefficient on lagged DFII is -0.0124 $(p = 0.7782)$, while the exclusion of 2020 yields a coefficient of 0.0134 $(p = 0.6422)$. In the reverse-causality specification, where DFII is used as the dependent variable and lagged HCD as the key regressor, the coefficient on lagged HCD is 0.2461 $(p = 0.5251)$.

Table 5. *Robustness and reverse-causality results*

Specification	N	Key coefficient	p-value	Adj. R^2
Baseline mean FE	108	0.0216	0.4350	0.8617
Additive DFII	108	0.0054	0.7897	0.8607
Pre-pandemic (2014-2019)	60	-0.0124	0.7782	0.8143
Exclude 2020	96	0.0134	0.6422	0.8192
Reverse causality: dependent variable = DFII; key regressor = lagged HCD	108	0.2461	0.5251	0.9916

Note: In the first four rows, the reported key coefficient is the coefficient on lagged DFII. In the reverse-causality row, the reported key coefficient is the coefficient on lagged HCD.

Source: Author's estimations

4.4 Subsample results

Table 6 presents the subgroup estimates for GCC and Non-GCC economies. In the GCC subsample, the coefficient on lagged DFII is 0.0554 $(p = 0.3830)$, whereas in the Non-GCC subsample it is 0.0125 $(p = 0.8305)$. The coefficient on GDP per capita growth remains positive and statistically significant in both groups. The coefficient on inflation is negative in both groups and statistically significant in the Non-GCC subsample only.

Table 6. *Subsample results: GCC versus Non-GCC*

Group	N	lag(DFII)	p-value	GDPG	p-value	INF	p-value	Adj. R^2
GCC	54	0.0554	0.3830	0.3275***	0.0005	-0.0136	0.8983	0.7397
Non-GCC	54	0.0125	0.8305	0.1686**	0.0236	-0.0982**	0.0372	0.8184

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Country and year effects included.

Source: Author's estimations

5 DISCUSSION

The findings show that digital financial inclusion is associated with household consumption dynamics in MENA economies, but the relationship is not uniform across the conditional distribution of consumption outcomes. This claim is supported by the baseline dynamic panel quantile estimates, where the coefficient of lagged digital financial inclusion is not significant at the lower quantiles, becomes positive across the distribution, and reaches statistical significance only at the upper quantile. By contrast, real GDP per capita growth remains positive and significant throughout, while inflation exerts a negative effect in the middle and upper quantiles. These results suggest that digital financial inclusion matters, but its measurable association with household consumption is conditional rather than universal.

This pattern is only partly consistent with the initial expectation of the study. The theoretical expectation was that digital financial inclusion might have stronger effects at the lower end of the consumption distribution, where liquidity constraints, payment frictions, and weak consumption-smoothing capacity are more likely to be binding. The results do not fully confirm that expectation. Instead, they indicate that the strongest observable effect appears in the upper quantile, not in the lower ones. This does not invalidate the distributional hypothesis; rather, it suggests that in MENA economies the benefits of digital financial inclusion may depend on whether the broader economic and institutional environment is sufficiently developed to transform digital access into effective household welfare gains.

In this respect, the results are broadly consistent with earlier studies that emphasize the conditional nature of digital financial inclusion. Previous research has shown that digital finance can strengthen financial inclusion and improve welfare, but only where supporting conditions such as institutional credibility, infrastructure, and actual service usage are present (Al-Smadi, 2023; Damra et al., 2023; Sha'ban et al., 2024). The present findings fit that line of argument. The positive coefficient of digital financial inclusion in the upper part of the distribution suggests that where digital ecosystems are deeper and more functional, the transmission from digital finance to consumption may become more visible. At the same time, the weaker and statistically insignificant coefficients at the lower quantiles suggest that access alone may be insufficient in more constrained settings.

The results also relate in a nuanced way to the broader household-welfare literature. Studies such as Jiang et al. (2024) and Liu et al. (2024) generally report positive welfare effects of digital financial inclusion, including higher household consumption and lower vulnerability. The present study does not contradict that literature, but it qualifies it in an important regional sense. In MENA, the estimated relationship appears weaker and more uneven than what has been documented in contexts with more mature digital ecosystems, such as China. This suggests that the welfare effects identified in international literature may not be automatically generalizable to MENA economies without considering regional differences in infrastructure, institutional effectiveness, and patterns of digital usage.

The control variables further reinforce the internal consistency of the results. The positive and stable role of real GDP per capita growth confirms that household consumption dynamics remain closely linked to broader income performance. Likewise, the negative effect of inflation is fully in line with standard macroeconomic theory, since higher inflation reduces real purchasing power and constrains consumption. These findings strengthen the credibility of the model because the main controls behave in theoretically expected directions. The results, therefore, do not suggest that digital financial inclusion replaces conventional macroeconomic drivers of consumption; rather, they indicate that its effect operates within, and is conditioned by, the broader macroeconomic environment.

The subgroup and robust analyses also support a cautious interpretation. The positive sign of digital financial inclusion is preserved across several alternative specifications and in both GCC and non-GCC subsamples, but statistical significance remains limited. In addition, the reverse causality check does not show strong evidence that lagged household consumption dynamics predict digital financial inclusion. These results do not prove strict causality, but they do suggest that the

baseline association is not merely an artefact of simple feedback from consumption to digital inclusion. For that reason, the claims advanced in this section remain reasonable and proportionate to the evidence.

Overall, the study supports the broader theoretical proposition that digital financial inclusion can contribute to household welfare, but it does not support a strong version of the theory in which such effects are automatically largest among the most constrained observations. Instead, the findings point to a more conditional interpretation: digital financial inclusion appears to matter more where economies already possess stronger structural readiness and where digital access can be translated into effective use. The study therefore adds to the literature by showing that, in MENA economies, the relationship between digital financial inclusion and household consumption is better understood as heterogeneous, context-dependent, and distribution-sensitive rather than linear and uniform.

6 CONCLUSIONS

This study examined the relationship between digital financial inclusion and household consumption dynamics in MENA economies using a dynamic panel quantile framework applied to a balanced panel of 12 countries over the period 2014–2023. The results show that the effect of digital financial inclusion is not uniform across the conditional distribution of household consumption. While the estimated coefficient becomes positive across most quantiles, it reaches statistical significance only at the upper quantile, indicating that the consumption-enhancing role of digital financial inclusion is present but uneven.

The findings also show that conventional macroeconomic fundamentals remain central to household consumption dynamics in the region. Real GDP per capita growth displays a positive and statistically significant effect across the full distribution, whereas inflation exerts a negative influence, particularly in the middle and upper quantiles. These results suggest that digital financial inclusion operates within a broader macroeconomic environment and does not substitute for the role of income growth and price stability in shaping household welfare outcomes.

The study contributes to the literature in three main respects. First, it shifts the focus from digital financial inclusion as an outcome in itself to its welfare relevance through household consumption. Second, it extends the debate to MENA economies, a region still underrepresented in the empirical literature on the consumption effects of digital finance. Third, it shows that a quantile-based dynamic panel approach provides a more informative framework than mean-based models for identifying heterogeneous effects across the consumption distribution.

Overall, the study concludes that digital financial inclusion can support household consumption dynamics in MENA economies, but its effect is conditional, uneven, and closely linked to structural readiness. The results therefore support a cautious interpretation: expanding digital access alone is unlikely to generate uniform welfare gains unless it is accompanied by stronger digital infrastructure, effective institutional support, and a stable macroeconomic environment. Future research may extend this analysis by incorporating household-level microdata, richer measures of digital financial usage, and alternative identification strategies to further clarify the channels through which digital financial inclusion affects welfare in the region.

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SHORT-TERM STUDY ABROAD EXPERIENCE: A TRANSFORMATIVE LEARNING PERSPECTIVE

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ABSTRACT

This study aims to explore the transformative learning experiences and internal mechanisms of Chinese postgraduate students in Short-Term Study Abroad (STSA) programs. This research adopts a qualitative research method, using purposive sampling and snowball sampling to conduct in-depth interviews with 15 Chinese master's students who have participated in STSA programs. The study found that the transformative learning mechanism in the STSA program presents a highly integrated path: (1) Triggering events: The conflict between external environmental heterogeneity and internal subjective expectations led to students' psychological imbalance; (2) Implementation process: Students completed cognitive reconstruction through deep critical reflection, rational discourse in social interactions, and adaptive actions; (3) Developmental effects: Students ultimately constructed a more inclusive and dialectical meaning structure and reshaped diverse values; (4) Enabling conditions: The reflective field, dialogue platform, and safety guarantees provided by the program design were the key external factors that triggered transformation. This study shows that to maximize the educational value of the STSA program, global universities and program designers should go beyond outcome orientation and focus on the design of process mechanisms.

1 INTRODUCTION

In the context of the internationalization of higher education, short-term study abroad (STSA) programs have evolved into a unique cross-border learning method distinct from long-term study abroad. Due to their shorter duration, flexible organizational form, and minimal interference with students' existing academic and life arrangements, STSA is gradually becoming one of the most common and important channels for international student mobility (Goldstein, 2022).

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Globally, the growth of Chinese universities participating in STSA programs and establishing partnerships with foreign universities has been particularly rapid (Iskhakova & Bradly, 2022). As an important source country of international students, the number of Chinese students studying abroad continues to increase (Huang, 2024; Li et al., 2023). Therefore, exploring the cross-cultural learning experiences of this large group of students in non-Western contexts is of great significance for understanding the global pattern of higher education.

Although STSA programs offer students valuable cross-cultural learning opportunities, their tight schedule and highly immersive nature also bring unique challenges. During the program, students need to quickly adapt to a foreign academic, social, and cultural environment, which often exposes them to a series of pressures, including cultural shock, language barriers, academic stress, and adjustment issues in daily life (Bradly et al., 2024). For Chinese students in particular, due to China's unique educational system, social cultural traditions, and collective expectations, they tend to experience intense internal cognitive conflicts when facing these cross-cultural challenges. These challenges are not only about adapting to life but also serve as a crucial opportunity for deep meaning construction.

With the widespread adoption of STSA programs, related research has been increasing. Many studies have confirmed the positive role of STSA programs in promoting the holistic development of students. These programs not only enhance academic learning and promote career development, but also cultivate students' appreciation of cultural diversity (Perry et al. 2012). In terms of cross-cultural competence, participants usually show a reduction in ethnocentrism, an enhancement in cross-cultural adaptability, and an improvement in cultural intelligence (Hachtmann, 2012; Engle & Crowne 2014). These challenging new experiences prompt students to break boundaries and form new perceptions of social issues and stereotypes (Gaia 2015), and promote personal development through self-reflection (Mather et al. 2012). However, the research results on the impact of STSA on participants' attitudes are inconsistent. Although some studies report significant improvements in students' respect and acceptance of different cultural perspectives (Nguyen 2017; LeCrom et al. 2015), other studies have found that the cross-cultural sensitivity or cultural intelligence of the participants did not change significantly (Bloom & Miranda 2015). Nevertheless, the development of cross-cultural knowledge is still considered the most reliable learning outcome in STSA programs (Engle & Crowne 2014; Gaia 2015; Nguyen 2017).

However, the existing literature mostly focuses on evaluating the programs' effectiveness and outputs (Iqbal, 2019). In recent years, the academic community has begun to call for a shift in research focus toward an "experience-oriented" approach (Zhao & Liu, 2025). As Davis and Knight (2023) emphasized, a deep understanding of the specific process of learning is crucial for improving overseas learning programs and maximizing their educational impact. Nevertheless, there is still insufficient exploration of the underlying mechanisms of how students construct meaning and achieve cognitive transformation from specific cross-cultural experiences (Davis & Knight, 2023).

To fill this research gap, this study, based on Mezirow's Transformative Learning Theory (TLT), analyzed the transformative learning (TL) experiences of Chinese postgraduate students in various STSA programs. The aim of this study is not only to conduct a static assessment of "learning outcomes", but also to systematically explore the "process mechanism" through which students undergo cognitive reconstruction after experiencing cross-cultural shocks. By focusing on this often overlooked yet crucial deep learning process, this study hopes to provide empirical support for understanding the deep learning of Chinese students in cross-cultural contexts, and offer theoretical references for global universities to establish and optimize STSA programs.

2 THEORETICAL FRAMEWORK

The concept of transformative learning was proposed by adult educationist Jack Mezirow. It is a learning method where an individual undergoes a fundamental change in their perception of the environment around them; at the same time, it is also a process of awakening critical consciousness and reconstructing preconceived notions (Mezirow, 1991). Adults have already constructed their own worldviews and developed

a meaning model for interpreting life experiences. During subsequent growth, although individuals will continuously encounter new knowledge and new experiences, in most cases, they tend to directly incorporate these new elements into their existing cognitive frameworks to achieve the compatibility and integration of the prior and new knowledge. However, when this integration process encounters obstacles, that is, when new experiences conflict severely with the existing paradigm and form an irreconcilable "dilemma", individuals will be forced to stop the integration. They must conduct a comprehensive examination and reflection on the established meaning model. Facing this dilemma, individuals usually have two choices: to reject new knowledge and new experiences and adhere to the original cognitive framework, or to actively correct or even reconstruct their meaning model. The second path is the core of TL.

Although Mezirow (1991) originally delineated ten phases of transformative learning, for the purpose of empirical application in the Chinese context, subsequent scholars like Hou et al. (2018) synthesized these into three core macro-stages:

1) Experiencing a disorienting dilemma, that is, experiencing life events that cause learners to question their internal beliefs (also known as triggering events);
2) Conducting critical reflection on the disorienting dilemma, thereby realizing one's limitations and areas for improvement;
3) Acquiring new knowledge, skills or attitudes to overcome one's limitations and achieve the transformation of one's individual conceptions.

The three-stage transformation learning theory is shown in Figure 1. When learners encounter a situation that does not match their expectations, causing them to be perplexed, the triggering event that leads to this situation is the catalyst for TL. When encountering a disorienting dilemma, learners will question their previously held beliefs and generate alternative concepts (Fletcher & Meyer, 2016). Critical reflection is considered the most effective tool and foundation for achieving the purpose of TL and is also the key to ensuring the quality and effectiveness of TL. Critical reflection refers to examining the underlying beliefs and assumptions that affect people's experiences, which is significantly different from general reflection. Here, reflection may be a process regarding knowledge or experience, while critical reflection may include reviewing how erroneous decisions were made, internalizing the lessons learned, and considering how to avoid similar problems from recurring.

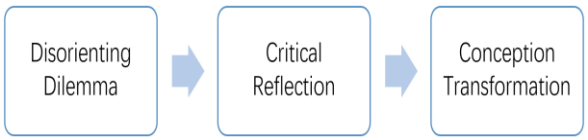


Figure 1. *Three stages of TLT*
Source: Adapted from Luo et al. (2018, 79)

Previous studies have shown that TL is an applicable framework for analyzing travel experiences. In a cross-cultural context, exposure to unfamiliar environments can effectively catalyze this learning process (Liu & Jiang, 2015; Stone et al., 2017). For adult learning, its "contextual nature" is of crucial importance. Many overseas learning programs are designed to facilitate such profound personal transformation (Dunn et al., 2014); at the same time, overseas journeys have been proven to yield transformative experiences (Cavender et al., 2020). This study focuses on the group of Chinese postgraduate students who participate in STSA programs. At a specific educational stage, these students seek to expand their global perspective and aspire to achieve personal growth in a cross-cultural environment. This clear goal gives their TL experiences unique exploratory value. The challenges they face in adapting to new environments, coping with cultural shocks, and pursuing personal growth provide a real and vivid field for studying the mechanisms of TL.

3 METHOD

We initially selected 8 Chinese postgraduate students using the purposive sampling method and then conducted interviews with 7 additional participants using the snowball sampling method. We found that the data had reached saturation, meaning no new themes emerged. Therefore, we set the interview sample size at 15 and numbered them as A1-A15. The information of the interviewees is shown in Table 1. The sample consisted of male and female participants in an 8:7 ratio, and third- and second-year students in a 3:2 ratio. Additionally, the participants were evenly

distributed across various academic departments. All the students tended to prefer online conversations, so we used the Tencent Voov Meeting platform to conduct interviews. Online interviews can flexibly arrange the interview time and can reduce the pressure associated with face-to-face communication, making it more conducive for the participants to express their opinions and speak freely. More importantly, online interviews have no location restrictions, which can greatly facilitate participation for the interviewed students. Our data collection period was from January to March 2026. Each interview lasted about 40 minutes, resulting in nearly 100,000 words of Chinese text materials. The interview topics mainly covered "Background and Expectations", "Confusion and Difficulties", "Critical Reflection", and "Conceptual Transformation".

Throughout the whole process of this study, ethical guidelines were strictly followed. Before conducting the data analysis, approval from the relevant institutions was obtained, and verbal consent was gained from each participant. All data have been anonymized and strictly kept confidential.

Table 1. *Demographic information of the participants*

Code	Gender	Duration	Department	Destination
A1	Male	7 days	College of Computer and Information Science	Italy
A2	Female	7 days	College of State Governance	Singapore
A3	Male	90 days	Law School	Sweden
A4	Male	14 days	College of Computer and Information Science	Italy
A5	Male	14 days	Center for Studies of Education and Psychology of Ethnic Minorities	Australia
A6	Female	7 days	College of State Governance	Japan
A7	Female	14 days	Law School	Australia
A8	Male	7 days	College of Computer and Information Science	Singapore
A9	Female	14 days	School of Marxism	Australia, Greece
A10	Female	21 days	Faculty of Education	Canada
A11	Female	7 days	College of State Governance	Japan
A12	Male	31 days	Faculty of Psychology	United States
A13	Male	10 days	College of Veterinary Medicine	South Korea
A14	Male	14 days	College of Plant Protection	Italy
A15	Female	14 days	Faculty of Education	New Zealand

This study employed thematic analysis and utilized the NVivo 14 software to code the transcripts. The coding process strictly followed the six steps of the thematic analysis method. The first step was to familiarize oneself with the data. The researcher transcribed all the interview recordings into nearly 100,000 words of text and read them repeatedly. The second step was to conduct initial coding using NVivo 14, adhering to the principle of openness, and conducting micro-coding sentence by sentence and paragraph by paragraph for each document, generating 79 initial nodes. The third step was to search for themes, classifying and summarizing the scattered initial codes according to internal logic (such as cognitive conflicts, adaptation challenges), forming preliminary themes. The fourth step was to review themes, returning to the original materials to verify whether the preliminary themes could accurately reflect the experiences of the respondents. The fifth step was to combine the TLT definition and name the core themes, defining and naming the themes, ultimately refining into 4 progressive core themes. The final step was to write the research findings. Table 2 shows the analytical process.

Table 2. *Thematic Analysis Framework*

Overarching Themes	Preliminary Themes	Examples of Initial Codes
1. Triggering Events for TL	Cognitive Conflict	Developmental cognitive bias; Educational stereotype; Cultural norm assumptions
	Adaptation Challenges	Climate/diet unadaptability; Social rule adaptation pressure; Time-zone social anxiety
	Communication Dilemmas	Accent comprehension barriers; Expression and thinking differences
2. Implementation Process of TL	Critical Reflection	Dialectical cognitive shift; Deconstructing cultural stereotypes; Self-awareness reconstruction
	Cross-Cultural Dialogue	Classroom collaboration; Reaching consensus through conflict
	Adaptive Actions	Optimizing communication strategies; Behavioral adaptation
	Environmental Support	Peer emotional support; Safety guarantees from leaders
3. Outcomes of Global Competence	Multicultural Inclusiveness	Enhancing cultural inclusiveness; Eliminating group stereotypes; Building cultural confidence
	Global Issue Cognition	Deepening understanding of global issues; Broadening academic frontiers
	Cross-Cultural Communication	Boosting foreign language confidence; Enhancing teamwork skills
	Global Career Intention	Breaking career planning boundaries; Expanding global academic vision
4. Enabling Conditions	Program Immersion Design	High-density arrangements; Autonomous exploration space
	Cross-Cultural Interaction Design	Multinational group collaboration; Local student pairing
	Pre-departure Support	Pre-training on cultural knowledge; Safety guarantees

The initial sentence-by-sentence coding for this study was independently completed by the second author. To ensure the objectivity and reliability of the coding, the first researcher conducted cross-checking. Both authors independently reviewed the initial coding and the preliminary themes. When the two researchers had disagreements on the coding attribution or theme naming, they would return to the original interview text for in-depth discussion until a consensus was reached. This approach effectively improved the internal reliability of the study.

To minimize potential researcher bias and enhance the trustworthiness of the qualitative analysis, several strategies were rigorously applied throughout the study. The first is investigator triangulation as mentioned. Second, both authors continuously evaluated the emergence of new codes during the analysis process. By the 15th interview, no new significant themes or codes emerged, indicating data saturation. This ensured that the findings comprehensively reflected the collective experiences of the sample rather than isolated, biased observations. Third, the analysis was grounded in participants' verbatim quotes (thick descriptions) to keep conclusions firmly tethered to students' original voices and limit interpretive bias.

4 FINDINGS

4.1 Triggering events for TL

TL begins when the individual's original meaning structure fails, leading to a disorienting dilemma. Data shows that this dilemma is the result of a sharp collision between the external objective heterogeneous context and the internal subjective expectation.

Heterogeneity of external contexts

The multi-dimensional impacts of the external environment have profoundly challenged the original cognitive frameworks of the students. At the macro level of social cognition, the long-established "Western centrism" stereotype that the students had formed was shattered. "After firsthand contact, I discovered that the development in Europe seemed to have stagnated, which was in sharp contrast to the perfect impression obtained from the internet. Only then did they realize how rapidly their home country was developing". (A1) This gap between the objective reality and the subjective assumptions forced the students to seek new explanatory frameworks. At the micro level of life experiences, the differences in infrastructure and living habits posed real challenges. "The least adaptable aspect was the diet; the local food was hard to eat." (A1) These life frictions transformed the external conflicts into necessary survival pressures that needed to be addressed.

Internal psychological dissonance

External shocks are transformed into inner anxiety and a sense of marginalization, becoming the internal tension that drives cognition. For instance, two participants stated:

- "As an outsider, due to the time difference, my schedule often differs from that of my domestic relatives." (A15)
- "Lack of communication partners, going alone every day, easily leads to depression or despondency." (A3)

The dual experiences of 'time-zone-induced social anxiety' and an 'outsider identity' destabilize the students' pre-existing self-identity. In turn, this psychological disequilibrium catalyzes the intrinsic motivation required for active cognitive reconstruction.

4.2 Implementation Process of TL

The core of TL lies in the reconfiguration of the meaning structure. This is a dynamic process that is guided by internal reflection, verified in external social interactions, and ultimately translated into action.

Deep operation of critical reflection

The interview revealed that the students' reflections reached the "premise reflection" level, that is, they questioned the underlying value assumptions they had previously held. In terms of self-awareness, the students broke away from their previous mindset. "After using AI tools, I realized that the traditional belief that 'as long as you work hard and don't worry about speed' was incorrect." (A14) In terms of cultural cognition, the students shifted from being self-centered to being open and inclusive. "After gaining a deep understanding of the development logic of different cultures, I changed my previous judgment of superiority and inferiority and realized that veery culture has its own valid rationale for existing." (A3) This marks an important growth in the students' multicultural cognition.

Rational verification through social dialogue

Rational discourse is the key to testing the new meaning structure. External interaction accelerates the social verification of internal reflection. Firstly, participants reached consensus in spontaneous life conflicts. "Facing the conflict in lifestyle caused by cooking fumes, we made effective adjustments through communication and mutual concessions." (A3) Students exercised cross-cultural communication skills by negotiating rules through dialogue.

Secondly, students reorganized their cognition in structured team collaboration. "I adjusted my communication method, extracted viewpoints using a logical framework and combined them with Chinese cases. Eventually, I gained recognition from foreign classmates." (A11)

Furthermore, dialogue eliminated stereotypes. "It was widely reported that foreign countries discriminated against Chinese students, but after actual contact, we found that they were very willing to communicate. This taught me to view problems dialectically and not blindly believe online comments." (A4) This cognitive transformation

ultimately led to an increase in students' willingness to interact.

Consolidation through adaptive action

Driven by reflection and dialogue, the students took adaptive actions. "I gradually got used to the local communication style and took the initiative to make changes, greeting people like the locals." (A12) This action was not merely a behavioral imitation but also a breakthrough in psychological boundaries, further consolidating the new self-awareness.

4.3 Outcomes of Global Competence Development

TL has led to a fundamental transformation in students' global competence at the cognitive, attitudinal and conceptual levels. Firstly, students have established a cognitive boundary that considers "differences" as the norm. "After seeing the differences in various countries, my mind has become broader, more inclusive, and I am able to slow down moderately in the fast-paced environment." (A9) They are no longer passive adaptors but actively integrate the logic of multiculturalism into their own value system. Secondly, through comparative reflection, students have developed rational cultural confidence and an equal attitude towards interaction. On one hand, they have formed a strengthened home-culture identity. "After observing the social environment in foreign countries, I better understood the difficulty of China's development and thus developed a strong cultural confidence." (A3) On the other hand, they have established an equal attitude towards cross-cultural interaction. "Now I can communicate with all groups with equal footing and confidence, and I have learned to accept diverse living rhythms, no longer believing that 'speed is everything'." (A9) This reshaping of values has a profound and lasting impact.

4.4 Enabling Conditions

The external supporting factors such as the design of the STSA program precisely match the psychological needs of students, effectively empowering the TL process. Firstly, the STSA program provides a field for reflection. The immersive local experience pushes students into real cultural dilemmas. "The experience in the host family was the most profound. Facing differences in eating habits and communication barriers caused by the landlord's accent, I had to actively solve the problems by using translation software". (A9) This environment's immersive nature stimulated students' urgent need to resolve cognitive conflicts. Secondly, the STSA program builds a platform for dialogue. The mandatory interactive design of the program reduces the threshold for cross-cultural social interaction. "In cross-national group cooperation, when facing differences in opinions and poor communication, we had to actively negotiate and communicate." (A11) Such design forces students to step out of their comfort zone, gain positive feedback through interaction, and enhance their confidence in communication. Finally, the STSA program also provides a safe guarantee. This is mainly manifested in the support from teachers and peers, which builds an emotional buffer zone. "The team leader (teacher) provided a great sense of security and assistance in a foreign country" (A10); at the same time, "peers effectively compensated for the sense of loneliness" (A9, A15). The external support of the team is internalized by students as their psychological strength, enabling them to face cultural conflicts instead of retreating, and ensuring the smooth progress of TL.

5 DISCUSSION

TL begins with a disorienting dilemma. In STSA programs, this predicament is systematically triggered through three paths:

1) The first is the change of the environment. The program separates students from their familiar cultural base and places them in an environment with extremely unfamiliar infrastructure, climate, and lifestyle.
2) The second is the transformation of identity roles. The identity of "learner" forces students to deeply engage rather than merely observing. Additionally, the continuous daily friction turns cross-cultural adaptation from an abstract concept into a practical issue related to daily living.
3) The third, and the most crucial point, is the gap between expectation and reality.

Students' preconceptions about developed countries, educational models, and social norms encounter a comprehensive challenge here. The

core function of this triggering mechanism lies in "problematization". It transforms students' accustomed things into issues that require re-examination, thereby breaking their state of "cognitive closure" and bringing the original meaning structure to the conscious level for inspection. This problematization process is particularly critical for Chinese students, who are deeply influenced by a teacher-centered, collective educational habitus, forcing them to negotiate their identity in a more individualized and interactive Western academic setting within a highly compressed time frame. Ultimately, the effectiveness of the program design depends on whether the cognitive challenge is appropriate:

1) If the challenge is excessive, it will cause students to adopt defensive avoidance;
2) if the challenge is insufficient, it will not form the necessary cognitive tension.

Reflection is the soul of TL, and its depth determines the level of transformation. The scenarios provided by the program support students to progress in their reflections, from content reflection to process reflection, and finally to premise reflection. Specifically, at the content reflection level, students describe what happened and what they perceived; at the process reflection level, students examine how they responded and whether the strategies were effective; at the premise reflection level, some students begin to touch upon "why I made such assumptions" and "where these ideas came from". Some students successfully moved to the deepest level and began to question their deep-seated assumptions. For example, student A14 reflected on the value premise of "hard work is correct", while student A3 reconstructed the cultural cognition of "cultural differences have distinct rationales". For the reflection mechanism to function effectively, two conditions are required. One is to maintain cognitive tension, and the other is to provide structural reflection time guarantees. In other words, "the perplexing situation" needs to continuously stimulate students; at the same time, the program needs to reserve time for students to explore and review autonomously during the high-density schedule, to support them to ascend from "immediate response" to "systematic cognitive integration".

The reconstruction of an individual's meaning must be achieved through rational dialogue. STSA programs encourage students to actively express themselves, jointly examine their past selves, provide new interpretations and accept constructive challenges, to test the rationality of their new hypotheses. This program mainly completes this verification process through two interactive designs, "institutionalization" and "immersion in daily life". Firstly, the program conducts activities such as multi-national group collaboration, local student pairing, and academic discussions. These institutionalized designs create mandatory scenarios for the confrontation and integration of viewpoints. Secondly, the program provides round-the-clock cross-cultural contact by having students integrate into host families and participate in daily communication. This everyday-life design makes conflict negotiation and consensus attainment inevitable. The key function of the dialogue mechanism lies in the confirmation of individual cognitive conflicts through others' feedback, and the transformation of new hypotheses from individual speculation to a shared social reality. The case of A11 typifies this mechanism. "The communication method was adjusted, starting with the case of environmental governance in China, and viewpoints were refined using a logical framework. As a result, the viewpoints were recognized." Feedback confirmation strengthened the new meaning structure.

The new meaning structures generated by transformation learning need to be consolidated through role-playing and behavioral practice. At this stage, the program mainly provides support to students in three aspects. Firstly, it offers opportunities for adaptive actions. Students can actively adjust their communication strategies and social behaviors. Secondly, it gives students new roles. The program encourages students to act as cultural communicators in cross-cultural teams and actively participate in various dialogues and exchanges. Finally, it links key experiences with long-term planning. The program guides students to adjust their research directions and reconstruct their future career ideals. The core of this integration mechanism lies in achieving the leap from "knowledge to action". The newly acquired meanings no longer remain only at the cognitive level but are strengthened through the feedback of

practice and eventually form relatively stable behavioral tendencies. The case of student A3 is an embodiment of this leap. A3 broke away from the mindset of making choices only within a narrow legal framework and instead hoped to explore the diverse meanings of life, eventually combining his research direction with artificial intelligence (AI).

The above four mechanisms are interlinked. Specifically, the triggering mechanism provides materials for reflection, the reflection mechanism provides content for dialogue, the dialogue mechanism provides validation for integration, and the integration mechanism may trigger new cognitive dilemmas. These steps together form an upward spiraling structure. However, the particularity of STSA programs lies in their very limited time. This places higher demands on the precision of program design. On one hand, to overcome the time pressure, the program must carefully embed "reflection guidance" into the itinerary; on the other hand, to improve communication efficiency, the program must provide structured institutional mechanisms for the "dialogue platform".

Mezirow (1991) pointed out that excessive cognitive challenges would lead learners to adopt defensive withdrawal, while insufficient challenges would fail to stimulate sufficient cognitive tension. Therefore, the STSA program design should place learners in a "tolerable confusion" state. Additionally, the program needs to be structured in a way that ensures participants have the opportunity for equal participation and authentic dialogue, thereby preventing interpersonal interactions from becoming superficial. The STSA program should also allocate sufficient time for students' reflection sessions. As Cranton (2006) emphasized, effective reflection requires sufficient psychological space; only with this condition can students complete the processing and transformation from sensory experience to deep meaning. Without this time guarantee, the intensive schedule of STSA programs often leads to fragmented experiences for students, thereby hindering their effective cognitive integration.

The findings of this study not only confirm but also further expand the previous research on STSA learning experiences. Consistent with previous studies, the participants reported changes in cross-cultural awareness, cultural adaptability, self-understanding, and an open attitude towards diversity, which are widely regarded as important outcomes of the STSA program (Engle & Crowne, 2014; Gaia, 2015; Nguyen, 2017). Like studies that emphasize the personal and professional value of overseas learning experiences (Mather et al., 2012), this study also found that students developed greater confidence, a broader perspective, and a stronger willingness for cross-cultural communication.

However, this study goes beyond previous outcome – oriented research and explains the way such changes occur. The existing STSA literature has extensively documented the benefits that students gain from STSA programs, including language confidence, cultural intelligence, cross-cultural sensitivity, and personal growth (Cubillos & Ilvento, 2012; Martinsen, 2010). However, these achievements are often presented as independent accomplishments rather than interconnected parts within the learning process. This study shows that students' transformation follows a comprehensive path: cross-cultural confusion first breaks their existing assumptions; critical reflection enables them to examine the sources of these assumptions; social dialogue provides opportunities to test and revise emerging interpretations; adaptive actions consolidate the new meaning structure. In this sense, this study responds to the recent call for a greater emphasis on experiential and process understanding in STSA learning (Davis & Knight, 2023; Zhao & Liu, 2025).

These findings also help explain why previous research reports have inconsistent results for the STSA program. Some studies found significant improvements in students' cross-cultural attitudes and acceptance of cultural differences (LeCrom et al., 2015; Nguyen, 2017), while others reported limited changes in cultural sensitivity or cultural intelligence (Bloom & Miranda, 2015). This study suggests that these differences may not only be related to the duration of the program or the destination, but also to whether the program provides sufficient conditions for TL. Just having cross – cultural exposure does not automatically lead to transformation. When confusing experiences are accompanied by structured reflection, meaningful conversations, and emotional support, students are more likely to

undergo profound changes. Without these facilitating conditions, students may remain at the stage of behavioral adaptation or defensive avoidance and cannot achieve fundamental – level reflection.

The transformation process detailed in this study holds particular significance within the Chinese educational and cultural context. When many Chinese students join the STSA program, their learning tendencies are shaped by teacher – centered teaching, exam – oriented education, respect for authority, and collective expectations. These previous educational experiences may have accustomed students to structured knowledge transmission rather than open discussions, critical inquiries, and spontaneous cross – cultural interactions. Therefore, when they encounter more dialogic, egalitarian, or student – centered academic environments abroad, this experience generates a strong cognitive tension. This tension is not merely an issue of adaptation; rather, it serves as a trigger for reexamining deeper assumptions regarding learning, communication, culture, and self-positioning.

The contributions of this research are twofold. Theoretically, traditional TLT research usually focuses on long – term adult learning experiences. However, this study extends the empirical application of TLT to STSA contexts by demonstrating how transformative cognitive restructuring can be achieved within a highly compressed timeframe. We found that the STSA environment played a strong catalytic role, and the density of external heterogeneity accelerated the transition from “content reflection” to “premise reflection”. Contextually, this study breaks the Western – centric paradigm in the STSA research and captures the specific transformation trajectory of Chinese graduate students. It provides new understandings of how non – Western students negotiate their unique socio – cultural scripts – such as family collectivist expectations and a structured educational habitus – when engaging with Western pedagogical models.

6 CONCLUSION

This study systematically revealed the mechanism of TL in a cross-cultural context by analyzing the experiences of Chinese graduate students in STSA programs. The research found that TL begins with the “disorienting dilemma” triggered by both external cultural shock and internal cognitive dissonance. Under this trigger, students undergo a dynamic process centered on deep critical reflection, verified through social dialogue, and ultimately achieved through adaptive actions to achieve cognitive integration. Not all students were able to complete the entire process of TL. Some participants remained at the defensive withdrawal stage, merely making behavioral compromises without delving into the premise reflection.

The research results indicate that the key to the success of STSA programs lies in elaborate design. It requires achieving a balance between providing sufficient cognitive tension and avoiding defensive withdrawal, creating a “tolerable disorientating dilemma”. At the same time, institutional design must be implemented to guarantee a structured space for equal dialogue and in-depth reflection among participants. These external supporting conditions match the internal psychological needs of students, jointly enabling the complete TL chain.

The implications of this study lie in the fact that the evaluation of the value of STSA programs should shift from being solely outcome-oriented to focusing on the depth of the learning process. Future program design and research should place greater emphasis on how to systematically create an environment that supports reflection, dialogue, and integration, to facilitate students to achieve profound and lasting meaning reconstruction within a limited time frame.

Several limitations must be acknowledged to inform future research. First, the sample in this research is small and homogeneous, made up only of Chinese postgraduates. Due to the deep embedding of the cognitive baseline, educational habitus and cross – cultural barriers within China’s particular socio – cultural setting, the results cannot be generalized to students who come from other socio – cultural settings, i.e., different cultures or educational backgrounds (undergraduate students) or individualistic cultures. The second limitation of the study is due to the use of retrospective self – report interview data. Even though interviews are good tools for meaning – making, they have limitations of recall bias and social desirability bias. This means that

although the change in the students' cognition is captured through the interviews, it is *perceived* change and not objectively observed behavior changes. Reflective journals, program evaluations, or participant observations in future studies would help make a better evaluation of the same. Third, the study concentrates on the movement of students from an Eastern setting into Western or developed contexts. It is not clear how transferable the mechanisms identified, especially the disorienting dilemma triggers, to cross – cultural mobility in the opposite direction are.

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