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The journal is published from Belgrade, Serbia and Toronto, Canada. Its focus is international, addressing topics from a global perspective. However, articles concerning specific local events may also be considered for publication.

Scientific and technological developments — along with their socio-political impact around the world — are welcome topics in the MEST Journal.

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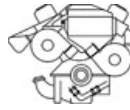
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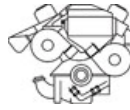


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These are basic themed areas and are not intended to be exclusive.





From the Editor

Belgrade, January 15th, 2026

Dear Readers, Authors, Reviewers, Language Editors, and Section Editors,

Between two consecutive issues of *MEST Journal*—particularly at the beginning of 2026, following the U.S. intervention in Venezuela and renewed debates on Greenland's future—the global economy and politics have continued to undergo rapid transformation. These complex processes of transition often appear contradictory.

Several key themes deserve heightened attention from the academic community: the geopolitical ambitions of major powers, uneven patterns of economic growth across regions, the paradoxes of European energy policy, and their implications for economic performance. Historical comparisons may serve as important warnings.

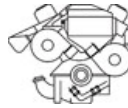
At a time when the United States imposes tariffs of several hundred percent and restricts Chinese products and manufacturers, Russian energy exports, and Venezuelan oil, global trade demonstrates resilience. It does not collapse but rather adapts and transforms. According to reports from the International Monetary Fund, global growth—though modest—remains stable, while trade flows continue to expand.

Behind this picture lies a series of paradoxes. The European Union occupies a special place in this context. By introducing broad sanctions on Russia, particularly in the purchase of fossil fuels, the EU has imposed constraints on itself. Consciously or not, it now finds itself purchasing fossil fuels at significantly higher prices than before the sanctions. The paradox is that part of its demand is still met by Russian energy, acquired through intermediaries at elevated costs. This paradox illustrates that the system does not collapse but expands through more expensive, complex, and politically charged channels.

The European Commission emphasizes in its energy reports that the goal is to reduce dependence on Russia and accelerate the transition to renewable sources. Yet dependence on fossil fuel suppliers is not eliminated but merely shifted—from Russia to the United States, Qatar, or other providers. This raises the question: to whom does the EU demonstrate diversification? Citizens, opponents, allies, or itself? If dependence is only transformed while costs rise, it is evident that economic rationality is being sacrificed for political objectives.

The shift to renewable energy is inevitable, but the choice of pathways and speed of implementation remains open to debate. The transition entails serious risks. In the short term, industry loses competitiveness, inflation rises, and households face higher bills. In the long term, if the transition is not sufficiently rapid, the EU risks sliding toward the periphery of the global economy.

Externally, the EU projects an image of unity, while internally each side pursues its own interests. This opens opportunities for researchers to draw comparisons with historical examples. Rhetoric about cohesion and readiness sounds strong, but without a well-designed and realistic plan, accompanied by disciplined implementation, it remains hollow. In Yugoslavia, the saying was often quoted: *“Work as if*



peace will last a hundred years but prepare as if war will break out tomorrow." In reality, preparations were not made. Today, the EU speaks of energy transition and independence, yet dependence on external fossil fuel suppliers inevitably persists, as such resources are not available in sufficient quantities within the Union.

Scenario analyses for the EU suggest three possible trajectories by mid-century. Industrial competitiveness is preserved only in the most optimistic scenario. The baseline scenario points to potential stagnation, with retention limited to high-tech sectors. The pessimistic scenario foresees deindustrialization, fragmentation, and loss of global relevance.

Looking ahead 20 or 50 years provides a clearer framework. If industry weakens now, regaining competitiveness later will be difficult. If dependence is merely shifted, it remains—and in the worst case may become even less favorable. Sanctions designed without deep consideration of consequences return as a boomerang.

It is therefore essential to illuminate the range of possibilities and recognize warning signals. Beyond economics, numerous other factors will shape the EU's future. The academic community has the responsibility to highlight these paradoxes, identify risks, and propose rational alternatives. This editorial thus calls for reflection on how to balance political cohesion with economic rationality.

MEST Journal will, within its means, continue to contribute to the dissemination of scientific thought and remain a platform for diverse perspectives and achievements. In this issue, 20 papers are published, 11 of which are co-authored. Seven papers originate from Algeria, offering readers insight into the work and accomplishments of Algerian researchers and contemporary developments in that region.

The journal has introduced a new design for article presentation. Alongside visual changes, it has adopted the APA 7 citation system. In addition to APA 7, readers are provided with citation options in Chicago 17th Edition, GOST R7.0.100-2018, Harvard Anglia Ruskin, and ISO 690 Numerical Reference styles. Our aim is to enhance visibility and facilitate citation of published works.

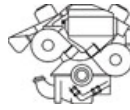
Due to the transition to the new design, updated templates will be available on the same website addresses as the previous versions, ensuring continuity for authors. In the coming period, calls will be announced for guest editors and members of the Scientific Board of *MEST Journal*.

We invite authors to publish with us—supported by comprehensive editorial guidance, free publication, and compliance with Creative Commons 4.0 principles. Thank you for joining us on this academic journey. Together, we strive to ensure that *MEST Journal* remains a hub of rigorous scientific analysis, innovation, and an unwavering commitment to research integrity and precision.

Warm regards,

Prof. Dr. Zoran Čekerevac
Editor-in-Chief





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THE AI BUBBLE: BETWEEN TECHNOLOGICAL PROMISES AND ECONOMIC REALITY

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ABSTRACT

This study examines the phenomenon of the artificial intelligence (AI) bubble through an integrated economic and technological lens, contextualizing the recent surge in AI development—particularly generative models like ChatGPT and Midjourney—within broader cycles of financial speculation and innovation hype. Drawing on classical economic theories of bubbles (Kindleberger, Minsky, Shiller) and contemporary reports from institutions such as the OECD, World Economic Forum, and McKinsey, the research examines whether current investment patterns and market valuations in the AI sector reflect sustainable growth or speculative excess. The study highlights parallels with previous episodes of technological overvaluation, such as the dotcom and cryptocurrency bubbles, and identifies behavioral and structural indicators of potential market distortion. While acknowledging the transformative potential of AI, the study argues that inflated expectations may obscure underlying risks, particularly for emerging economies vulnerable to global financial shocks. It concludes that the AI bubble, if managed prudently, could serve as a corrective phase that redirects innovation toward long-term sustainability. Policy recommendations include diversifying funding sources, safeguarding labor markets, strengthening regulatory frameworks, and investing in human capital to ensure a responsible and inclusive transition toward humane artificial intelligence.

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1 INTRODUCTION

Since the beginning of 2022, the world has witnessed a radical shift in the technological and economic landscape, embodied by the unprecedented boom in artificial intelligence applications, particularly generative AI models, which have been widely discussed in scientific, economic, and media circles. The launch of tools such as OpenAI's ChatGPT, the image generation platform Midjourney, and the emergence of many other smart solutions have marked a pivotal turning point in the human relationship with technology. This technological revolution has not only accelerated the pace of scientific research and improved productivity, but has also sparked widespread economic activity, reflected in growing investments, rising market values of companies operating in this field, and increasing bets by governments and major financial institutions on this technology as the primary driver of the Fourth Industrial Revolution.

Amid this momentum, ambitious predictions have emerged that view artificial intelligence as the key to a prosperous economic future, capable of reshaping value chains, stimulating innovation, reducing production costs, and improving resource allocation. Many countries have adopted national strategies for artificial intelligence, considering it a pillar of future economic development. However, this rapid boom has been accompanied by significantly inflated expectations, prompting a growing number of experts and analysts to warn of the potential emergence of an "AI bubble." This is an economic phenomenon characterized by an unjustified increase in market and investment values compared to the actual economic value of technology. This phenomenon is strikingly like what occurred during the Internet bubble of the late 1990s and early 2000s, and the cryptocurrency bubble of 2017.

Talk of an "AI bubble" does not necessarily mean downplaying the importance of technology. Rather, it reflects the need for objective and balanced reading between the true potential of new technologies and exaggerated expectations that could lead to unsustainable investment waves. This issue is doubly important for emerging economies and developing countries, which can be directly or indirectly affected by

global market fluctuations. Excessive investment in AI could lead to unstable economic consequences in the event of a sharp correction or bubble burst. From this perspective, it is imperative to study the phenomenon from a comprehensive economic-technological perspective, linking global transformations with their local repercussions, while analyzing quantitative and qualitative indicators that may indicate investment inflation or overvaluation. This phenomenon also requires a deep understanding of market dynamics, investor behavior, the strategies of major corporations, and government trends, enabling the formulation of strategic visions and recommendations for developing countries to avoid the potential side effects of any global technological crisis.

2 RESEARCH PROBLEMATIC

Despite the rapid growth in the artificial intelligence sector, there are indications that its current economic potential is being overestimated, raising questions about:

- Is the world truly experiencing an AI bubble?
- What factors could lead to this bubble bursting?
- What are the implications for emerging economies and developing countries?

2.1 Research Objectives

- To analyze the concept of the "AI bubble" from an economic and technological perspective.
- To study indicators of the sector's inflation (investments, expectations, market values).
- To identify potential economic risks in the event of a bubble bursting.
- To anticipate the future of technology after the correction phase.
- To provide recommendations for decision-makers in developing countries to avoid potential negative impacts.

2.2 Research Methodology

The research adopts a descriptive-analytical approach through:

- Analysis of international economic data and reports (OECD, IMF, World Economic Forum, McKinsey).
- Review of recent academic literature on technology bubbles.

- Comparing the case of artificial intelligence with the dot-com bubble and cryptocurrencies.
- A case study of major AI companies (OpenAI, Nvidia, Anthropic, Microsoft).

3 THE CONCEPTUAL AND THEORETICAL FRAMEWORK OF ECONOMIC BUBBLES

3.1 Concept of the Bubble in Financial and Technological Economics

The concept of the economic bubble is a pivotal concept in financial and macroeconomic analysis, as it refers to a structural imbalance between the intrinsic value of assets and their market value. A bubble occurs when asset prices, whether stocks, real estate, digital currencies, or emerging technologies, rise to exaggerated levels that cannot be justified by fundamental factors such as profits, productivity, or real demand. This rise is typically driven by overly optimistic future expectations rather than solid economic or financial fundamentals. (Reinhart & Rogoff, 2009)

Kenneth Rogoff and Carmen Reinhart defined economic bubbles as "states of significant disconnect between actual financial valuations and investors' behavioral expectations" (Reinhart & Rogoff, 2009). Hyman Minsky, in his theory of "unstable stability," also pointed out that bubbles arise not only from external shocks but also from reckless financial behavior and excessive speculation, which leads to the accumulation of financial fragility that later bursts. (Minsky, 1986)

From a behavioral perspective, several factors contribute to the formation of financial bubbles. Among the most prominent are herd behavior, where investors imitate one another without rational analysis; unrealistic expectations—a term coined by U.S. Federal Reserve Chairman Alan Greenspan in 1996 and later elaborated by Shiller; and short-term speculation driven by the pursuit of high profits without corresponding gains in productivity or real economic value (Shiller, *Irrational Exuberance*, 2000).

In the technological field, economic bubbles often exhibit unique features, frequently accompanying the emergence of new technologies perceived as revolutionary and capable of reshaping economic or market structures. During these periods, capital

flows into sectors related to these technologies accelerate, from both individual investors and major financial institutions. The media exaggerates expectations about the future of these technologies, leading to significantly inflated financial valuations of companies operating in them, even if their business models are immature or lack stable cash flows. (Perez, 2002; OECD, 2023)

A prominent example of this occurred during the dot-com bubble, which spanned from 1995 to 2000. Digital technology startups saw astronomical increases in their market values despite weak returns. When expectations collided with reality, the bubble burst, resulting in losses of hundreds of billions of dollars (Kindleberger & Aliber, 2011). Another example is the cryptocurrency bubble of 2017, when the prices of Bitcoin and other cryptocurrencies rose to unsustainable levels before subsequently collapsing. (WEF, 2024)

At the core of any financial or technological bubble lies a large gap between the true value of assets and their inflated market capitalization. This gap represents structural fragility, and upon the first shock—such as a change in expectations, a slowdown in growth, or a rise in interest rates—this gap closes abruptly, causing a price collapse (Minsky, 1986; Shiller, 2000).

Carlotta Perez's analysis suggests that most technological revolutions go through similar phases: irruption, frenzy, crash, and finally synergy—the same stages that shape the dynamics of any major technological bubble. (Perez, 2002)

3.2 Stages of an Economic Bubble

Economic bubbles typically go through a series of successive stages that recur throughout economic history, whether in traditional financial markets or emerging technology sectors. In her theory of technology cycles, Carlota Perez (2002) explained that every technological revolution goes through a specific cycle: hype, expansion, explosion, and maturity (Perez, 2002). The work of Hyman Minsky (1986) and Kindleberger & Aliber (2011) further supported this model through their analysis of market and investor behavior during financial crises. (Minsky, 1986; Kindleberger & Aliber, 2011)

The following is a detailed breakdown of the stages of this cycle.

3.2.1 Irruption Phase

In this first stage, a new technology or innovative economic opportunity emerges that is perceived as having the potential to profoundly transform the economy. This stage is often associated with a technological breakthrough or new discovery, such as the advent of the internet in the 1990s or artificial intelligence technologies in the current decade.

Investment appetite at this stage is relatively limited, and participation is restricted to early adopters such as venture capital funds, universities, research labs, and institutions with a high tolerance for risk. Prices are not yet inflated, but an optimistic narrative about the future of technology begins to take shape. Specialized media coverage plays an important role in creating a mobilizing discourse that reinforces the impression that an "economic revolution" is imminent. The basic features of this phase are evident (Perez, 2002):

- Initial measured optimism.
- Limited investments within a narrow scope.
- The "market story" around the new technology begins to take shape.
- Focus on technical feasibility rather than financial feasibility.

3.2.2 Frenzy Phase

In this stage, capital flows into the new sector to accelerate. Institutional investors and large investment funds are attracted to the opportunity, and mass media coverage increases, generating a state of collective enthusiasm. Prices begin to rise at a faster pace than the actual growth in economic value.

Here, what is known as herd behavior appears, where investors rely less on rational analysis and are increasingly influenced by what others are doing. Market expansion and rising prices attract new investors, many of whom lack sufficient experience, thereby increasing momentum and market volatility. The basic features of this phase are evident: (Minsky, 1986)

- Rapid expansion of the investor base.
- Price growth at a pace disproportionate to intrinsic value.

- Dominance of the economic narrative by the mainstream media.
- The beginning of a disconnect between price and intrinsic value.

3.2.3 Mania Phase

This phase represents the peak of the bubble, when prices reach economically unjustified levels. Irrational exuberance, a concept coined by Robert Shiller (2000), prevails. There is a growing belief that prices will not decline and that the "historical opportunity" will last indefinitely.

Short-term speculation is widespread, and inexperienced individuals, driven by the fear of missing out (FOMO), participate in the market. Financial valuations of companies operating in the sector expand to unprecedented levels, often without sustainable business models. At this stage, economic analysis standards weaken and are replaced by faith in the market itself.

The basic features of this phase are evident: (Shiller, Irrational Exuberance, 2000)

- Excessive speculation and exorbitant price increases.
- Entrance of unprofessional investors.
- Nearly complete disregard for risk.
- Complete disconnect between price and intrinsic value.

3.2.4 Crash Phase

After the peak, a sudden shift in market expectations occurs. The trigger may be an economic shock, a negative announcement from a key company, or a liquidity crisis. Large investors begin preemptively selling their assets, leading to a series of panic sales.

At this stage, prices decline sharply, and the market loses confidence in the sector. Several small or financially unstable companies collapse, and funding rapidly declines. This phase is often characterized by a complete loss of confidence, and exiting the market becomes the goal of most investors. The basic features of this phase are evident: (Kindleberger & Aliber, 2011)

- A sudden and sharp decline in prices.
- A state of mass panic and loss of confidence.
- The exit of large capital.
- The beginning of the collapse of financially weak companies.

3.2.5 Consolidation Phase

After the crash, the market enters a structural correction phase, during which assets are revalued according to their true economic value. Fragile companies or those built on unsustainable speculation disappear, while those with true value and the ability to adapt remain.

This phase is extremely important because it allows the market to be purified and rebuilt on more solid foundations. Often, this correction leads to the sector's maturity phase, where technology transforms from a speculative phenomenon into a productive and stable economic sector. This happened, for example, with the internet after the 2000 bubble, and with e-commerce after the 2008 crisis. The basic features of this phase are evident: (Perez, 2002; Reinhart & Rogoff, 2009)

- Prices return to reasonable levels.
- Screening of companies and players.
- Gradual maturation of technology.
- Building a more stable investment environment.

By analyzing these five stages, it becomes clear that bubbles are not merely fleeting aberrations but rather a recurring part of the dynamics of financial and technological markets. They arise from the interaction of technological innovation with speculative investment behavior and evolve through relatively predictable stages. While the bursting stage often leaves significant losses, the correction stage can be an opportunity to build a stronger and more mature sector.

Accordingly, understanding these stages is essential for developing proactive economic strategies, especially for developing countries that could be affected by the repercussions of any global AI bubble.

3.3 Lessons from Previous Technological Bubbles

Modern economic history has witnessed numerous technological bubbles that have left profound impacts on the structure of the global economy, from the railroad bubble of the nineteenth century to the internet bubble of the late 1990s, and the cryptocurrency and artificial intelligence bubble of the last two decades. Despite the losses these bubbles cause, they

often contribute to accelerating technological innovation and the building of future infrastructure, making them a dual-effect phenomenon, combining creative destruction with long-term growth opportunities. (Perez, 2002)

3.3.1 The Dot-Com Bubble (1995–2001)

The dot-com bubble is one of the most prominent examples of the interaction of technological innovation with financial speculation. During the 1990s, valuations of emerging internet companies rose to unprecedented levels, even though most lacked a sustainable business model or real returns. Media and public optimism about the "new economy" dominated investment decisions until the bubble burst in 2000, causing losses exceeding \$5 trillion in market capitalization. (Shiller, *Irrational Exuberance*, 2000)

After the correction, a few companies—such as Amazon and Google—were able to adapt and survive, confirming that bubbles do not end innovation but rather filter it out in favor of the most efficient players (Perez, 2002). Recent analyses indicate that the artificial intelligence phenomenon of the current decade bears similar characteristics in terms of investment rush and inflated expectations. (INET, 2025)

Considering the above, it becomes clear that technological innovation alone is not enough to justify high valuations; it must be supported by a realistic economic model and sustainable returns.

3.3.2 The Crypto Bubble (2017–2022)

This bubble was characterized by an unprecedented surge in digital asset prices, driven by speculation and herding behavior. Recent studies indicate that most cryptocurrencies have experienced repeated cycles of inflation and deflation, and that the collective behavior of investors played a crucial role in bubble formation (Zhang, Wang, & Li, 2022).

In the post-crash phase, researchers have observed persistent patterns of renewed optimism despite losses, reflecting that digital speculation has become a structural component of modern markets (Kou & Xu, 2024). The bubble has also expanded into subsectors such as non-fungible tokens (NFTs) and decentralized finance (DeFi) platforms, increasing market volatility (Yousaf, Yarovaya, & Mirza, 2023)

Based on the previous analysis, it can be concluded that financial innovation requires effective regulatory frameworks and oversight institutions to avoid a recurrence of extreme bubble cycles.

3.3.3 The AI Bubble (Currently in the Making)

Since 2022, generative AI has emerged as the most attractive technology for investment, with valuations of companies operating in it rising to levels that exceeded actual expected returns (Campbell & Shiller, 2024). Recent economic reports indicate that this phenomenon represents an "emerging bubble" driven by unrealistic promises of a comprehensive transformation in productivity (Arrucha, 2025)

A report by the US Federal Reserve Bank (FRBR, 2025) warned that the trajectory of AI investments closely resembles that which preceded the dot-com bubble. A recent study concluded that the "investment hype" around AI may persist as long as tangible returns are not yet proven (INET, 2025).

Given the preceding analysis, distinguishing between technical and economic value becomes critical, as inflated expectations could trigger significant market corrections over the next few years.

3.3.4 Cumulative Lessons from Tech Bubbles

Comparing these cases reveals that all bubbles share common psychological and economic characteristics: herd behavior, excessive optimism, weak regulation, and detachment from economic fundamentals. However, they also represent periods of transition toward innovation maturity, during which resources are redirected toward more efficient actors (Kindleberger & Aliber, 2011; Reinhart & Rogoff, 2009).

Historical experience shows that bubbles are not the end of technology, but rather a natural correction process to rebalance future promises and actual value (Perez, 2002; Arrucha, 2025).

4 FEATURES OF THE ARTIFICIAL INTELLIGENCE BUBBLE

Since 2022, the world has witnessed a massive surge in interest in artificial intelligence (AI), especially after the launch of generative AI models, which revolutionized the way humans interact with machines. This technology has

become a major focus of global economic and political discourse, described as the "new oil" and a "fourth industrial revolution" capable of reshaping productivity, innovation, and the labor market (MGI, *The Productivity Illusion: Assessing AI's Real Economic Impact*, 2025).

However, this momentum was not without worrying indicators, strikingly similar to what the world experienced with the dot-com bubble at the beginning of the new millennium. Excessive inflation in market values, excessive investment expansion without a solid production basis, and the exaggerated media and political discourse about the "claims of surpassing human capabilities of AI" are all manifestations that reflect the characteristics of an economic bubble in its early stages (FRBR, 2025).

In this context, the most prominent features of the AI bubble can be identified in four main, interconnected elements: rapid and uneven investment growth, inflated media and political expectations, limited actual returns, and extreme concentration in a limited number of companies.

4.1 Rapid and Uneven Investment Growth

Recent years have witnessed an unprecedented influx of investment in AI technologies. According to a PwC (2024) report, global AI investments reached more than \$50 billion in 2024, compared to only \$12 billion in 2022. The United States and China contributed more than 80% of this total, highlighting the geographical imbalance in innovation funding. (PwC, 2024)

Arrieta et al.'s (2023) study indicates that this rapid growth is not always linked to real factors of productivity, but rather is fueled by "herd investing" behavior, which drives investors to fund startups for fear of missing out on future opportunities (Arrieta, Rodriguez, & Sanchez, 2023)

Despite the importance of investments in developing technical infrastructure, the rate of return on these investments remains relatively low due to the high cost of cloud computing and the expense of training large language models. For example, it is reported that training a model like GPT-4 costs over 100 million USD. (OECD, *Artificial intelligence, data and competition*, 2024, p. 18)

This disparity between the size of investments and actual returns is one of the most prominent signs of financial bubbles, as it has historically recurred whenever a futuristic narrative dominates realistic economic analysis (Perez, 2002).

4.2 Media and Political Expectations Inflated

It is noteworthy that the media has played a central role in inflating AI expectations, just as it did during the dot-com bubble of the 1990s. Since 2023, we have witnessed a "rhetorical hype" about AI's potential to radically transform education, health, administration, and the digital economy, to the point of portraying it as a substitute for humans themselves (Le Monde, 2024).

On the other hand, governments have entered the fray by announcing national plans and strategies for "sovereign AI," as the European Union did with its 2024 strategy (European Union, 2024), and the United States with its "Executive Decree on Responsible AI" (The White House, 2025)

However, most of these programs have yet to progress beyond the announcement or experimentation stage.

This media and political discourse leads to what Shiller (2000) calls "narrative contagion," the spread of optimistic expectations through media and financial channels, which reinforces exaggerated investment behavior. Companies are seeking to catch up with AI not out of feasibility, but rather out of fear of losing market confidence (Shiller, Irrational Exuberance, 2000).

4.3 Limited Actual Returns in Many Sectors

Despite significant investment expansion, recent data reveal a clear gap between promises and results. According to a McKinsey Global Institute report (2025), less than 15% of organizations that invested in AI achieved tangible productivity gains, while the majority faced difficulties in integrating intelligent systems into their operations. (MGI, The Productivity Illusion: Assessing AI's Real Economic Impact, 2025)

The sectors that have benefited most so far are digital advertising, software, and financial services, while agriculture, manufacturing, and

education remain far from achieving actual returns (OECD, 2024). This is due to several reasons:

- High cost of infrastructure (data centers, cloud computing).
- Lack of specialized human resources.
- The complexity of integrating AI with traditional systems.
- Weak legal and regulatory frameworks exist in many developing countries.

In this context, the Global Institute's (2025) study indicates that the net economic return from AI investments during the period 2022–2025 does not exceed 0.4% of global GDP, a modest percentage compared to expectations that predicted a jump of more than 3% annually (Arrucha, 2025)

4.4 Extreme Concentration in a Few Companies

According to the OECD, the AI computing supply chain is often characterized by a limited number of suppliers due to high capital intensity and economies of scale, creating significant barriers to entry. Furthermore, in the GPU accelerator market (used for AI training), "the GPU market is highly concentrated, with NVIDIA emerging as the market leader, with recent estimates suggesting the company holds over 80% of the market share for GPU chips used in AI." (OECD, Competition in artificial intelligence infrastructure, 2025, p. 29)

This excessive concentration creates structural fragility in the AI ecosystem; any decline in the performance of a single company can shake the entire market, just as happened during the dot-com bubble when the values of major technology companies collapsed in an interconnected chain (Kindleberger & Aliber, 2011).

This concentration also undermines opportunities for competition and innovation and gives large companies the power to control the path of technological development through their monopoly on data, big models, and computing infrastructure. According to the European Union (2025) report, 70% of AI applications in the European market rely on infrastructure owned by American companies, raising questions about digital sovereignty and technological independence. (European Union, 2024)

5 THE POTENTIAL IMPLICATIONS OF A BURST OF THE AI BUBBLE

The contemporary world is witnessing an unprecedented rush to adopt AI technologies, driven by a general perception that it represents the "Fifth Industrial Revolution" and a major driver of future growth. However, many observers and economists warn that this current momentum bears the hallmarks of a financial and technological bubble—that is, an inflationary state in market valuations that exceeds the true value of the economic and innovative applications of AI (MGI, *The Productivity Illusion: Assessing AI's Real Economic Impact*, 2025; OECD, 2023).

If the so-called "bubble burst" occurs, a collapse in the value of companies operating in this field and a decline in confidence in the technology—the repercussions will be multidimensional, spanning financial markets, employment, scientific innovation, emerging economies, and societal confidence in the technology itself.

The following is a detailed analysis of the most prominent of these implications.

5.1 The Impact of the AI Bubble on Financial Markets and Employment

Financial markets are the most sensitive environment for the emergence of technology bubbles, given their heavy reliance on future expectations and investment speculation fueled by media narratives about the "Fourth Industrial Revolution" and "generative AI." In recent years, data has shown that the valuations of many AI companies have experienced unprecedented inflation, at a rate that outpaces their actual profit growth or market share. Companies such as OpenAI and Anthropic have also received funding exceeding billions of dollars despite the absence of a clear and defined profit model, reflecting the dynamic of "narrative speculation," where financial valuations are based more on future promises than actual results (Shiller, 2019). However, historical experience—such as the dot-com bubble at the turn of the millennium—confirms that these periods of excessive optimism are often followed by sharp price corrections, with markets losing between 40% and 60% of their value in a short period (Kindleberger & Aliber, 2011). This explosion typically leads to a decline in confidence in technology sectors, a mass withdrawal of

venture capital, and the cessation of many startups that relied on consistent funding streams.

In the case of artificial intelligence, the repercussions of the explosion may be deeper and more widespread due to the cross-cutting nature of the technology, which touches vital sectors such as industry, finance, education, and healthcare. A sudden decline in investment could lead to mass layoffs of workers and engineers, especially in startups that rely on external funding without generating stable cash flow. The World Economic Forum (WEF, 2024) warns that nearly 25% of new AI jobs could disappear within three years if investment slows, particularly in the development of large language models (LLMs), big data services, and algorithm training (WEF, *The Future of Jobs Report 2024*, 2024).

In the longer term, the collapse of the AI bubble could spill over into major financial institutions themselves, including the investment banks and hedge funds that financed the expansion of technology companies. This intertwining of the financial and technology sectors increases the fragility of the global financial system and increases the likelihood of financial contagion if valuations suddenly decline (Reinhart & Rogoff, 2009).

Economist Hyman Minsky argues that "financial stability breeds instability," meaning that extended periods of recovery encourage investors to take on increased risk and borrow, ultimately resulting in the accumulation of structural fragility in the financial system, which can eventually cause a collapse. This logic applies perfectly to the case of artificial intelligence today: massive investment flows and exaggerated hopes create an inflationary cycle in digital and technological assets, which quickly turns into a crisis if not supported by real productivity. (Minsky, 1986)

Thus, it can be argued that the bursting of the AI bubble could lead to a wave of financial and structural volatility, including a decline in technology company valuations, a decline in innovation funding, widespread layoffs in the tech sector, and a decline in investor confidence in high-tech markets. However, this correction—if managed rationally—can be viewed as an opportunity to reset the market and direct investments toward more sustainable projects with real economic value.

5.2 The Impact of the AI Bubble Burst on Innovation and Scientific Research

Artificial intelligence (AI) is one of the most dynamic fields in the history of modern science, as evidenced by the pace of scientific publications, volume of patents, and rate of research funding. However, this rapid development is closely linked to investment funding cycles and market dynamics, making research activity in the field vulnerable to the fluctuations resulting from economic bubbles. When financial valuations peak, capital flows into AI projects without scrutiny, leading to an explosion in short-term applied research focused on "the race to the biggest and most expensive models," rather than long-term basic research (OECD, 2023).

However, when the bubble bursts, there is a sharp contraction in research funding, especially for start-ups and private innovation centers that rely on venture capital. This decline in funding has a direct impact on scientific activity. Data from the Organization for Economic Co-operation and Development (OECD, 2023) shows that periods following financial crises typically witness a decline in R&D spending of between 20% and 35% in high-risk sectors. Historically, studies by Perez (2002) show that periods following the bursting of technology bubbles—such as the dot-com bubble—experience a decline of approximately 30% in the number of new patents during the first three years after the crisis. (Perez, 2002)

However, this slowdown is not interpreted as a permanent decline in the pace of innovation. Rather, as Carlota Perez (2002) argues, it represents a phase of "structural purification" that separates true innovation from scientific speculation. In the post-dot-com bubble period, despite the disappearance of hundreds of startups that focused on quantitative growth, a few companies emerged, such as Google and Amazon, that were able to build sustainable business models based on genuine innovation and the practical application of technology. By analogy, it can be argued that the bursting of the AI bubble, despite the temporary stagnation, may represent an opportunity to redirect research activity toward added economic and social value

rather than focusing on "demonstrating technical capabilities." The focus of research is expected to shift from large, expensive AI models to small, specialized innovations and toward the promotion of edge AI, which focuses on efficiency and resource conservation (MGI, The State of AI 2024: From Hype to Value Creation, 2024)

This shift could also encourage a rebalancing of academic and industrial research, with universities and national scientific research centers reasserting their leadership role in developing open-source technologies that serve the real economy, rather than relying entirely on the initiatives of giant corporations, whose activities may decline after the crisis. A McKinsey report (2024) indicates that the post-correction phase may be characterized by a "rationalization of AI use," meaning its integration into the real economy in a more cost-benefit-balanced manner, with an increased focus on sustainability and transparency in research models. Therefore, the bursting of the AI bubble does not necessarily mean the collapse of innovation. Rather, it can be viewed as a transitional turning point that reshapes the scientific research environment along more stable and realistic foundations, establishing a new phase of responsible and sustainable innovation that links technology to long-term development. (MGI, The State of AI 2024: From Hype to Value Creation, 2024)

5.3 On Emerging Economies and Developing Countries (Risks and Opportunities)

Since 2023, the world has witnessed an unprecedented wave of investment in artificial intelligence (AI), with global investments exceeding \$500 billion in 2024, most of which are in major American and Chinese companies (Huaxia, 2025)

However, this rapid rise has been accompanied by excessively inflated startup valuations and unrealistic expectations regarding economic returns, prompting many experts to warn of the imminent emergence of a "new technology bubble."

If the bubble bursts, developing countries will be the most affected due to their near-total reliance on imported technology, weak digital

infrastructure, and limited investment in domestic research.

5.1.1 Macroeconomic Impacts

– Shrinking Foreign Direct Investment (FDI) Flows

The bursting of the bubble is expected to lead to a rapid withdrawal of capital directed towards technology projects in emerging markets, such as digital services and cloud computing companies in Africa and Asia.

In previous experiences—following the dot-com bubble of 2000—investment flows to developing countries declined by 35% over two years (UNCTAD, 2002).

Since most AI investments in the South are financed externally, any correction in global markets will directly translate into the freezing or downsizing of local projects, slowing the digital transformation and increasing unemployment in emerging technology sectors.

– Declining Value of Technology Startups

The lack of robust data infrastructure, limited AI research capacity, and reliance on foreign partnerships constrain the growth and commercial viability of AI startups in Africa. ((CIPIT), 2023, p. 17)

– Impacts on Currencies and Inflation

The decline in the value of digital companies and the decline in financial flows will affect local exchange markets, especially in countries that rely on foreign dollar investments to finance their digital infrastructure.

The rising cost of importing smart technologies and devices will also increase inflationary pressures in the short term (IMF, 2025)

5.1.2 Technological and Knowledge Impacts

– Disruption of Technology Supply Chains

With the stagnation of global markets, exports of cloud artificial intelligence (Cloud AI) services by major companies will decline, deepening the gap in access to technology between rich and poor countries. For example, most African and Arab universities rely on OpenAI, Google Cloud, and Amazon Web Services for research and training. Any

disruption to these services will lead to a partial paralysis of academic research and local applications (UNESCO, 2024).

– Slowdown of Government Digital Transformation Projects

Digitization plans in many developing countries rely on external funding or partnerships with global companies. The bursting of the bubble will force these companies to re-prioritize their technologies, potentially freezing government digital programs such as smart education and e-government (WB, 2024).

– Slowing the adoption of artificial intelligence in productive sectors

The industrial and agricultural sectors in developing countries are still in the early stages of smart transformation. If a global technological recession occurs, these sectors will find it difficult to obtain software, licenses, or technical support, weakening productivity and widening the efficiency gap with developed countries (OECD, 2024).

5.1.3 Social and Institutional Impacts

– Loss of Trust in Technology and Innovation

In developing countries, technology is often associated with the image of a "perceived solution" to unemployment and inefficiency. However, when digital projects fail due to the global recession, a negative social backlash against digital transformation itself may arise, weakening the incentive for innovation and entrepreneurship (Deloitte, 2024)

– Tech Brain Drain

When local job opportunities and funding in startups shrink, programmers and researchers will increasingly migrate to Europe, America, and Asia, a phenomenon known as the "tech brain drain." This will deepen knowledge dependency and delay the development of national AI systems (UNDP, 2025)

– Declining Digital Justice

Economic crises lead to reduced public spending on digitization and digital education, leaving large segments of society outside the digital transformation. This deepens the gap between digitally connected elites and vulnerable groups, creating a new form of

digital inequality (OECD, Bridging the Digital Divide: AI and Productivity in Emerging Markets, 2024)

– **Opportunities for Positive Transformation After the Bubble**

Despite the bleak picture, tech crises often open a window for rebalancing. In the event of a global correction, developing countries can benefit from:

- Declining software and cloud services prices after investors withdraw.
- Redirecting resources toward low-cost local research.
- Encouraging small national companies to fill the gap left by the withdrawal of foreign companies.
- Developing more flexible national regulatory frameworks that take local specificities into account, rather than importing ready-made policies.

5.4 The Impact of the Artificial Intelligence Bubble Burst on Societal Trust in Technology

Societal trust in technology is one of the most important intangible components of sustained digital innovation, representing the link between technological development and its social acceptance. However, historical experience shows that the bursting of technology bubbles not only leaves an economic impact but also creates a cognitive shock in societal consciousness, eroding trust in technology and its promoters (Shiller, *Irrational Exuberance*, 2000). In post-crisis periods, the public mood shifts from enthusiasm to skepticism and caution, and public discourse becomes more critical of innovations that were only recently considered symbols of progress.

In the case of artificial intelligence, the potential bursting of the bubble could lead to a decline in societal faith in the ability of algorithms to bring about the desired change, especially after the media and technology institutions have inflated expectations regarding the ability of intelligent models to replace humans in the fields of work, education, and artistic creativity. However, when these promises fail to materialize as quickly as hoped or when the current limitations of AI are exposed, collective disillusionment arises,

resulting in slow adoption of new technologies and a decline in demand for smart products (WEF, *The Future of Jobs Report 2024*, 2024).

This erosion of trust is further compounded when it coincides with ethical and technical failures such as loss of privacy, algorithmic bias, data leaks, or fears of losing control over autonomous systems. Reports from the Organization for Economic Co-operation and Development (OECD, 2023) emphasize that declining trust in digital technologies after crises can slow the adoption of new innovations for a period of five to ten years, known in tech economics as the "technological legitimacy rebuilding phase."

However, this phase does not necessarily represent a permanent setback. History shows that technological crises often catalyze the emergence of new governance and regulatory reforms that redefine the relationship between society and technology. After every financial or technological collapse, institutional responses emerge that seek to establish an ethics of innovation, such as establishing standards for transparency, accountability, and data protection, which (Perez, 2002) refers to as the "constructive side of bubbles."

In this context, the bursting of the AI bubble—despite its short-term negative effects—may contribute to a global debate about building ethical and humane AI, based on the principles of trust and digital justice, rather than an obsession with profitability and expansion. The bubble can thus be viewed not only as a financial or technological disaster, but also as an opportunity to re-establish social trust on more mature and sustainable foundations that balance technological progress with ethical considerations, and between innovation ambitions and human rights in the digital age.

6 FUTURE SCENARIOS AND ADAPTATION STRATEGIES

Global economies today face a critical crossroads in their relationship with artificial intelligence (AI). After a period of excessive investment and expectations, the signs of a "tech bubble" are clear, but at the same time, new opportunities are emerging to transform this wave into a stage of technological maturity and sustainability.

Several recent economic reports indicate that the years 2025–2026 will be decisive in determining the future of the sector: either the world will head toward a price correction and temporary investment stagnation, or toward equilibrium and sustainable growth based on the actual integration of AI into the real economy (WEF, *AI Futures: Managing the Next Technological Transition*, 2025)

Therefore, understanding future scenarios is not limited to predicting a burst or continuation, but rather extends to analyzing how to adapt in each possible scenario. Four strategic paths are proposed here, representing the pillars of the transition toward sustainable technological maturity:

- Moving from bubble to technological maturity.
- Rational investment in AI infrastructure.
- Supporting local research and development.
- Enhancing digital culture within organizations.

6.1 The Transition from Bubble to Technological Maturity

From the perspective of the history of innovation, every technological wave goes through a cycle of hype → expansion → explosion → maturity (Perez, 2002). Today's AI is likely experiencing the peak of hype and price inflation, just as the internet did in 1999.

However, history demonstrates that the bursting of a bubble does not mean the end of innovation, but rather the beginning of its true productive phase. After the bursting of the internet bubble, companies like Amazon and Google emerged as leaders because they focused on actual added value rather than market speculation (Mazzucato, 2013)

By the same logic, technology experts predict that the next phase of AI will witness a shift from large-scale models to specialized AI models capable of serving specific sectors such as agriculture, health, education, and energy (OECD, 2024).

The Stanford AI Index (2025) also indicates that investment is beginning to shift from developing a single "large language model (LLM)" to more

efficient and less expensive hybrid solutions. This shift is an early sign of "maturity," with the focus

shifting to sustainability and economic viability rather than hype (Maslej et al., 2025)

From an economic perspective, this shift can be represented by the "market correction" model, which rebalances the (overvalued) symbolic value of a technology with its true economic value (Campbell & Shiller, 2024)

From an analytical perspective, if a correction occurs in 2025–2026, companies with solid scientific foundations (such as Nvidia, Microsoft, and Anthropic) will remain in the lead, while hundreds of startups without a sustainable profit model will disappear. So, the transition from bubble to maturity is not a crisis; rather, it is a necessary corrective mechanism that paves the way for a new, more rational and stable production phase.

6.2 Rational Investment in AI Infrastructure

According to Axis Intelligence, about 33.7% of AI funding in 2024 went into infrastructure and foundation models. (Axis Intelligence, 2025)

However, after every bubble, leading economies realize that the real return lies in infrastructure: servers, data centers, green energy, and fast connectivity.

According to recent analyses, training frontier AI models requires substantial power inputs, with individual models demanding on the order of hundreds of megawatts. The largest AI model currently requires a power draw of approximately 154 MW. Cumulative training consumption for large-scale AI systems has been estimated at about 1,700 GWh, highlighting the need for robust and environmentally efficient infrastructure (International Energy Agency, *Energy and AI*, 2025, p. 49; Down, 2025).

For developing countries, investing in digital infrastructure is a strategic priority. This includes:

- Building national data centers.
- Developing high-speed internet networks.
- Providing sustainable energy sources to reduce operating costs.
- Supporting partnerships with local universities and startups to develop national computing solutions.

When this phenomenon is subjected to logical analysis, it becomes clear that if a price correction occurs in global markets, countries that have focused on infrastructure will subsequently benefit from lower technology costs, giving them a competitive advantage after the bubble bursts. Therefore, rational investment is to build the foundations (computing infrastructure, energy, and connectivity), as these are the assets that remain after the speculative wave subsides.

6.3 Supporting Local Research and Development

UNESCO (2024) confirms that the North-South AI gap is not only a technological gap, but also a knowledge-research gap. (UNESCO, 2024)

Developed countries produce more than 90% of academic research registered in AI journals, while developing countries contribute no more than 2%, often with limited applied research.

Therefore, promoting local research and development (R&D) is a central step in any national AI strategy.

This includes:

- Establishing national AI centers linked to universities and decision-making centers.
- Encouraging public-private partnerships.
- Funding applied research directed at national priorities (such as smart agriculture, water management, and renewable energy).
- Integrating AI as a key component of higher education curricula.

In comparative studies, India, South Korea, and Canada are successful models in building integrated research systems that have enabled the production of local solutions with high export value (WB, 2024).

From a strategic perspective, it can be said that investing in local research transforms AI from an "imported technology" to a "national development tool," reducing the vulnerability of emerging economies to global market fluctuations. Therefore, without a local R&D system, developing countries remain mere consumers of technology, not active users.

6.4 Enhancing a Digital Culture in Organizations

A true digital transformation cannot be achieved without changing organizational culture.

Deloitte (2024) indicates that approximately 65% of AI projects in organizations fail due to the lack of a digital culture and employees' refusal to change. (Deloitte, 2024)

In other words, integrating AI is not just a technical decision; it is an organizational and cultural change process that requires conscious leadership and a strategic vision.

In this context, organizations should focus on:

- Training human resources to use everyday AI tools (such as predictive analytics and automation).
- Restructuring decision-making systems to be data- and analytically based rather than intuition-based.
- Encouraging a culture of innovation and experimentation without fear of failure, as AI is a rapidly evolving field.
- Adopting clear ethical and regulatory policies for the use of data and intelligent systems (AI governance).

From an organizational perspective, organizations that invest in an internal digital culture possess a high degree of adaptive flexibility, enabling them to survive even in the event of a market correction or recession. So, the success of artificial intelligence depends not only on algorithms, but also on the human beings who understand and employ them well.

By linking theoretical data with practical reality, indicators show that the world is approaching an inflection point in the path of artificial intelligence.

While some fear a "new bubble," others see this phase as paving the way for AI to enter a stage of economic and institutional maturity.

The real challenge lies not in predicting the bubble's bursting, but in the ability to adapt after it.

The economies that will succeed are those that:

- Build their digital infrastructure on sustainable foundations,
- Invest in local knowledge and research,
- Reshape their corporate culture around innovation and digital responsibility.

7 CONCLUSIONS

This study concludes that what is now known as the "AI bubble" represents a multidimensional phenomenon, combining financial dynamics, technological bets, and high societal expectations regarding the future of AI. As historical experiences with previous technology bubbles, such as the Internet bubbles of the late 1990s, have shown, overestimating the short-term potential of emerging technologies often leads to inflated financial valuations, followed by a painful explosion that resets the trajectory toward a more balanced economic reality.

The results of the analysis indicate that the AI sector is currently experiencing a "boom and bust" phase, with investments flowing at an unprecedented pace into startups and research labs, without all of them translating into tangible productivity returns. This situation holds significant opportunities for innovation, but also entails economic and structural risks, especially if a "hard correction" occurs in the market, which could lead to widespread financial losses, a contraction in research funding, and a decline in investor and societal confidence in the technology.

On the social level, a potential bubble burst could negatively affect the labor market, especially in economies that have not yet prepared for the repercussions of a profound digital transformation. Failure to manage this phase could also slow innovation in critical areas such as scientific research or even hinder digital transformation in emerging economies, which rely heavily on technology as a driver of development.

The potential bursting of the AI bubble, despite the economic and investment losses it may cause, represents a necessary corrective phase in the course of technological development. As previous technological revolutions have demonstrated, bubbles are not the end of development, but rather part of its dynamics. They expose exaggerated valuations, reveal the limits of commercial applications, and push toward a new level of cognitive and technological maturity. Therefore, the impact of the crisis depends on the willingness of countries and institutions to adopt proactive policies based on:

- Diversifying sources of investment in scientific research to avoid excessive reliance on private funding or speculative investments, and ensuring the sustainability of scientific progress even during periods of technological stagnation.
- Protecting the labor market from digital disruptions through vocational rehabilitation programs and employment support policies in sectors affected by automation.
- Investing in human capital as the foundation for ensuring a responsible and sustainable transition to AI, through education, continuous training, and building a critical digital culture among individuals.
- Adopting proactive policies to monitor financial valuations in the technology sector, to limit excessive speculation, and ensure transparency in financial disclosure.
- Supporting long-term academic research instead of focusing excessively on short-term commercial projects, to ensure the sustainability of innovation after any market correction.
- Developing national legislative frameworks for AI that take into account local specificities and limit overreliance on foreign companies for digital infrastructure.
- Activating international cooperation between developing countries and global research institutions to share knowledge and exchange experiences on the responsible use of AI.
- Enhancing societal trust through ethical policies in the development and application of AI, embracing transparency, privacy protection, and algorithmic fairness.
- Establishing a national or regional observatory to monitor the development of the AI market and periodically assess the indicators of the technology bubble.

Artificial intelligence—despite all the hype and aspirations it generates—is only one stage in a long process of technological transformations that the global economy has witnessed. Therefore, approaching it rationally and with foresight, avoiding both hype and alarmism, is the best way to avoid a "new bubble" scenario and ensure that the AI revolution serves humanity and development, rather than merely a passing wave in the history of digital capitalism.

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IMPACT OF EXPERT SYSTEMS ON IMPROVING ACCOUNTING INFORMATION SYSTEM QUALITY

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ABSTRACT

This study aims to investigate the impact of expert systems on improving the quality of accounting information systems (AIS) in Algeria. Digitalization and automation have become firmly established practices across financial and administrative domains. Among these advancements, intelligent accounting systems play a decisive role in improving data quality and enhancing the precision of financial reporting. These improvements directly support more informed and reliable managerial decisions. A quantitative explanatory research design was used to investigate whether the adoption of expert systems has an impact on the four dimensions of AIS quality: accuracy and reliability of accounting data, timeliness of financial information, relevance and completeness, and efficiency and ease of system use. Questionnaire data were gathered through email to 150 accounting professionals (73 usable responses). The data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The study's results demonstrated that expert systems have a positive impact on all dimensions of AIS quality. The strongest relationships were observed with the accuracy and reliability of data, followed by timeliness, relevance, and efficiency. The findings demonstrate the strategic importance of expert systems in improving the performance of accounting information systems (AIS). They also provide actionable insights for accounting professionals and institutions seeking to advance their digital competencies. The study makes a valuable contribution to literature by addressing a geographic gap and presenting evidence from a developing country context.

1 INTRODUCTION

The ongoing digital transformation in accounting has accelerated the adoption of intelligent

technologies to enhance the efficiency, accuracy, and reliability of financial reporting. Among these technologies, expert systems, defined as AI-based programs that replicate human expert

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reasoning through rule-based logic and knowledge bases, have become particularly relevant in the context of accounting information systems AIS (Ahmad & Zawaideh, 2014). Integrating these systems into AIS enables automated execution of complex decision-making tasks, minimizes human error, and strengthens data validation and internal control mechanisms (Zayed, Nour, Al Attar, Almubaideen, & Abdelaziz, 2024; Johri, 2025).

Globally, numerous studies have demonstrated that expert systems support real-time analysis, fraud detection, and strategic decision-making by enhancing the quality and relevance of accounting outputs (Al Astal, Nomran, & Milhem, 2025; Alramahi, Alzagaybeh, Almubaydeen, & Binsaddig, 2024). However, most of these studies have been concentrated on developed economies, where advanced infrastructure and digital readiness facilitate widespread Artificial Intelligence (AI) deployment. In contrast, there is little empirical evidence regarding the use and impact of expert systems within developing countries, particularly in North Africa.

In Algeria, despite growing interest in digital innovation, the integration of expert systems into AIS remains in its early stages. Organizations face several challenges when adopting expert systems. These include limited understanding of their applications, insufficient technical expertise, and inadequate financial resources. Such obstacles have hindered the integration of AI-based solutions in the accounting profession, and although there is a research gap in knowledge regarding the effect of expert systems on AIS quality in the local context. To fill this gap, this research aims to examine the influence of expert systems on AIS quality. It is grounded in the perceptions of accounting professionals in Algeria. It revolves around four main quality dimensions: accuracy and reliability of accounting data, timeliness of financial information, relevance and completeness of information, and efficiency and ease of system use. By integrating empirical findings with locally sourced data, this research contributes to the growing body of literature on the implementation of expert systems within accounting information systems.

It also offers practical implications for Algerian companies and regulatory bodies aiming to

modernize their accounting frameworks through AI-based tools.

In the Algerian context, and based on the previous literature, the study aimed to answer the following research question.

RQ: What is the impact of expert systems on the quality of accounting information systems, as perceived by Algerian accounting professionals?

To explore this question, data were collected by a structured questionnaire sent to members of the accounting profession in Algeria. Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed to analyze the measurement components and structural relationships within the proposed model.

The structure of the paper is as follows: the second section presents the theoretical framework and literature review; the third section outlines the research method; the fourth section presents the results, which are discussed in Section five; and finally, Section six concludes the study, summarizing key insights and implications.

2 THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1 Application of Expert Systems in Accounting

Expert systems represent a category of AI applications fashioned to emulate human expert decision-making by utilizing logical rules of a formal knowledge structure (Ahmad & Zawaideh, 2014). These systems have the capabilities to model rule-based inference, fuzzy logic, adaptive learning, and mimic intelligent analysis. They can simulate the professional decision-making process in various areas, such as accounting. Within the domain of AIS, expert systems are implemented to support complex decision-making processes, including audit planning, fraud detection, earnings management assessments, and real-time financial reporting.

These systems are designed to manage the increasing volume and complexity of financial data and decision variables.

Emerging research highlights the pivotal role of expert systems in strengthening the automation,

accuracy, and cognitive functionality of AIS infrastructures. Ahmad and Zawaideh (2014) also observed that the application of expert systems based on fuzzy systems had simplified the AIS after they removed the classical mathematical programming interface and replaced it with the linguistically built modules. The simplified and user-friendly design enhanced the overall user experience.

It also reduced training time and minimized the need for IT staff involvement.

These improvements collectively surpassed the expectations of the financial departments of large enterprises regarding AIS availability and functionality.

Additional empirical evidence demonstrates that the application of expert systems within AIS contributes to greater operational effectiveness and supports improved decision-making. Al Astal et al. (2025) reported on a study of organizations in the Kingdom of Bahrain, claiming they developed an AIS by integrating expert systems into their infrastructure. This integration consequently increased both the efficiency of processing tasks and the accuracy of financial reporting. These environments also focused on automating repetitive tasks and supporting more evidence-based financial decisions. The study recommended implementing training programs to ensure effective use of these systems.

Additionally, the system would not only process data but also perform more sophisticated predictions and anomaly screening. For example, Zayed et al. (2024) examined the role of expert systems in the AIS in enhancing fraud detection in the hospitality industry. The authors inferred that the prediction rule generation model of the developed expert system enhanced its ability to detect financial fraud and prevent its recurrence. In a separate study, Alramahi et al. (2024) found that the implementation of expert systems contributed to the reduction of risks associated with cloud accounting in Jordanian telecommunication firms. The authors proposed that expert systems may strengthen system control and improve risk identification processes.

From a system design perspective, Yan and Ji (2024) highlight the role of expert systems in

designing intelligent, adaptive AIS systems. Their theoretical analysis suggests that expert systems enhance the reliability and credibility of AIS by facilitating automation, minimizing human errors, and ensuring the accuracy of accounting information. Properly integrated, these systems help make AIS a more adaptive strategy for financial decision-making.

All these studies demonstrate that expert systems are moving from technical auxiliaries to integral parts of AIS. Their ability to mimic expert judgment, interpret data autonomously, and enhance decision-making precision positions among the principal drivers of innovation in contemporary accounting systems.

2.2 Quality of Accounting Information Systems

The effectiveness of AIS revolves around the quality of the system in supporting financial processes, decision-making, and statutory obligations. Four primary dimensions have been central to the perception of AIS quality:

- accuracy and reliability of accounting data;
- timeliness of financial information;
- relevance and completeness of information;
- efficiency and ease of system use.

2.2.1 Accuracy and Reliability of Accounting Data

Accuracy and reliability are critical dimensions that underpin the quality of AIS, as they ensure that the accounting information accurately reflects financial reality and is free from material misstatements. Recent empirical studies confirm that the new AIS, particularly AIS with embedded intelligent technologies, can greatly enhance data quality. For example, Johri (2025) examines the effects of integrating AI into AIS systems, highlighting improvements in the reliability of financial reports achieved by reducing manual input errors, enhancing data consistency, and optimizing the production process within the financial reporting cycle. Similarly, Al Astal et al. (2025) found that the implementation of automated AIS systems was associated with more accurate financial results and reduced errors, particularly when internal controls and validation mechanisms were embedded in the system's design.

2.2.2 Timeliness of Financial Information

AIS timeliness refers to the alignment between the issuance and availability of financial data and real-time business conditions. This alignment is considered crucial for enabling informed decision-making. The use of intelligent systems in AIS across its architecture introduced faster information processing as the much-needed solution for timely decision-making and reporting (Quan, 2025). Timing is critical in high-risk industries such as telecommunications, particularly in the detection of anomalies and fraudulent activities. Zayed et al. (2024) highlighted that the timely detection of financial irregularities was made possible through predictive monitoring functions embedded in AIS platforms, reducing reporting delays and enhancing control responsiveness.

2.2.3 Relevance and Completeness of Information

Financial information should be relevant and complete to ensure that reports meet users' informational needs, reflecting the organization's overall financial operations. Johri (2025) claimed that AIS enhanced with intelligent tools generates more comprehensive analytical reports by integrating data from both internal and external sources, thereby enhancing its strategic value. Alramahi et al. (2024) also emphasized that expert systems contribute to the completeness of AIS output by systematically evaluating large datasets, identifying gaps in data entry, and ensuring that critical financial indicators are captured comprehensively.

2.2.4 Efficiency and Ease of System Use

Efficiency and user-friendliness determine how effectively users interact with the AIS. Ahmad and Zawaideh (2014) demonstrated that AISs incorporating fuzzy logic and expert system-guided design significantly reduces overall system complexity.

As a result, even users without accounting backgrounds, particularly non-technical staff, can more easily navigate, analyze, and interact with financial data. Al Astal et al. (2025) reported that systems with lower usability were less frequently adopted and demonstrated reduced operational efficiency, primarily due to limited training duration and minimal user error feedback. Yan and Ji

(2024) also indicated that user-friendly AIS developed using AI technologies expedited all processes, reduced the burden of financial reporting, and improved productivity at a broader scale.

2.3 Literature Review and Research Hypotheses Development

The use of expert systems in AIS has received growing attention in recent times to enhance decision quality, reporting quality, and operational efficiency. Expert systems that simulate expert cognitive processes by utilizing rule-oriented logic, fuzzy inference, and information embedded in knowledge bases are useful and structurally sound for automatically solving challenging accounting problems (Ahmad & Zawaideh, 2014). In the context of AIS, such tools promote consistency in evaluative decision-making, facilitate automated data verification, and produce reporting outputs that are both timely and analytically relevant.

Recent research presents empirical evidence demonstrating how expert systems enhance key AIS quality attributes. Automated procedures and internal consistency mechanisms support the generation of high-quality and reliable data. For example, according to Johri (2025), AI-based AIS reduces the likelihood of manual input errors and incorporates system-level financial data validation, thereby enhancing the reliability of reported outcomes. This result is also supported by Al Astal et al. (2025), who found that expert systems enhance data quality and reduce the level of inconsistency across reporting periods in the case of Bahraini firms.

One other advantage of the expert systems embedded in AIS is the timelier reporting of financial information. Quan (2025) demonstrated that automated accounting systems, particularly those integrated with intelligent components, optimize data processing and deliver real-time financial insights. This result is consistent with Zayed et al. (2024), who found that expert system-driven fraud detection functionalities enhanced speed and reduced the time required to address the anomalies, especially in high-risk sectors.

Literature likewise describes the potential impact of expert systems in the context of making AIS information more relevant and complete. These

tools can contextualize and synthesize large amounts of data into decision-relevant products. According to Johri (2025), expert systems can generate more meaningful reporting by combining both internal and external data. Similarly, Alramahi et al. (2024) showed that expert systems in cloud-based AIS platforms filled data gaps and ensured the completeness of financial records.

Furthermore, efficiency and system usability are substantially enhanced through the integration of expert systems. Ahmad and Zawaideh (2014) highlighted how expert systems reduced system complexity and improved user accessibility, particularly by providing interfaces that mimic natural reasoning. Yan and Ji (2024) further noted that intelligent AIS improved staff productivity and simplified accounting workflows, making systems more user-centered and efficient in operation.

This research contributes to the literature by extending the scope of expert system studies into a North African developing countries context, where empirical evidence remains scarce. Unlike prior works that treat AIS quality generically or focus on broader AI tools, this study isolates the specific role of expert systems within AIS. It also offers practitioner-oriented insights that may assist Algerian organizations, technology developers, and policy stakeholders in designing more effective, user-responsive accounting systems that align with modernization goals.

Based on the conceptual and empirical foundations reported above, the following hypotheses are proposed:

- H1:** The use of expert systems positively impacts the accuracy and reliability of accounting data.
- H2:** The use of expert systems positively impacts the timeliness of financial information.
- H3:** The use of expert systems positively impacts the relevance and completeness of information.
- H4:** The use of expert systems positively impacts the efficiency and ease of system use.

3 METHODOLOGY

3.1 Research Design

To achieve the study's purpose, the research adopted a quantitative, explanatory design to discover the effect of expert systems on the quality

of accounting information systems. We examined how the adoption and usage of expert systems affect critical facets of system quality, like the accuracy and reliability of accounting data, the timeliness of financial reporting, the relevance and completeness of information, and the efficiency and ease of system use.

The data were subjected to analysis, and the proposed hypotheses were evaluated via PLS-SEM using SmartPLS software. Hair et al. (2022) emphasize its appropriateness in exploratory research contexts that employ multifaceted modeling structures, non-standardized indicators, and moderate sample sizes, particularly within nascent analytical domains. PLS-SEM facilitated the full assessment of both the measurement model (construct validity and reliability) and the structural model (testing of the hypothesized relationships).

3.2 Research Sample

A simple random sampling method was used to select 73 Algerian accounting practitioners in this study. As pointed out by Rahman et al. (2022), this sampling technique adheres to the principle of equal likelihood, meaning that each member of the population has an equal chance of selection. This strategy enhances sample representativeness and minimizes selection bias, thereby increasing the credibility of the findings.

3.3 Data Collection Tool and Research Data

Data collection was conducted via a structured questionnaire grounded in prior research. The instrument assessed Algerian accountants' views on the application of expert systems and the resulting impact on the quality of accounting information systems. The survey comprised two distinct components: one captured respondent demographics, and the other included predefined items focused on the core research objectives.

Section 1 explored the adoption of expert systems in accounting through a ten-point scale survey. The items were designed to assess both familiarity with and implementation of such systems in professional practice.

Section 2 focused on the quality of the accounting information system and was developed along four thematic axes. The first axis assessed perceptions

of the accuracy and reliability of accounting data. The second examined views on the timeliness of financial information. The third construct examined user perceptions of information relevance and completeness. The fourth focused on perceived system efficiency and ease of use. Each dimension was assessed using five measurement items.

All items employed a five-point Likert scale ranging from "Strongly Disagree (1)" to "Strongly Agree (5)." The questionnaire was distributed electronically to 150 accounting professionals, yielding 81 responses (54% response rate). After excluding eight incomplete submissions, 73 valid responses were retained for analysis, resulting in a usable response rate of 48.7%. Although lower than traditional face-to-face survey rates, online

response levels are considered acceptable in academic research, particularly for dispersed professional populations (Nulty, 2008; Evans & Mathur, 2005), due to their cost-effectiveness, convenience, and efficiency.

4 RESULTS

4.1 Descriptive Statistics

The sample comprised 73 Algerian accounting professionals. Table 1 illustrates the distribution of respondents based on their professional categories and years of academic experience. Certified accountants made up 16.4% of the total sample, external auditors accounted for 53.5%, and chartered accountants represented 30.1%.

Table 1. Cross-tabulation of Professional Category and Years of Experience

Experience (years)	Professional category	Frequency	% within Experience	% of Total
< 5	Certified Accountant	8	42.1%	11.0%
	External auditor	8	42.1%	11.0%
	Chartered Accountant	3	15.8%	4.1%
	Total	19	100.0%	26.0%
5–10	Certified Accountant	3	17.6%	4.1%
	External auditor	12	70.6%	16.4%
	Chartered Accountant	2	11.8%	2.7%
	Total	17	100.0%	23.3%
11–15	Certified Accountant	0	0.0%	0.0%
	External auditor	11	55.0%	15.1%
	Chartered Accountant	9	45.0%	12.3%
	Total	20	100.0%	27.4%
> 15	Certified Accountant	1	5.8%	1.3%
	External auditor	8	47.1%	11.0%
	Chartered Accountant	8	47.1%	11.0%
	Total	17	100.0%	23.3%

Most respondents with fewer than five years of experience were certified accountants and external auditors (42.1%). Just 15.8% chartered accountants were reported in this group. Among those having between 5 and 10 years of experience, the majority were external auditors (70.6%), followed by certified accountants (17.6%), and chartered accountants (11.8%).

Among respondents with 11 to 15 years of professional experience, external auditors represented the majority (55%), while chartered accountants comprised 45% of the group. Lastly, respondents with over 15 years of experience were evenly split between external auditors (47.1%) and chartered accountants (47.1%), followed by certified accountants (5.8%).

4.2 Measurement Model Analysis

4.2.1 Convergent validity Analysis

Table 2 presents a summary of the convergent validity and reliability outcomes for all latent constructs within the measurement model. Convergent validity evaluates whether the indicators of a construct exhibit sufficient shared variance, as determined by outer loadings, composite reliability (CR), and average variance extracted (AVE) (Hair, Hult, Ringle, & Sarstedt, 2022). Most item loadings surpassed the 0.70

threshold, signifying robust construct-item relationships. Four items (B3, D2, E1, E4) exhibited loadings between 0.65 and 0.70; however, they were retained due to their conceptual significance and negligible impact on reliability. CR values ranged from 0.893 to 0.959, and AVE values from 0.627 to 0.739, indicating compliance with recommended measurement standards. These findings confirm adequate convergent validity and internal consistency, thereby supporting the reliability of the measurement model for structural analysis.

Table 2. Convergent Validity (CV) and Construct Reliability (CR) Statistics

Constructs	Items	Factor loading	Average variance extracted	Composite reliability
Adoption of Expert Systems in Accounting	A1	0.780	0.680	0.959
	A2	0.821		
	A3	0.784		
	A4	0.817		
	A5	0.821		
	A6	0.825		
	A7	0.877		
	A8	0.816		
	A9	0.850		
	A10	0.803		
Accuracy and Reliability of Accounting Data	B1	0.769	0.645	0.914
	B2	0.759		
	B3	0.650		
	B4	0.903		
	B5	0.836		
Timeliness of Financial Information	C1	0.790	0.627	0.893
	C2	0.825		
	C3	0.810		
	C4	0.775		
	C5	0.756		
Relevance and Completeness of Information	D1	0.710	0.648	0.900
	D2	0.652		
	D3	0.908		
	D4	0.858		
	D5	0.865		
Efficiency and Ease of System Use	E1	0.674	0.739	0.934
	E2	0.846		
	E3	0.817		
	E4	0.686		
	E5	0.725		

4.2.2 Discriminant Validity Analysis

Discriminate validity pertains to the extent to which a latent construction is genuinely distinct from other constructions within a model. Establishing this validity indicates that each construct embodies a unique dimension not encapsulated by the others (Hair, Hult, Ringle, & Sarstedt, 2022). A frequently utilized method for evaluating discriminant validity is the Fornell-Larcker criterion, which entails comparing the square root of the AVE for each construct with its correlations with other constructs. Discriminate validity is deemed satisfactory when the square root of the AVE (presented on the diagonal in Table 3) surpasses the correlations with other constructs (off-diagonal). As illustrated in Table 3, all

diagonal values exceed the inter-construct correlations, signifying that each latent variable is sufficiently distinct. For example, the square root of the AVE for the construct Adoption of Expert Systems in Accounting is 0.815. This value is higher than its observed correlations with the constructs Accuracy and Reliability of Accounting Data (0.621) and Timeliness of Financial Information (0.590). Similarly, Efficiency and Ease of System Use have a diagonal AVE value of 0.792, which is greater than their correlations with all other constructs. These findings confirm that the model satisfies the Fornell-Larcker criterion, demonstrating adequate discriminant validity and supporting the application of the measurement model in subsequent structural analyses.

Table 3. Fornell-Larcker Criterion for Discriminant Validity

Latent Variables	Adoption of Expert Systems in Accounting	Accuracy and Reliability of Accounting Data	Timeliness of Financial Information	Relevance and Completeness of Information	Efficiency and Ease of System Use
Adoption of Expert Systems in Accounting	0.815				
Accuracy and Reliability of Accounting Data	0.621	0.801			
Timeliness of Financial Information	0.590	0.686	0.805		
Relevance and Completeness of Information	0.442	0.579	0.725	0.753	
Efficiency and Ease of System Use	0.358	0.352	0.53	0.621	0.792

4.3 Structural Model Analysis

4.3.1 Structural Model Quality Assessment

After estimating the structural model, its model's quality was assessed using several standard metrics in PLS-SEM: predictive relevance (Q^2), coefficient of determination (R^2), adjusted R^2 , and the goodness-of-fit (GOF) index. As shown in Table 4, all Q^2 values are positive, ranging from 0.039 to 0.234, which indicates that the model has acceptable predictive relevance for the dependent constructs (Hair, Hult, Ringle, & Sarstedt, 2022). The R^2 values, which measure the model's

explanatory power, range from 0.128 for Efficiency and Ease of System Use to 0.385 for Accuracy and Reliability of Accounting Data. The adjusted R^2 values are closely aligned with their respective R^2 values, supporting the model's parsimony and structural stability. The model's GOF value is 0.39, exceeding the 0.36 threshold for a large effect size (Wetzels, Odekerken-Schröder, & Van Oppen, 2009), suggesting a strong balance between measurement and structural quality. Collectively, these metrics confirm the robustness and relevance of the model in assessing the impact of the adoption of expert systems on accounting information systems quality in Algeria.

Table 4. *Quality Assessment of the Structural Model Using R², Q², and GOF*

Latent Dependent Variables	Q ² = (1-SSE/BSP)	R-squared	R-squared adjusted	GOF (goodness of fit)
Accuracy and Reliability of Accounting Data	0.234 -	0.385 -	0.377 -	0.39 -
Timeliness of Financial Information	0.202 -	0.348 -	0.339 -	
Relevance and Completeness of Information	0.109 -	0.196 -	0.184 -	
Efficiency and Ease of System Use	0.039 -	0.128 -	0.116 -	

4.3.2 Hypotheses Testing

The final phase of the structural model evaluation focused on testing the study's hypotheses by analyzing the direct effects of expert systems on key dimensions of AIS quality. Table 5 presents the standardized path coefficients (β), t-values, and p-values for each proposed relationship. The results reveal that the integration of expert systems significantly and positively influences all four targeted constructs. The strongest effect was observed for Accuracy and Reliability of Accounting Data ($\beta = 0.621$, $t = 8.354$, $p < 0.001$), lending strong support to H1 and highlighting the pivotal role of expert systems in enhancing the precision and dependability of financial reporting processes. Similarly, expert systems showed a significant positive impact on Timeliness of

Financial Information ($\beta = 0.590$, $t = 6.985$, $p < 0.001$), supporting H2; on Relevance and Completeness of Information ($\beta = 0.442$, $t = 4.198$, $p < 0.001$), confirming H3; and on Efficiency and Ease of System Use ($\beta = 0.407$, $t = 3.438$, $p < 0.001$), validating H4. These findings highlight that the integration of expert systems significantly enhances accounting information systems by improving the accuracy, timeliness, relevance, and usability of financial data. In the Algerian context, such technological adoption strengthens the overall effectiveness and reliability of accounting processes. This affirms the strategic role of expert systems in advancing the performance of accounting functions and ensuring alignment with international standards and best practices.

Table 5. *Structural Model Path Coefficients and Hypothesis Testing Results*

Hypothesis	Path	β (Coefficient)	t-value	p-value	Supported
H1	Expert Systems → Accuracy and Reliability of Accounting Data	0.621	8.354	<0.001	Yes
H2	Expert Systems → Timeliness of Financial Information	0.590	6.985	<0.001	Yes
H3	Expert Systems → Relevance and Completeness of Information	0.442	4.198	<0.001	Yes
H4	Expert Systems → Efficiency and Ease of System Use	0.407	3.438	<0.001	Yes

5 DISCUSSIONS

The study's findings provide strong empirical support for the theoretical proposition that the application of expert systems substantially

improves the functionality of accounting information systems across several domains. These results align with and extend existing literature, confirming that expert systems offer tangible benefits to the accounting function by

enhancing data reliability, decision timeliness, information relevance, and operational efficiency.

First, the significant positive effect of expert systems on the accuracy and reliability of accounting data ($\beta = 0.621$, $p < 0.001$) suggests that automation and embedded intelligence within expert systems can effectively reduce human error and improve the precision of financial records. This supports the findings of Zhang (2021), who demonstrated that integrating artificial intelligence, data mining, and machine learning into accounting information systems significantly improves the accuracy and operational efficiency of data processing, thereby reinforcing the integrity and reliability of financial information.

Second, the impact of expert systems on the timeliness of financial information ($\beta = 0.590$, $p < 0.001$) highlights their utility in streamlining routine accounting operations, thereby accelerating reporting processes. These findings corroborate those of Haddad (2021), who observed that intelligent automation reduces latency in financial disclosures, particularly in environments with limited staffing or manual bottlenecks.

Third, regarding relevance and completeness, expert systems demonstrated a statistically significant positive influence ($\beta = 0.442$, $p < 0.001$). This finding aligns with Kadhim and Al Ani (2024), who emphasized that artificial intelligence-based accounting information systems significantly enhance the accuracy and completeness of accounting outputs, thereby improving user interpretation and aiding informed decision-making.

Fourth, expert systems significantly enhanced efficiency and ease of system use ($\beta = 0.407$, $p < 0.001$). This suggests that these systems not only reduce operational complexity but also improve user interface experiences, a finding consistent with Alrfai et al. (2023), who confirmed that the application of expert systems in accounting information systems significantly improves operational efficiency, reduces complexity, and enhances user experience and ease of use in organizations.

The findings enhance methodological discourse by presenting evidence that PLS-SEM is effective in capturing the influence of emerging technologies on accounting systems. Model

quality indices (e.g., $R^2 = 0.385$ for accuracy and reliability, $GOF = 0.39$) showed a good fit, validating the strength of the chosen model to reflect system-level outcomes in a real-world scenario.

While the study offers valuable insights, its geographic limitation to Algeria suggests the need for broader cross-country empirical validation. Previous studies have focused on more technologically advanced markets without considering how expert systems operate in countries with limited digital infrastructure or different institutional arrangements (Zhen & Zhen, 2024). The implications of the results are also wider for the deployment of smart systems in developing economies.

6 CONCLUSION

This study provides empirical support regarding the role of expert systems in improving AIS performance within the Algerian context. Empirical data gathered from accounting professionals, analyzed using PLS-SEM, indicate that expert systems positively influence key attributes of AIS quality.

These include accuracy and reliability, timeliness of financial reporting, informational relevance and completeness, as well as system efficiency and user-friendliness.

These results highlight the significant advancements of smart technologies within contemporary accounting landscapes. By improving operational performance, expert system technology also contributes to the creation of reliable financial information. This, in turn, is essential for sound decision-making and strengthening organizational openness. These results align with prior empirical studies that demonstrate the potential benefits of implementing AI and expert systems in enhancing data integrity, process automation, and system performance (Al Astal, Nomran, & Milhem, 2025). The study also closes a significant gap in literature by locating its investigation in a developing country setting, where empirical studies on expert systems and AIS integration are rare. By contributing new empirical insights, the research strengthens the body of literature indicating that technological innovation can substantially enhance accounting processes, even in

environments with underdeveloped digital infrastructure.

From a practical standpoint, these results suggest that organizations aiming to modernize their accounting systems should prioritize the adoption of expert systems as a strategic tool. Additionally, policymakers and educational institutions may consider integrating training on knowledge-based

system technologies to build the digital capabilities of accounting professionals. Future research could expand this work by examining longitudinal effects, incorporating other AI-based tools, or exploring sector-specific applications of expert systems in accounting. Cross-country comparisons may also offer deeper insights into contextual factors that mediate the relationship between expert systems and AIS effectiveness.

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BIBLIOMETRIC STUDY OF THE GREEN AMMONIA ECONOMY (2010–2025)

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ABSTRACT

This study presents a comprehensive bibliometric analysis of the green ammonia economy, aiming to map its evolution, structure, and thematic trends from 2010 to 2025. Green ammonia is emerging as a key solution for hydrogen storage and carbon-free fuel in decarbonizing hard-to-abate sectors. The analysis uses a dataset of 2,520 peer-reviewed articles and reviews sourced from the Scopus database, employing R-Studio and VOSviewer for quantitative analysis of publication trends, citation impact, international collaborations, and keyword co-occurrence. The results reveal significant growth in research output, particularly after 2020, driven by global interest in low-carbon energy solutions. Geographically, China leads in publication volume, while the United Kingdom and the United States are central hubs for international research collaborations. Thematic analysis identifies four main clusters: core chemistry and electrochemical conversion, combustion science, techno-economic analysis, and engine applications. The field has transitioned from foundational studies to applied research and policy-oriented analysis. The study emphasizes the need for further interdisciplinary collaboration, particularly in socio-economic and policy research, to address the remaining challenges of commercial deployment and systemic integration of green ammonia technologies.

1 INTRODUCTION

The global energy sector is undergoing a significant transformation driven by the urgent need to address climate change and meet carbon neutrality goals by mid-century (Anekwe et al., 2025; Evro et al., 2024). In this context, green hydrogen has emerged as one of the most promising solutions due to its status as a clean, carbon-free energy carrier (Kurien & Mittal, 2022). However, challenges associated with its storage

and transportation over long distances, such as low volumetric density and the need for liquefaction at extremely low temperatures or high-pressure conditions, continue to hinder its widespread adoption (Anekwe et al., 2025; Negro et al., 2023).

To address these challenges, ammonia (NH₃), specifically "green ammonia," has emerged as a strategic and efficient hydrogen-carrier (Kurien & Mittal, 2022; Valera Medina et al., 2025).

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Ammonia boasts a significantly higher volumetric energy density compared to liquid hydrogen, in addition to being easily liquefied, stored, and transported using existing global infrastructure, which helps reduce initial investment costs (Boretti, 2024b). Moreover, ammonia can be directly used as a carbon-free fuel in sectors that are difficult to electrify, such as maritime shipping, power generation, and heavy-duty transportation, positioning it as a key player in the future hydrogen economy (Ishaq & Crawford, 2024).

Despite its promising potential, the direct use of ammonia as a fuel faces significant challenges, including its less-than-ideal combustion properties, such as low flame speed, ignition difficulty, and narrow flammability limits (Doosti et al., 2025; Zhang et al., 2025).

Its combustion can release harmful emissions, including nitrogen oxides (NO_x), nitrous oxide (N₂O)—a potent greenhouse gas—and unburned ammonia ('ammonia slip'), highlighting the need for advanced combustion technologies and treatment systems (Mashruk et al., 2024; Valera Medina et al., 2025).

In recent years, the green ammonia economy has witnessed remarkable advancements, particularly due to the increasing global focus on sustainable energy solutions. This surge in interest has been matched by a corresponding rise in research and development, with significant improvements in ammonia production technologies using renewable energy sources such as solar and wind power (Boretti, 2024a). Additionally, the progress in ammonia cracking technologies for onsite hydrogen production is a key factor enhancing ammonia's role as a low-carbon fuel for the future (Prodkornburee et al., 2025). Furthermore, innovations in ammonia combustion and catalysis technologies are improving its efficiency and reducing harmful emissions, further enhancing its economic and environmental viability (Mashruk et al., 2024; Saif & Mokheimer, 2025).

As the research surrounding green ammonia continues to evolve, it is increasingly important for policymakers, researchers, and industrial stakeholders to understand the dynamics of this field. Given the growing body of work in this area, it is crucial to explore the development of green ammonia research and identify key themes, challenges, and opportunities that lie ahead. The

following questions encapsulate the primary issues that this research aims to address:

What has been the development of research in the field of green ammonia over recent years (2010–2025)?

- How has the substantial growth in research been influenced by the Paris Agreement on Climate Change?
- What are the main themes that researchers have focused on in this field?
- How is research on green ammonia distributed across different disciplines (e.g., energy, engineering, chemistry)?
- Is there interdisciplinary overlap, and how does this affect the progression of the field?
- What areas require further research and development?
- What bibliometric patterns reflect the impact of green ammonia research on policy and economics?
- How do economic and technological studies on green ammonia influence its strategic integration into the energy markets?

By examining these aspects, this study endeavors to provide a comprehensive analysis of the green ammonia economy, highlighting the future trajectory of this promising technology and the factors that drive its development.

2 MATERIALS AND METHODS

2.1 Search methodology

This bibliometric study aimed to map the evolution, structure, and thematic frontiers of research on the green ammonia economy. The Scopus database was selected for its comprehensive coverage of peer-reviewed publications across energy systems, environmental sciences, chemical engineering, and policy research.

A concept-driven keyword strategy was initially applied, encompassing terms related to technical pathways (e.g., ammonia fuel, power-to-ammonia) and economic dimensions (e.g., green ammonia economy, techno-economic analysis, LCOA). The complete Boolean query and filtering steps are detailed in Table 1, ensuring transparency and reproducibility.

The initial search retrieved 3,374 records. After applying filters for publication year (2010–2025),

document type (articles and reviews), and language (English), a final dataset of 2,520 documents was obtained. This time frame spans both the formative years of ammonia energy research and the post-2015 growth period following the Paris Agreement, which catalyzed global interest in low-carbon energy vectors.

This selection strategy prioritizes peer-reviewed research (n = 2,449) and review articles (n = 305), excluding conference papers, book chapters, and grey literature to ensure methodological rigor and citation consistency.

Table 1. Search Criteria and Bibliometric Summary for Green Ammonia Economy Research

	Criteria	Details	N° of Documents
Search Criteria	Search Equation	Keywords related to green ammonia technologies, economics, energy use, and value chains (see full query below)	3,374
	Year Range	From 2010 to 2025 (as of 21 October 2025)	3,243
	Document Type	Only Articles and Reviews (Articles = 2,449; Reviews = 305)	2,754
	Language	English only	2,520
	Final Search Query	TITLE-ABS-KEY ("green ammonia" OR "renewable ammonia" OR "ammonia energy" OR "ammonia fuel" OR "NH3 fuel" OR "power-to-ammonia" OR "ammonia cracking" OR "ammonia combustion" OR "ammonia as energy carrier") OR TITLE-ABS-KEY("green ammonia economy" OR "economics of green ammonia" OR "techno-economic analysis of green ammonia" OR "green ammonia market" OR "ammonia value chain" OR "LCOA" OR "ammonia trade") AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"re")) AND (LIMIT-TO (LANGUAGE,"English")) AND PUBYEAR > 2010 AND PUBYEAR < 2026	2,520
	Subject Area Distribution	Energy (1,896); Engineering (1,320); Chemical Engineering (1,172); Chemistry (1,045); Environmental Science (694); Physics & Astronomy (660); Materials Science (414); Mathematics (241); Computer Science (125); Biochemistry & Molecular Biology (86); Business & Management (63); Earth Sciences (49); Social Sciences (44); Multidisciplinary (33); Agriculture & Biology (32); Medicine (26); Economics & Finance (16); Decision Sciences (6); Pharmacology & Toxicology (5); Neuroscience (5); Immunology (5); Veterinary (1); Nursing (1); Dentistry (1)	
Bibliometric Indicators	Metric	Sources (Journals)	441.0
		Average years from publication	1.75
		Average citations per documents	32.29
		Total Documents,	2520.0
		Total Unique Authors	5836.0
		Author Appearances (Total)	14032.0
		Single-authored Documents	57.0
		Multi-authored Documents	2463.0
		Authors of Single-authored Documents	52.0
		Authors of Multi-authored Documents	5803.0
		Documents per Author	0.43
		Authors per Document	5.57
		Co-Authors per Document	4.57
		Collaboration Index	2.36

Table 1 summarizes the search strategy, subject area distribution, and core bibliometric indicators derived from the final dataset. These descriptive metrics, while informative, are further analyzed and interpreted in the following sections.

2.2 Data sources and analytical tools

To process and analyze the bibliographic dataset, a dual-platform methodology was employed, utilizing R-Studio and VOSviewer to ensure methodological rigor and reproducibility.

R-Studio (version 2024.09.1+394), combined with the bibliometric package, was used to perform advanced bibliometric analyses. These included descriptive statistics, citation burst detection, co-authorship networks, source impact metrics, and thematic evolution mapping — offering a quantitative foundation for identifying influential authors, journals, and research trends.

VOSviewer (version 1.6.20) was applied to construct keyword co-occurrence networks, segmented by three strategic time periods. These visualizations revealed the conceptual structure of the field and traced how research themes have shifted — from early studies on ammonia production pathways to its emerging role in sustainable and decarbonized energy systems.

Together, these tools enabled a high-resolution mapping of the green ammonia research landscape, combining longitudinal, structural, and thematic perspectives.

2.3 Methodological considerations

Despite its methodological rigor, this bibliometric study has limitations. The exclusive use of the Scopus database may omit publications indexed elsewhere. Additionally, the English-only filter introduces potential linguistic bias, and the exclusion of non-peer-reviewed materials may overlook certain emerging insights. However, cross-validation between Python and R outputs was performed to ensure analytical consistency and data reliability.

3 RESULTS

3.1 Descriptive Bibliometric Analysis

A foundational step in bibliometric assessment involves understanding the structural

characteristics of the retrieved literature. This includes analyzing the overall volume of publications, subject area distribution, authorship patterns, and citation performance. Such descriptive indicators provide crucial insights into the maturity, interdisciplinarity, and scholarly engagement of a research field.

The bibliometric overview of the final dataset (Table 1) reveals several key characteristics of the green ammonia research landscape. A total of 2,520 peer-reviewed documents were identified, published between 2010 and 2025, reflecting a substantial and steadily growing body of knowledge. The field demonstrates a strong interdisciplinary profile, with dominant contributions from Energy ($n = 1,896$), Engineering (1,320), Chemical Engineering (1,172), and Chemistry (1,045). These subject areas underscore the technological and applied orientation of the domain.

The collaboration index of 2.36 and the average of 5.57 authors per document indicate a high degree of research collaboration, consistent with patterns observed in complex, cross-sectoral fields such as energy systems and environmental technologies. The low number of single-authored papers ($n = 57$), compared to multi-authored publications ($n = 2,463$), further reinforces this trend.

In terms of authorship dynamics, the dataset comprises 5,836 unique authors and 14,032 author appearances, yielding an average of 0.43 documents per author. This suggests a distributed contributor base rather than concentration among a small group of prolific researchers. The average of 32.29 citations per document points to a moderate to high scholarly impact, highlighting the field's increasing relevance within both academic and policy arenas.

Despite the broad disciplinary spread, certain fields remain underrepresented. These include Economics ($n = 16$), Social Sciences ($n = 44$), and Business and Management ($n = 63$), indicating potential gaps in the integration of economic modelling, policy frameworks, and market analysis within green ammonia research. These underexplored areas may offer promising directions for future interdisciplinary collaboration, especially as the field moves from technological feasibility toward commercial deployment.

Figure 1 illustrates the evolution of research output and citation activity related to the green ammonia economy from 2010 to 2025. The data reveal a clear trajectory of exponential growth,

particularly over the last five years, reflecting a shift from conceptual exploration to mainstream academic and policy interest.

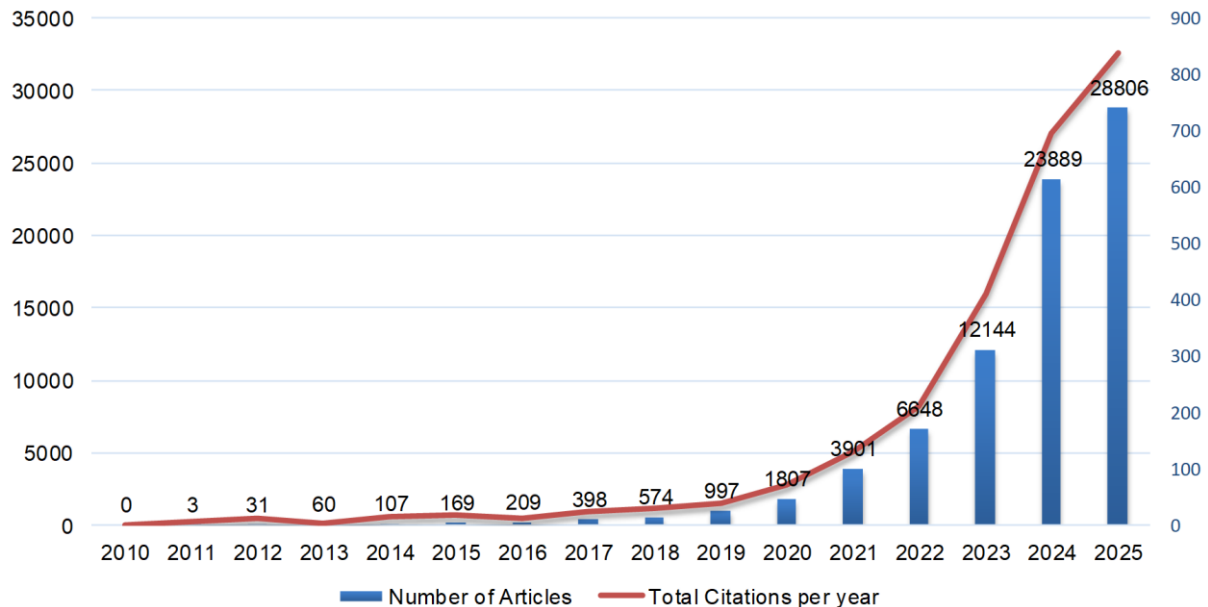
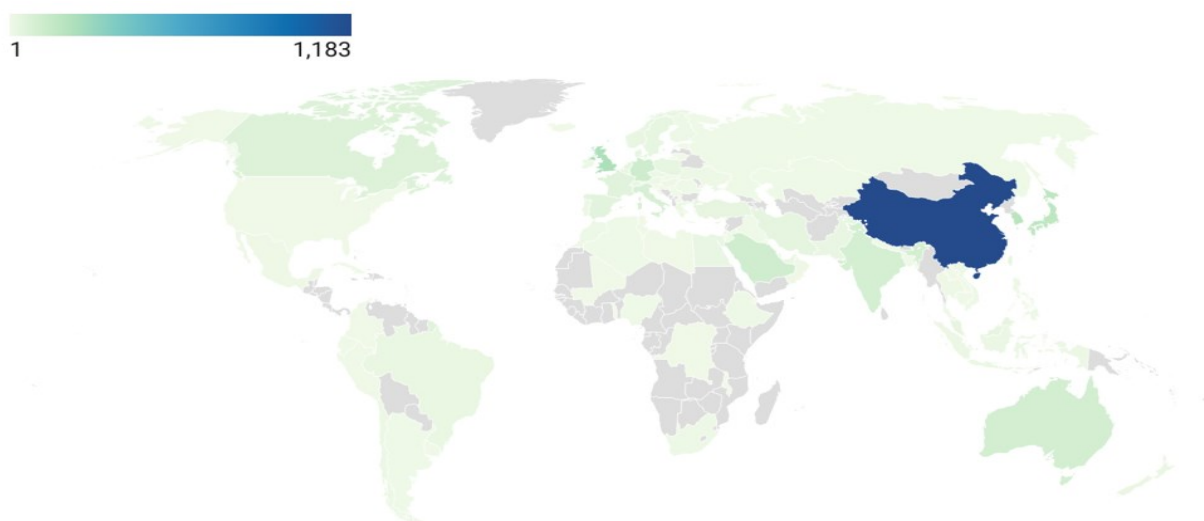


Figure 1. Documents Published and Citations Received on the Green Ammonia Economy Over the Years (Data Until October 2025).

Note: The 2025 data were retrieved in October 2025 and may continue to evolve.

Between 2010 and 2015, the field remained in its nascent stage, with very limited output (only 18 articles in 2015) and modest citations (169). This early phase was characterized by foundational studies exploring the technical feasibility of green ammonia in energy systems (Marçano et al., 2024)

From 2016 to 2020, research activity gradually increased, growing from 12 articles in 2016 to 71 in 2020. Citations during this period also rose steadily, reaching 1,807 in 2020. This stage reflects growing academic interest as green ammonia began to be recognized as a potential vector in decarbonization pathways



Created with Datawrapper

Figure 2. Global Geographical Distribution of Scientific Publications on the Green Ammonia Economy

A significant turning point occurred after 2020. Publications increased rapidly from 132 in 2021 to 837 in 2025, while citations escalated from 3,901 in 2021 to 28,806 in 2025. Notably, 2024 and 2025 alone accounted for more than 50% of the total citations in the dataset. This surge can be attributed to multiple factors, including increased public and private investment in hydrogen-derived fuels, national and international roadmaps for ammonia deployment, and its emerging role in hard-to-abate sectors such as maritime transport (IRENA, 2023; Marçano et al., 2024). Despite the slight temporal lag typically seen between publication and citation accumulation, 2025 already shows the highest annual citation count (28,806), indicating exceptional scholarly and perhaps industrial attention.

These findings confirm that the green ammonia economy has rapidly evolved from a fringe

research topic into a central pillar of the global energy transition discourse. (Marçano et al., 2024)

The geographical distribution of publications on green ammonia highlights a concentration of research activity in technologically advanced nations. China leads significantly with 1,183 documents, followed by the United States (247), the United Kingdom (222), Japan (167), and South Korea (180). Strong contributions from European countries such as Germany, Italy, and the Netherlands, alongside emerging players like Saudi Arabia, Australia, and India, reflect both policy-driven and market-oriented research agendas. In contrast, limited output from regions in Africa, Latin America, and Southeast Asia indicates ongoing disparities in research infrastructure and funding access, despite the global relevance of green ammonia.

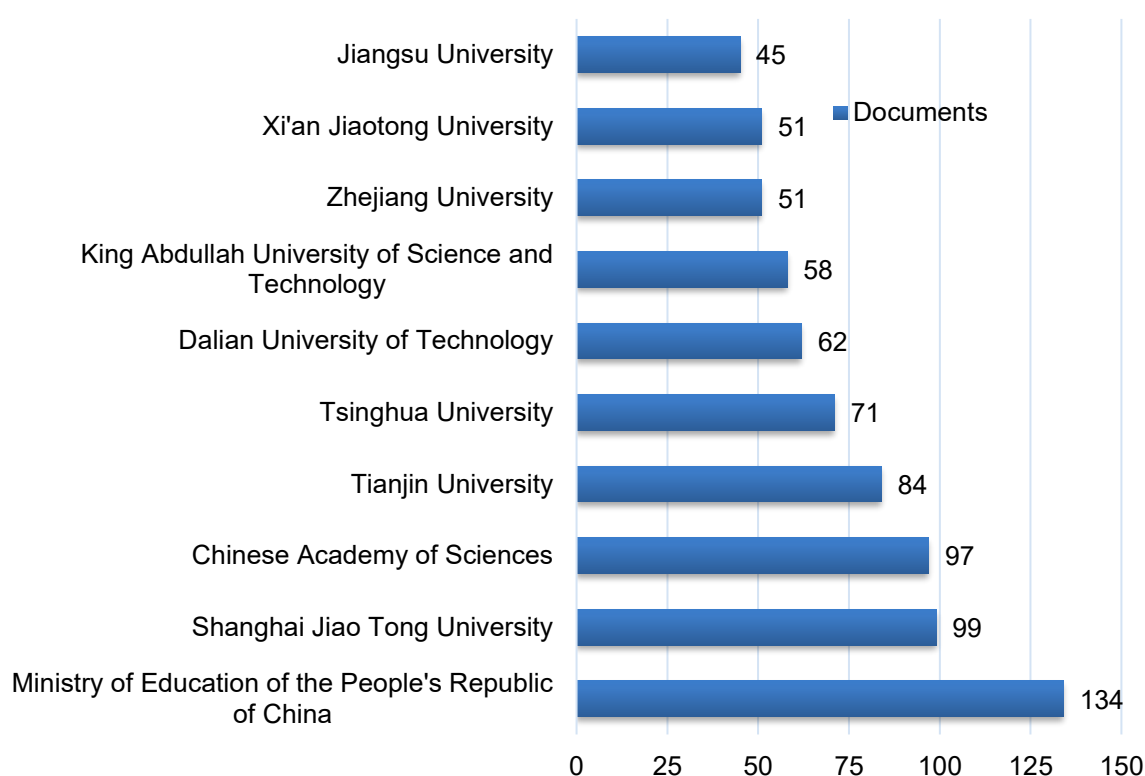


Figure 3. Top 10 Most Productive Institutions in Green Ammonia Economy Research

Figure 3 highlights the top ten most productive institutions in the field of green ammonia research. The data reveal an overwhelming dominance by Chinese institutions, which occupy nine out of the ten leading positions. At the forefront is the Ministry of Education of the People's Republic of China, contributing 134 documents—an indicator not of a single institution, but rather a coordinated national effort, reflecting a strategic prioritization of

this research area at the governmental level. Following closely are prestigious Chinese universities and research bodies such as Shanghai Jiao Tong University (99 documents) and the Chinese Academy of Sciences (97), demonstrating the concentration of scholarly output within China's leading academic centers. The only non-Chinese institution in this group is King Abdullah University of Science and

Technology (KAUST) from Saudi Arabia, ranking seventh with 58 publications. KAUST's presence underscores not only its strong research capacity but also Saudi Arabia's strategic investment in hydrogen and green ammonia technologies as part of a broader vision to diversify its post-oil economy.

Table 2. *Leading Authors in the Green Ammonia Economy*

Rank	Author	N° Doc	Total Citation	H-index
1	Valera-Medina, A.	32	2,203	17
2	Long, W.	32	896	16
3	Dincer, I.	27	1,882	20
4	Wei, H.	21	699	12
5	Siddiqui, O.	19	722	13
6	Dong, P	19	542	11
7	Tian, J.	18	570	11
8	Guiberti, T.F.	17	741	11
9	Lu, X.	17	299	8
10	Wang, Z.	17	414	11
11	Meng, X.	17	343	8

Table 2 identifies key contributors to green ammonia research. Valera-Medina, A. and Dincer, I. stand out as the most influential scholars—

combining high productivity (32 and 27 documents, respectively) with exceptional citation metrics (2,203 and 1,882 citations; h-indices of 17 and 20). Long, W. matches Valera-Medina in output but has a lower citation count, indicating a potentially narrower or more recent research focus.

Other core authors, including Siddiqui and Guiberti, display strong citation performance despite fewer publications, reflecting high per-paper impact. A broader group of active contributors (e.g., Wei, H., Dong, P., Wang, Z.) sustains the field's growth, with stable h-indices (11–12) and steady output.

Overall, leadership in the field is defined not only by volume but by consistent scholarly influence, marking a well-developed and mature research community.

The Sankey diagram offers a panoramic visualization of the interconnected landscape of green ammonia research, illustrating the dynamic relationships between institutions (left), first authors (center), and indexed keywords (right). The thickness of the flows represents the volume of publications, allowing for immediate identification of the most influential contributors and research themes.

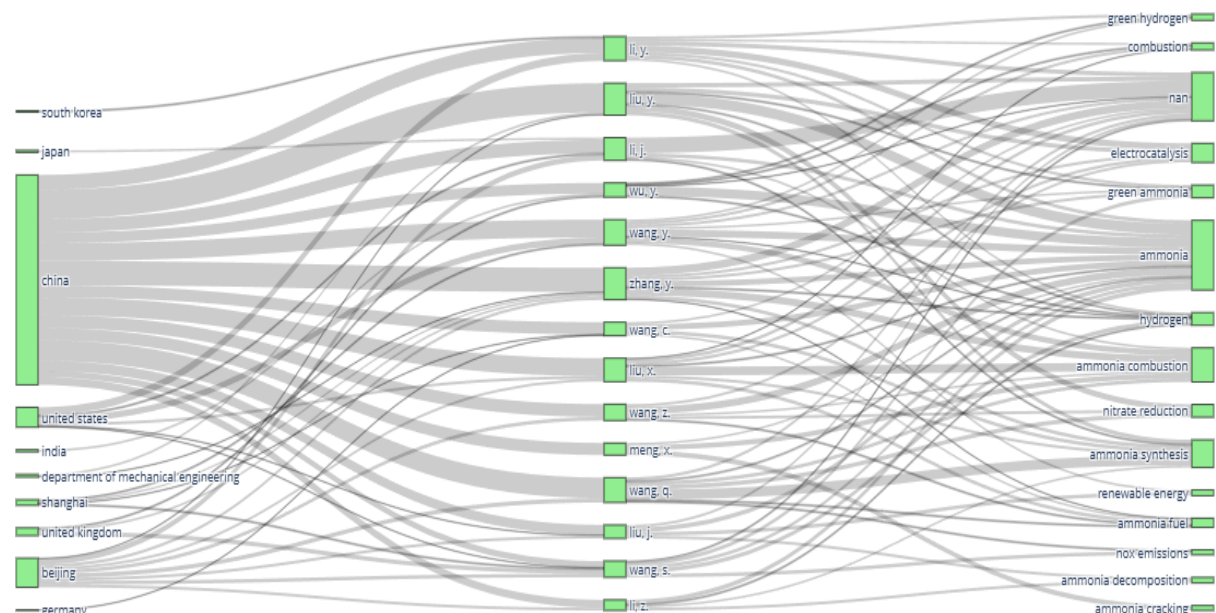


Figure 4. *Three-field Plot of Institutions, Authors, and Keywords*

A clear and overwhelming dominance by China is observed, both in terms of institutional affiliations and prolific authorship. The largest flow originates from Chinese institutions, particularly those linked to leading researchers such as Wang, Y. and Liu,

Y., and converges on high-frequency keywords like ammonia combustion, electrocatalysis, and green ammonia.

This suggests that China not only leads in research volume but also drives key thematic developments within the field.

Other notable contributors include institutions and authors from the United States, Japan, South Korea, and the United Kingdom, albeit with smaller flows. These highlight important but more specialized or regionally focused research clusters.

Crucially, the diagram reveals direct linkages between specific researchers and their topical specializations. For instance, authors affiliated

with South Korea and Japan appear to be strongly connected to hydrogen production and solid oxide fuel cells, suggesting a geographical clustering of thematic expertise.

The thematic flows on the right confirm the field's central research axes, reinforcing earlier co-occurrence and cluster analyses. Keywords such as hydrogen, ammonia, combustion, and catalysts dominate, reflecting sustained academic focus on ammonia's dual role as a fuel and hydrogen carrier, as well as its relevance in sustainable energy systems.

Table 3. Top Ten Journals Publishing Documents on the Green Ammonia Economy

Rank	Journal Title	N° of Publications	Citations	H-Index	Cite Score	SJR	SNIP	Year Start
1	International Journal of Hydrogen Energy	291	10,680	53	13.3	1.685	1.777	2010
2	Fuel	225	8,225	47	16.5	1.614	1.739	2010
3	Energy	110	2,241	27	7.3	0.713	1.739	2019
4	Combustion and Flame	94	2,899	27	10.9	2.015	1.871	2012
5	Energies	80	2,044	24	7.3	0.713	1.027	2019
6	Energy Conversion and Management	73	3,504	27	19.8	2.659	2.261	2019
7	Proceedings of the Combustion Institute	62	4,548	24	8.6	1.524	1.524	2017
8	Chemical Engineering Journal	58	1,402	18	/	0.125	/	2021
9	Energy and Fuels	49	748	15	9.5	1.124	1.145	2018
10	Applied Energy	48	3,495	25	20.1	2.902	2.512	2014
TOTAL		1,090 (43.25%)						

Note: The 2025 data were retrieved in October and may continue to evolve

Table 3 presents a comprehensive view of publication activity in the green ammonia economy, showcasing both productivity and scholarly impact. The International Journal of Hydrogen Energy and Fuel clearly dominates in terms of publication volume. International Journal of Hydrogen Energy leads with 291 articles, representing the largest share of the total output, followed by Fuel with 225 articles. Together, these journals contribute to 43.25% of the total publications in the field, highlighting their dominance as primary venues for publishing research on green ammonia. This suggests a

concentration of research in a small number of high-output journals, which serve as the main dissemination platforms for work in this area.

On the other hand, while Energy Conversion and Management and Applied Energy publish fewer articles (73 and 48, respectively), they stand out in terms of impact. These journals boast high CiteScores of approximately 20 and are among the highest in the field. Their SJR (SCImago Journal Rank) and SNIP (Source Normalized Impact per Paper) scores also surpass those of the more prolific journals. This indicates that while these journals may not be published as frequently,

the articles they do publish are of strong influence, as evidenced by their substantial citation counts. These journals, therefore, represent the "elite" within the field, where quality and prestige are more significant than publication volume.

Combustion and Flame and Proceedings of the Combustion Institute emerge as highly influential journals in the combustion sector, though they are more specialized. Combustion and Flame has an SJR index of 2.015, positioning it at the forefront of combustion-related research. Remarkably, Proceedings of the Combustion Institute has achieved 4,548 citations from just 62 articles, resulting in the highest average citations per article in the list. This exceptional performance highlights the journal's significant impact, despite its smaller volume of publications. These journals publish pivotal research in their specific niche within the green ammonia economy.

Additionally, the relatively new Chemical Engineering Journal began publishing in 2021 and, as expected, does not yet have calculated CiteScore or SNIP values. Its publication count (17

articles) reflects its early stages in contributing to green ammonia research. In contrast, broader journals such as Energy and Energies, while publishing a substantial number of articles, have lower SJR and CiteScore values compared to more specialized journals. This suggests that while these broader journals contribute to the literature, they are not as tightly focused on green ammonia as other journals in the list.

This analysis suggests that while the International Journal of Hydrogen Energy and Fuel dominate in terms of volume, journals like Energy Conversion and Management and Applied Energy lead in terms of the quality and impact of their articles. Specialized journals such as Combustion and Flame continue to be instrumental in advancing specific areas of research, such as combustion science within the green ammonia field. The data also highlights the emergence of newer journals like Chemical Engineering Journal, which may increase its influence in future years as more data becomes available.

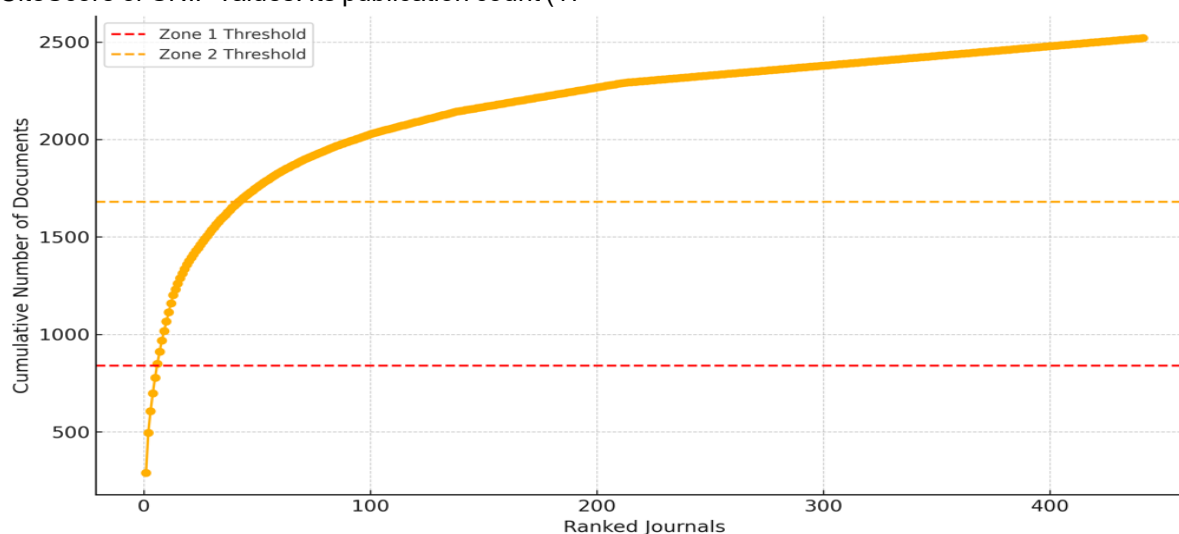


Figure 5. Bradford's Law: Distribution of Publications by Source

Figure 5 presents Bradford's Law of Scattering distribution for publications in the green ammonia economy domain. The graph plots cumulative document counts against ranked journals, offering insight into the concentration and dispersion of scholarly output.

As illustrated, the curve can be segmented into three distinct zones of approximately equal volume (~850 documents each), revealing a typical Bradfordian distribution pattern:

Zone 1 (Core Zone): The first ~850 documents are concentrated in a small set of high-yield journals (around 20–25). These represent the core journals in this field, characterized by their thematic specialization and consistent output on green ammonia topics. The steep gradient in this segment reflects the high productivity of each journal.

Zone 2 (Peripheral Zone): The next third of documents is distributed over a larger group of journals, indicating broader but less frequent

engagement with the topic. The slope here is less pronounced, suggesting diminishing returns in publication count per journal.

Zone 3 (Scattered Zone): The final 850 publications are dispersed across several hundred journals, each contributing only one or two articles. The near-flat slope in this segment underscores the marginal presence of green ammonia research in these outlets.

3.2 Thematic Evolution and Conceptual Structure

To map the conceptual structure of green ammonia research, a keyword co-occurrence analysis was conducted in VOSviewer. Indexed keywords were selected for their consistency, and full counting was applied to capture all co-occurrences.

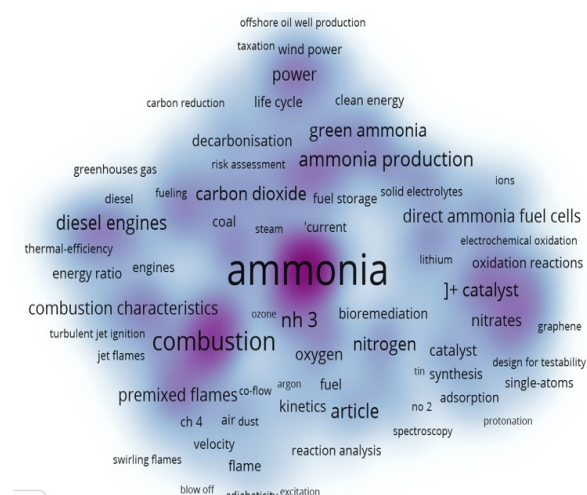


Figure 6. Density Visualization Map of Keywords Related to Green Ammonia Research

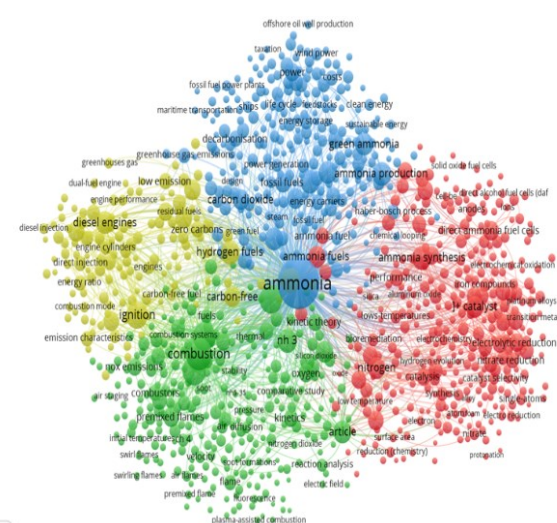


Figure 7. Keyword Co-Occurrence Network Map of Green Ammonia Economy Research

A minimum threshold of five occurrences reduced the dataset to 1,456 keywords, from which the top 1,000 were chosen based on total link strength. This ensured a focused and interpretable representation of the field's main research themes.

Figures 6, 7, and 8 together provide a comprehensive view of the green ammonia economy research landscape: Figure 6 displays the thematic map derived from keyword co-occurrence, while Figure 8 presents the temporal heatmap of keyword prominence.

In Figure 6, the term “ammonia” occupies the central position, anchoring three major thematic clusters. The first — lower left — is the “combustion & engines” cluster (e.g., “ammonia combustion”, “diesel engines”, “premixed flames”); the second — upper center — is the “sustainable production” cluster (e.g., “green ammonia”, “ammonia production”, “decarbonization”); the third — right — is the “electrochemical conversion” cluster (e.g., “direct ammonia fuel cells”, “catalyst activity”, “electrochemical oxidation”). Figure 8 adds the dynamic dimension: research in 2010-2020 emphasized foundational topics such as “ammonia fuel” and “direct ammonia fuel cell”, whereas 2021-2025 shows a pronounced pivot towards applied topics, with “green ammonia” rising sharply (from near absence to high frequency), and intensified interest in “ammonia combustion”, “nitrogen oxides” and “emission control”. Meanwhile, the electrochemical conversion cluster remains steady, though less accelerated. At the core of all clusters is catalytic technology — highlighted through terms like “catalysts”, “electrocatalysts”, and “catalyst activity” — which acts as the enabling link between production, utilization, and value-chain integration. Together, the figures indicate that the field has transitioned from early exploratory research into a mature, sustainability-driven discipline where green ammonia is now firmly embedded at the interface of fuel innovation, environmental imperatives, and energy systems application.

Our co-occurrence analysis, implemented via VOSviewer, delineates four major conceptual clusters that encapsulate the field of green ammonia economy research. Each cluster is color-coded and represents a distinct thematic domain within the broader discipline.



Figure 7. Temporal Evolution of the Top 20 Author Keywords (2010–2025)

Cluster 1 (Red): Core chemistry, materials, and electrochemical conversion

Prominent keywords include “direct ammonia fuel cells”, “catalyst”, “ammonia synthesis”, “electrochemical oxidation”, “solid oxide fuel cells” (SOFC), “nitrogen reduction”, and “nano-catalyst”. This cluster spans three interlinked axes: (i) electrochemical conversion technologies, evidencing the diversification of fuel-cell architectures (DAFC, SOFC, alkaline) and investigations into electrodes, electrolyte, and power-density optimization; (ii) advanced materials and catalysis science, focused on nano-structured and single-atom catalysts using transition-metal systems and addressing stability issues; and (iii) sustainable ammonia synthesis pathways, notably electrochemical ammonia synthesis and nitrate-reduction approaches, as alternatives to the conventional Haber–Bosch process. In essence, this cluster represents the molecular-scale research frontier that underpins both green ammonia production and utilization.

Cluster 2 (Green): Fundamental combustion science and fluid-chemical dynamics

Key terms such as “combustion”, “kinetics”, “flame”, “nitrogen oxides”, “chemical kinetic model”, “hydrogen”, and “simulation” characterize this cluster. It encompasses (i) flame dynamics and combustion physics, informed by CFD and large-eddy simulation of laminar vs turbulent burning behavior; (ii) chemical-kinetic modelling of reaction pathways and pollutant formation (particularly NO_x); and (iii) co-firing and fuel-blending strategies (ammonia–hydrogen, ammonia–methane) to improve ignition and flame stability. This cluster, therefore, provides the foundational science required for practical implementation. Such aspects are likely addressed in other clusters.

Cluster 3 (Blue): Strategic systems, economics, and energy-policy integration

Highlighted keywords include “green ammonia”, “decarbonization”, “techno-economic analysis”, “renewable energy”, “hydrogen economy”, “costs”,

and “life-cycle assessment”. This cluster explores (i) environmental motivation and sustainability frameworks (LCA, carbon footprint); (ii) economic viability and market integration (cost–benefit, value-chain, supply-chain analyses); and (iii) energy-systems integration and the role of ammonia in the hydrogen economy (power-to-ammonia, hydrogen carrier). It effectively bridges technological innovation with policy, market, and system-level considerations.

Cluster 4 (Yellow): Engine applications, performance, and emissions control

With keywords such as “diesel engines”, “dual-fuel engine”, “engine performance”, “emission characteristics”, “ammonia-diesel”, “thermal efficiency”, and “ammonia slip”, this cluster focuses on the applied engineering of ammonia in internal-combustion engines. Its three axes are (i) engine technologies and dual-fuel modes; (ii) performance and efficiency metrics; and (iii) emissions management (NO_x control, ammonia slip, after-treatment devices such as selective catalytic reduction). Thus, it represents the translation of foundational science into system-level engineering for deployment.

Viewed together, these clusters reflect the field’s dual trajectory of specialization and expansion. The progression, from foundational combustion science (Cluster 2) and electrochemical materials (Cluster 1) toward system applications (Cluster 4) and strategic integration (Cluster 3), underscores a mature and multi-dimensional research landscape. Emerging themes such as “green ammonia” and advanced catalysis signal shifting priorities from proof-of-concept to environmental and market relevance. Additionally, the overlap between clusters—visible in shared keywords and thematic bridges—points to an increasingly interdisciplinary domain, where chemistry, engineering, economics, and policy converge.

3.3 Collaboration Networks and Source Analysis

The analysis of international collaboration in green ammonia research presents a complex and hierarchical global landscape, providing valuable insights into both the productivity of countries and the strength of their research ties. This evaluation highlights key players, collaboration patterns, and

emerging research trends, with a particular focus on the role of both major contributors and emerging hubs in shaping the future of the field.

The international co-authorship network, visualized in Figure 9, reveals a research landscape dominated by China (1,183 documents), which leads not only in publication volume but also holds the highest total link strength (410). This positions China as the primary driver of research in this domain, contributing significantly to both the quantity of output and centrality in the global collaboration network.

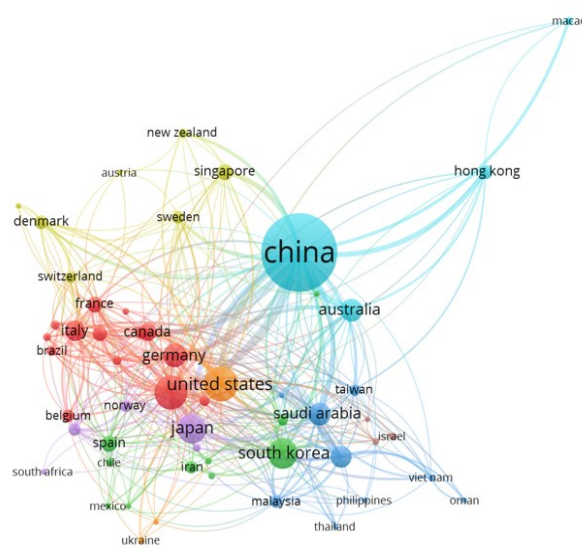


Figure 9. International Co-Authorship Network in Green Ammonia Economy Research.

The United Kingdom (222 documents) and the United States (247 documents), while producing fewer publications than China, play critical roles as collaborative hubs. The UK, with a total link strength of 224, is particularly significant in fostering international collaboration, with research being highly interconnected across borders. Similarly, the US, with a link strength of 204, connects multiple research networks, underlining its importance in facilitating global collaboration.

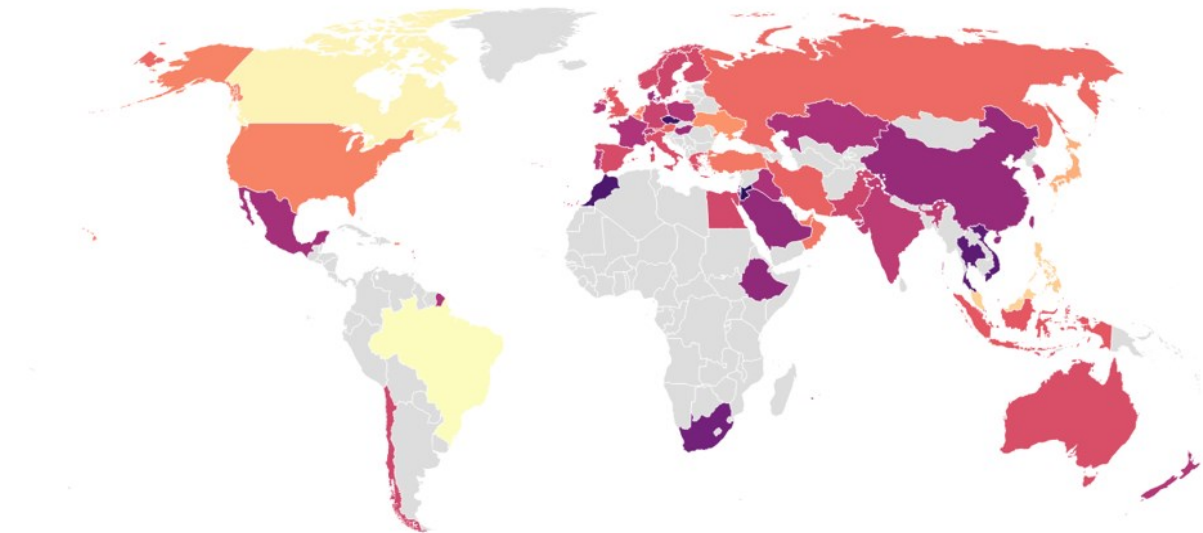
East Asian countries, such as South Korea (180 documents) and Japan (167 documents), remain significant contributors to green ammonia research. However, their link strength values (95 and 93, respectively) suggest that their collaborations are more regionally focused, highlighting a robust local network within East

Asia. These countries are key players in technological advancements related to green ammonia, particularly within the region.

Emerging hubs like Saudi Arabia (107 documents), Australia (98 documents), and others are making noteworthy contributions. Saudi Arabia, with a link strength of 123, which exceeds its publication count, stands out. This indicates that Saudi Arabia is rapidly positioning itself as a key global research partner, helping to connect the Middle East with broader international networks.

Countries such as Qatar (6 documents) appear more isolated, with a total link strength of 0,

2,021.23 2,024.8



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Figure 10. Geographical Expansion and Emerging Players in Green Ammonia Research

As shown in Figure 10, geographical green ammonia research has shown significant expansion, with new players emerging alongside traditional leaders. Early contributors like Brazil, Canada, and Malaysia, with relatively early publication years (2021.23, 2021.33, and 2021.7, respectively), were among the first to engage deeply with green ammonia technologies, laying the foundation for its development within the global sustainability framework.

More recently, countries such as Jordan (2024.8), the Czech Republic (2024.6), and Morocco (2024.5) have entered the field, reflecting a broader global interest and the increasing

indicating limited international collaboration. While Qatar contributes to research output, it has yet to integrate into the broader global network of green ammonia research.

Conversely, countries like Canada (64 documents) and Finland (11 documents) demonstrate high levels of impact despite publishing fewer papers. Canada, with 4,055 citations (63.35 average citations per document), and Finland, with an average citation rate of 63.45 per document, showcase exceptional research quality. Their smaller publication output does not diminish their significant intellectual contributions to the field.

momentum in green ammonia research. These nations, with high average publication years, signal the rapid growth and growing importance of this field in emerging regions, contributing to the diversification of global research efforts.

China has been a dominant force in green ammonia research and continues to lead the field. Its average publication year of 2023.8 indicates that its surge in research productivity is a recent phenomenon, driven by significant strategic investments in green ammonia technologies. This reflects China's increasing centrality in the global network of green ammonia research.

Table 4. Analysis of International Collaboration Clusters by Key Bibliometric Indicators.

Country	Documents	Citations	Total Link Strength	Avg. Pub. Year	Avg. Citations
Cluster 1					
United Kingdom	222	11204	224	2022.98	50.47
Germany	112	3267	117	2023.29	29.17
Italy	83	2735	74	2023.13	32.95
Netherlands	47	2163	64	2022.53	46.02
France	53	1923	60	2023.57	36.28
Canada	64	4055	43	2021.33	63.36
Egypt	24	794	36	2023.21	33.08
United Arab Emirates	19	1130	34	2022.63	59.47
Belgium	32	1736	26	2022.56	54.25
Brazil	22	730	20	2021.23	33.18
Greece	12	242	18	2023.08	20.17
Turkey	33	976	17	2022.64	29.58
Portugal	16	749	14	2023.50	46.81
Morocco	10	77	5	2024.50	7.70
Cluster2					
South Korea	180	4605	95	2023.46	25.58
Spain	50	1246	39	2023.16	24.92
Pakistan	24	644	38	2023.25	26.83
Iran	34	720	18	2022.88	21.18
Chile	13	722	13	2023.23	55.54
Ireland	10	247	16	2023.50	24.70
Iraq	5	142	12	2023.60	28.40
Mexico	6	139	8	2023.67	23.17
Russian Federation	5	164	8	2022.80	32.80
Finland	11	698	4	2023.18	63.45
Cluster 3					
Saudi Arabia	107	2514	123	2023.82	23.50
India	92	2780	88	2023.43	30.22
Malaysia	30	1386	40	2021.70	46.20
Taiwan	25	333	37	2023.68	13.32
Viet Nam	9	193	27	2024.33	21.44
Thailand	6	29	11	2024.33	4.83
Oman	6	264	10	2022.67	44.00
Ethiopia	7	192	11	2023.86	27.43
Philippines	8	81	8	2021.75	10.13

Cluster 4					
Singapore	49	788	51	2024.16	16.08
Sweden	31	968	35	2023.26	31.23
Denmark	39	981	33	2023.72	25.15
Switzerland	25	721	31	2023.44	28.84
New Zealand	19	799	21	2023.53	42.05
Hungary	8	173	6	2023.75	21.63
Austria	7	48	6	2022.86	6.86
Cluster 5					
Japan	167	8837	93	2022.08	52.92
Poland	31	859	38	2023.52	27.71
Norway	28	1255	33	2023.18	44.82
Indonesia	15	719	18	2023.00	47.93
South Africa	8	58	3	2024.13	7.25
Cluster 6					
China	1183	28517	410	2023.80	24.11
Australia	98	4813	87	2023.12	49.11
Hong Kong	37	1226	46	2023.08	33.14
Macao	12	477	15	2023.92	39.75
Cluster 7					
United States	247	13557	204	2022.52	54.89
Kazakhstan	5	44	8	2023.60	8.80
Ukraine	11	82	9	2022.36	7.45
Cluster 8					
Czech Republic	10	68	16	2024.60	6.80
Israel	13	250	9	2023.85	19.23
Jordan	5	23	8	2024.80	4.60

The cluster analysis, detailed in Table 4, reveals that international collaboration is not random but structured into distinct research blocks, each with unique characteristics in terms of productivity, impact, and scientific focus.

Cluster 1, the largest and most interconnected group, represents a robust European-global network. It is anchored by the United Kingdom, which acts as a major collaborative hub (Total Link Strength = 224). This cluster also includes other European powerhouses like Germany, Italy, and France, and has strong transatlantic links to Canada. Notably, this cluster contains countries with some of the highest research impact, such as Canada (Avg. Citations = 63.36) and the United

Arab Emirates (Avg. Citations = 59.47), indicating that this network is a hub for high-quality, influential research.

In contrast, Cluster 6 is clearly the East Asian powerhouse cluster, dominated by China (1183 Documents, Total Link Strength is 410). This cluster, which also includes Australia and Hong Kong, is characterized by massive research output driven primarily by China's recent and extensive engagement in the field (Avg. Pub. Year for China is 2023.80).

Cluster 3 highlights an emerging and influential research network spanning South Asia and the Middle East. It is led by Saudi Arabia (Total Link Strength is 123) and India (Total Link Strength

is 88). The recent entry of countries like Vietnam and Thailand (Avg. Pub. Year $\approx$ 2024.33) into this cluster signals a dynamic expansion of research activity in this region. The older publication records of Malaysia (Avg. Pub. Year = 2021.70) suggest it was a foundational member of this bloc.

Other clusters represent smaller but significant networks. Cluster 7 is notable for being anchored by the United States, another major global hub (Total Link Strength is 204), but with fewer direct partners in this specific visualization. Cluster 2 brings together a diverse group of countries, including South Korea and Spain, and importantly, Finland, which, despite having very low link strength (4), boasts the highest average citation rate in the entire network (63.45), marking it as a source of exceptionally high-impact research. Finally, Cluster 8 represents a group of highly specialized or newly emerging players like Israel and Jordan, with Jordan having the most recent average publication year (2024.80) in the dataset.

4. CONCLUSIONS

This bibliometric study reveals the significant evolution, structure, and thematic frontiers of research on the green ammonia economy. The analysis of the Scopus database, covering publications from 2010 to 2025, highlights a sharp increase in research activity, especially post-Paris Agreement 2015. This surge can be attributed to the global shift towards low-carbon energy solutions, with green ammonia emerging as a viable energy carrier for sustainable development.

The study identifies two primary thematic dimensions that dominate the green ammonia research landscape: technical pathways and economic dimensions. On the technical side, there has been a substantial focus on ammonia fuel production technologies, such as power-to-ammonia, and their integration with renewable energy sources like wind and solar. These findings are consistent with the growing emphasis on developing ammonia as a clean hydrogen carrier. On the economic side, the techno-economic analysis of green ammonia, including metrics like the Levelized Cost of Ammonia (LCOA), remains a critical area of research as scholars aim to assess the commercial viability of ammonia-based energy systems.

A notable trend observed in this study is the increasing interdisciplinary nature of the research. While most publications were originally centered around chemical engineering and energy systems, a significant portion now emerges from environmental economics and policy research. This shift underscores the necessity of combining both technical and socio-economic perspectives to understand the full potential of green ammonia technologies and their role in global energy transitions.

The study also reveals challenges related to the direct use of ammonia as a fuel, particularly its combustion characteristics. As highlighted in previous research, ammonia faces significant challenges such as low flame speed, ignition difficulty, and a narrow flammability range, which limit its practical applications. Additionally, concerns regarding ammonia slip and harmful emissions like NO_x and N₂O were prevalent in the findings. These results emphasize the need for further technological development to optimize ammonia combustion processes and mitigate its environmental impact.

Geographically, the study identifies that leading contributors to green ammonia research are China, the United States, and the United Kingdom, with China standing out due to its strong governmental support for clean energy technologies. This aligns with the broader trend of strategic investments in low-carbon energy systems, particularly in countries that are heavily focused on reducing emissions from their industrial and transportation sectors. In contrast, regions like Africa and Latin America still face significant barriers, including a lack of research infrastructure, which hinders their participation in the development of green ammonia technologies.

The results also indicate a growing focus on sectors such as maritime transport and heavy industry, which are among the largest carbon-emitting sectors globally. This trend reflects a shift from foundational studies to more practical applications of green ammonia, particularly in industries where traditional energy sources are difficult to replace. These findings suggest that future research should continue to explore the application of green ammonia in these sectors, where it could offer significant environmental benefits.

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DOES TRESPASSING REQUIRE HUMAN ACTION? REJOINDER TO KINSELLA AND ARMOUTIDIS ON EVICTIONISM

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ABSTRACT

Libertarian scholars Kinsella and Armoutidis criticize the libertarian theory of evictionism. This is a principled compromise between the pro-life and the pro-choice positions. Its conclusion overlaps with the former in the last trimester of pregnancy and with the latter in the first two trimesters. That is, the pregnant mother may expel the fetus from her body whenever she wishes but may not ever kill this pre-born baby. This theory is predicated upon the notion that the unwanted fetus is a trespasser; an innocent one, to be sure. Thus, he may be expelled from her body, her private property, but not treated as a criminal, since he is innocent of any crime. Evictionism stands or falls on this one claim. If the fetus is not a trespasser, this solution to the abortion controversy is a failure. Kinsella (2023) and Armoutidis (2024) maintain, to the contrary, that trespassing is a human action, and that the fertilized egg, the beginning of human life, is capable of nothing such thing. This essay aims to refute their position.

RESPONSE TO KINSELLA AND ARMOUTIDIS

There are three possible viewpoints on evictionism: pro-life, pro-choice, and evictionism. Together, they are exhaustive explications of this very complicated and challenging issue. Advocates of the first option take the position that human life starts with the fertilized egg, and that the fetus may not be evicted from the mother's body before the usual nine months.* The second

entry in these sweepstakes posits that human life begins with birth. Before that, the fetus is merely a bunch of living cells, with "rights" compatible with those of the appendix. That is, the pre-born baby has no rights at all, and if its life is ended, there is no crime whatsoever involved. Evictionists agree with the pro-lifers that rights-bearing human beings begin life with conception. They have as many rights as anyone else. But they are occupying space owned by someone else, their mother. Thus, they are trespassers. Innocent as the driven snow, to be sure, but still, squatters,

* Assuming away premature births and the mother's health

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occupying property owned by another rights-bearing person. Thus, they may be evicted from her property but not killed. Unhappily, with today's medical technology, they will die if removed from the womb in the first two trimesters but can survive if evicted in the last three months of pregnancy.

I am an advocate of evictionism. My two critics, Kinsella (2023) and Armoutidis (2024), reject the notion that the fetus can be a trespasser and thus a violator of the private property rights of his¹ mother.²

With this introduction, let us consider the claim as to whether or not the fetus can be an intruder.

Alan hypnotizes Bob and places the latter in Charley's house. Is Bob a trespasser? Is it difficult to see why this contention should be rejected? What should we call Bob? An interloper? A person taking up space to which he has no right? A squatter? But these are only synonyms for "trespasser." To be sure, Bob is an innocent trespasser. He lacks any and all mens rea. Is Alan the trespasser? Not at all. After doing this evil deed, he exits from the scene, and, also, from our little scenario. He may well be guilty of assault and battery, or kidnapping, but not surely of trespassing. It is not Alan who is now residing in Charley's house. It is Bob!

Ditto for rape. David drugs both Ed and Frances. He pumps enough Viagra down the throat of Ed to give him an erection. David places Ed's penis inside Frances's vagina. What is going on here? Rape is going on here. Who is raping whom? Obviously, Ed is raping Frances. David is not engaging in this evil deed. His penis is safely locked up inside his own pants. Is Ed guilty of rape? Certainly not. He is a totally innocent

person. He has no mens rea. He does not even realize he is raping Frances. Is Ed a criminal? No, he is entirely innocent of committing any crime. Of what crime is David guilty, besides being a weirdo? Kidnapping, assault and battery, etc., but not rape.

We could extend this type of scenario to fit virtually all crimes: theft, murder, arson, etc. But we have made the point. People can engage in any and all sorts of crimes, without being in the slightest guilt of any of them. Let me rephrase that: People can *be made to* engage in any and all sorts of crimes, without being in the slightest guilt of any of them. For example, they can be hypnotized into so doing. They can be drugged to this effect. They can be forced to drink large amounts of alcohol in this regard. Sleepwalkers can commit crimes. To be sure, if the person knows he is a sleepwalker, he can be legally blamed for not doing something such as tying himself to his bed. But if he has no idea that he suffers from this malady and engages in the debility during which he commits a crime, he totally lacks all mens rea. Suppose he slips on the proverbial banana peel, and in an attempt to maintain his balance thrusts his arms out and about. During this process, he interdicts someone else's nose. He has engaged in something akin to assault and battery, but proper law would consider this only a tort,³ not a crime.⁴

Now consider this possible objection to the foregoing. Oddly, and inconsistently, the author allows that a rapist remains a rapist even after the rape is complete, so why can't a trespasser remain a trespasser even after the act is finished? This does not mean that the zygote cannot possibly count as "a" trespasser. Rather, the

¹ I use this description rather than "its" to indicate that the pre-born infant is a person.

² Unless otherwise specified, all mention of these two authors will be limited to these two essays of theirs.

³ To be sure he could then turn around and sue the owner of the sidewalk which left banana peels lying around, but that is a different story.

⁴ Consider the following pushback: "... it is common in prison movies for a powerful inmate (often a gang leader) to tell a vulnerable new inmate that he must stab someone else or get stabbed himself. But can an inmate who is faced with that 'choice' really go stab someone else with impunity because he was 'made to do it'? I think that is highly questionable; it is not just self-evident. Again, it appears that the author comes to

that conclusion, in part, because he assumes there can be only one guilty party, rather than shared blame. But why?" I plead not guilty to this charge. In my view, both the gang leader and the new inmate are both guilty of criminal behavior. The former for the threat, the latter for the stabbing. I have a paper trail discussing this very issue. See on this Block 2010, 2011, 2019, 2025A, 2025B. This constitutes an objection to me holding only David guilty of the crime of rape, even though he did not rape anyone, but not Ed, the actual rapist, who did so, but entirely innocently. However just because I did not "share blame" in this rape case, does not mean I cannot logically do so in this referee's prison example. The two are not analogous.



author mistakenly assumes there can be only one, and that mistaken assumption is what then leads him to “nominate” the zygote as “the” trespasser. Here is my response to the critique: Yes, the rapist “trespassed” upon the body of the woman during the actual rape. Afterward, after he leaves her body, he stops being a trespasser. He is no longer an uninvited guest within her body. But he is still a rapist. The resulting baby is a trespasser for nine months.

Armoutidis (2024) disagrees with this analysis. He asserts: “... a zygote is not—and in fact can’t possibly be—a trespasser, because a trespasser is an aggressor and aggression is a type of action. Implicit in this argument is that to even be capable of committing aggression—trespassing, in this case—one must first be an actor. But a zygote—or even a born baby, for that matter—is not an actor, because it has not yet developed the ability to act, and it’s therefore impossible for it to commit aggression.”

Assume that this zygote is the product of rape. Where, pray tell, is this preborn baby now located? I’ll tell you where. He is now situated inside the body of his mother. And precisely who is the rightful owner of that particular real estate? It is the unwilling parent. Did she invite her child to reside within her? Of course not.⁵ She is now the unwilling host of an uninvited person. If that fetus is not a trespasser, there is no such thing as trespassing. True, he, just as in the previous made-up cases, is entirely lacking in mens rea. Is the father a trespasser? Well, sort of, in the sense that rape is also a trespass upon the body of the woman and he was indeed guilty of that crime. But he has long departed the scene. He is still a rapist, but he is no longer a trespasser. Someone else must be a trespasser in this scenario. For there is a very small young person residing inside the body of another person without the permission of the latter. I nominate the fertilized egg as the trespasser.⁶

Kinsella (2023) also objects. He asserts, “But libertarians don’t say humans have rights because they ‘are humans’; if we encountered some other intelligent, sapient animals, or aliens from outer space, surely libertarians would say they also have rights, even though they are not ‘human.’ Or as I said in response to Doris, an intelligent cow would have rights. So, it is not ‘being human’ that gives humans rights, but something about the nature of humans. Most libertarians would say this has to do with our intelligence, conscience, self-awareness, or other characteristics such as reciprocity, language, discourse, reason, social nature or social setting, and so on. But it is not clear that all humans qualify for rights, depending on whatever criteria are adopted as relevant for rights. As a crude example, most of us believe a murderer has forfeited some, or all, of his rights; this is why he may be punished, perhaps capitally. Yet he is still ‘a human.’ So obviously, rights do not stem solely from ‘being human.’”

The implication, here, is that since the fetus lacks “...intelligence, conscience, self-awareness, or other characteristics such as reciprocity, language, discourse, reason, social nature or social setting,” he⁷ also lacks rights. But this argument is far too good. It proves far too much. For example, the comatose person is without reason. The sleeping person has no language. The last thing on the mind of the two-week-old baby is reciprocity; rather, for him, it is me, me, me. The person running a marathon in the last few miles is so winded, he cannot engage in any discourse; he can barely breathe. Given that this logically implies that these folk have no rights, it would not be murder to put a bullet in their heads. This conclusion is obviously highly problematic.

I conclude that the case for evictionism is untouched by these two authors. To be brief, this viewpoint regards the zygote as an innocent trespasser who may be evicted but not murdered. It is a compromise between the pro-life and the

⁵ Pay attention, she was raped.

⁶ When does human life begin? There are only three choices. One, with birth. But that is only a very slight change of address from inside of the mother to directly outside of her. Two, sometime during the pregnancy. According to the Talmud, it begins with the heartbeat. But this, too, must be rejected. The patient undergoing

a heart transplant for a time has no heartbeat at all. Yet, he is still a person. (A better Jewish interpretation is that life begins with graduation from medical school). Obviously, the only correct position is the third, it begins with the fertilized egg.

⁷ I refuse to refer to the pre-born child as an “it.” This is a precious human being we are talking about.

pro-choice positions. Assuming present medical technology, in the first two trimesters, the results of evictionism and pro-choice overlap. The evicted pre-born baby cannot survive outside of the womb and will perish. In the third trimester, there is a congruency between evictionism and pro-life. The baby may be evicted but not killed and thus will survive.⁸

I am fully aware that this abortion issue is a highly contentious, debatable, complicated, and challenging issue. It is not for nothing that two leaders of our libertarian movement diverge on it. Murray Rothbard was pro-choice; Ron Paul is pro-life. Happily, no one has accused either of “not really being a libertarian” and attempted to banish one or the other from the libertarian movement.

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⁸ The present essay is limited to a refutation of Kinsella and Armoutidis. There is much more of course to be said about the libertarian position on abortion. For example, rape, happily, accounts for a very small percentage of pregnancies. For an evictionist oriented

examination of that issue and many, many more, see Block, 1977A, 1977B, 1978, 2001, 2004, 2008, 2010A, 2011A, 2011B, 2012, 2014A, 2014B, 2014C, 2018, 2021; Block and Whitehead, 2005; Dyke and Block, 2011; McGee and Block, 2022.



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REJOINDER TO NINO ON ZIONISM AND THE CANCEL CULTURE OF THE LIBERTARIAN MOVEMENT

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ABSTRACT

Nino (2025) is an attack on libertarianism in general and on my views in particular. He maintains that it is impossible, without contradiction, to both support this free-market philosophy which is grounded upon the non-aggression principle (NAP), and, also, to defend the recent and previous behavior of Israel. That country, he contends, is a blatant violator not only of libertarian principle, but also of civilized behavior. Further, Israel has also violated the private property rights of the Palestinians. Thus, their actions of October 7, 2023, can be seen as just a retaliation of the injustice previously perpetrated upon them. The Jewish state has stolen lands from the Gazans and other Palestinians. It has turned Gaza itself into "an open-air prison." My defense of the only civilized country in the Middle East, thus, cannot possibly be logically compatible with the principles of libertarianism, he avers. In his diatribe against me, Nino pulls out all the stops. He sees nothing whatsoever of any value in my defense of the Jewish state. The present paper consists of my refutation of each and every one of this author's critical claims. In my view, his screed is not motivated by a search for the truth of the matter. Rather, he wishes to tear down the case in behalf of Israel, and defend that of Hamas, Hezbollah, the Houthis, and their paymaster and leader, Iran.

1 INTRODUCTION

Nino (2025)¹ is very critical of yours truly. But, they say, there is no such thing as bad publicity, as long as the critic spells your name correctly. This author

does that, I readily acknowledge. He also accurately renders my Jewish, Austrian and libertarian antecedents; how I came to bear all three descriptions. I also thank him for the few compliments he bestows upon me regarding my

¹ All mentions of this author, below, refer to this one essay of his.

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Defending and privatization series of books.² But, alas, I fear that this is almost all the material upon which he and I can agree. As for the rest of it, here is my critical response.

In section II of this paper, I discuss my excommunication on the part of several otherwise libertarian organizations. The burden of section III is to address the issues of free association, argument and anti-Semitism. Section IV is devoted to an analysis of my Zionist awakening, V to the Gazan children, VI to ethnic cleansing, VII to Nino as historian, VIII to Hoppe, IX to the assertion that the Jews created libertarianism, and are criminally liable for so doing. I conclude in section X.

2 MY CANCELLATION

Nino's first error is this: "What seemed like an argument over ideas was, at its core, a reckoning of identities no theory could contain. The recent falling out between economist Walter Block and the Ludwig von Mises Institute was not a routine dispute over doctrine. It revealed something far deeper, a reminder that even among those who preach the supremacy of logic and liberty, human nature resists the purity of abstraction."

I must disagree. At least at the outset, where I and the leaders of the Mises Institute (Hans Hoppe, Lew Rockwell, Tom DiLorenzo, Guido Hulsmann, David Gordon, & Ryan McMaken)³ depart concerns an idea, and only an idea: Are the actions of Israel in the war that started in October 7, 2023, and its antecedents, compatible with libertarianism or not? I say they are; my intellectual opponents diverge from this claim of mine.

I also find this problematic: "Intellectual movements, however rational they may appear, remain vulnerable to the same ethnic and cultural

divisions that have divided men for centuries." Yes, libertarianism is, among other things, an "intellectual movement." But the movement as a whole is not "vulnerable" to any such thing. This applies only to those persons, and to several of their organizations, that have excommunicated me from my former relationship with them. Among these I would certainly list the aforementioned Mises Institute in Auburn Alabama.⁴ There is also the Ron Paul Institute, the Libertarian Institute, antiwar.com and the Future of Freedom Foundation which has severed all relationships with me.⁵ But these are only a part, a small part, of the entire libertarian movement.

In attributing differences over how libertarianism applies to Israel, to genetic backgrounds, Nino is committing the ad hominem fallacy in logic. He in effect claims that I support the Israel side of this debate due to the irrelevant fact that I happen to be Jewish. But, as we shall see, there are numerous libertarians who take the side of Hamas, and some of them are Jewish. One cannot deduce truth from genetic background, ethnicity, religion, or any other such phenomenon, contrary to Nino. Ideas, and ideas alone, determine veracity, not personal antecedents.

3 FREE ASSOCIATION, ARGUMENT, ANTI-SEMITISM

According to Libertarian Doctrine, free association is one of its foundational aspects. Thus, these people are legally entitled to never speak to me ever again, as several have chosen to do, despite a warm and friendly relationship of in many cases three and even four decades and more.

However, they also consider themselves as intellectuals. And, here, they fall by the wayside. We libertarians, and also conservatives, properly

² I am grateful to Nino, also, for covering many of the relevant bases; he writes very clearly, which makes refutation all the easier.

³ Libertarians who are mistaken in their support of Hamas vis a vis Israel include Rothbard (1967), Hoppe (2024), DiLorenzo (2024), McMaken (2024), Rectenwald (2024), Joffe (2024), Burgis (2024) and Mosquito (2018, 2023). For refutations of these papers, see, respectively, Block and Futerman (2021) on Rothbard; Block and Futerman (2024) on Hoppe; Block (2024A) on DiLorenzo; Block (2024B) on McMaken; Block (2024C) on Rectenwald; Block (2024D) on Joffe; Block (2024F) on Burgis; Block (2024E), Farber, Block

and Futerman (2018) on Mosquito. See also Gordon and Njoya (2024) and this response to them: Futerman and Block (2024).

⁴ There are almost a dozen Mises Institutes spread all around the world, and this is the only one which has cut most ties with me, but not all of them. I continue to be allowed to publish in their high-profile journal, the Journal of Libertarian Studies. See on this Block (2025).

⁵ They refuse to have anything whatsoever to do with me. They will no longer accept for publication in their respective journals articles of mine wherein we fully agree; e.g., do not touch upon the subjects of Israel, Judaism, antisemitism, etc.



condemn leftists for their cancel culture. If you use the wrong pronouns, or utter such horrid words as “Orientals,” or “cotton,” or spell black in lower case, you are subject to canceling, and consignment to sensitivity “training” e.g., attempted brainwashing. No debate, no nothing, just cancellation, banishment.

Unhappily, as can be seen in the present case, this virus has infected parts of the libertarian movement, to its shame. Thus, the groups and individuals who have excommunicated me are entirely within their legal rights, at least according to libertarian theory. But their much-vaunted claim as intellectuals is much diminished by this decision of theirs. Intellectuals, proper intellectuals, do not shut down intellectual opponents. They debate them.

Hans Hoppe has done important work in exploring the foundation of libertarianism in terms of his argument from argument.⁶ Yet, he, hypocritically, refuses to debate me on issues pertaining to Israel. As a matter of some curiosity, he has never personally debated anyone at all, in an effort to spread libertarianism. He is courageous in writing critically about perceived enemies of liberty. But this does not carry over into personal verbal confrontation.⁷

It is more than passing curiously that the same phenomenon did not contaminate any part of the libertarian movement whatsoever in the case of abortion. Murray Rothbard was unwaveringly pro-choice. Ron Paul, equally adamantly, pro-life.⁸ Yet they were fast friends all during the life of the former. No one else came within a million miles of cancelling either or both of them. But abortion affected many more human lives than were impacted by all the wars participated in by Israel. How to explain this? See below.

Consider Nino’s comment on what he kindly calls my “1976 masterwork *Defending the Undefendable*.” He writes that this book created “... a framework that embodied Block’s Jewish character of challenging gentile norms wherever possible.” This is more than passing curiously.

What would people say if I wrote that Einstein’s theories challenged “gentile norms.” They would say that I had some sort of weird ax to grind. What we fellow Jews, Einstein did and I did in this book (Block, 1976), had absolutely nothing to do with Judaism or with “gentile norms.” What controlled substance has this man Nino been smoking? Einstein and I did what we did not because we are Jews; we did it qua scientist and economist. Similarly, the contributions of Christian physicists and economists have nothing whatsoever to do with their ethnicity or religion, nor that of thousands of other non-Jewish intellectuals.

Consider this statement: “The Canadian newspaper *Le Devoir* used the anti-Semitic phrase ‘the Jew Einstein.’ According to a review of Mordecai Richler’s book *Oh Canada! Oh Quebec!* in *The New York Times*, *Le Devoir* wrote that ‘the Jew Einstein made us accept on his word his theory of relativity.’” (Doughty, 2006)

Nino, here, is channeling *Le Devoir*. This sort of thing may have been barely acceptable in polite company at the turn of the last century. Nowadays, hopefully, it is not, Nino to the contrary notwithstanding.

Judaism has absolutely nothing to do with either physics, or economics or just law, the province of libertarianism. True, there is a statistical correlation between people of The Book and all of these disciplines. Jews are disproportionately involved with all intellectual arenas. But that hardly undermines the theories of practitioners of any of these callings merely for being Jewish.

According to this reporter, I have been “... maintaining respectability within academic circles” based on my books on “road privatization, water capitalism, and space economics?”⁹ Not a bit of it. I was not tenured until age 61 due to my adamant support of privatization, private property rights and other accoutrements of free enterprise. I gained tenure at Loyola University New Orleans at that ripe old age mainly due to the fact that the donor of my endowed chair specifically called for a professor who would propound this particular

⁶ Or argumentation ethics. See Block, 2004C, 2011; Gordon, 1988; Hoppe, 1988, 1993, 1995; Kinsella, 1996, 2002; Meng, 2002; Rothbard, 1998.

⁷ In sharp contrast, I have publicly debated perhaps over 100 times.

⁸ Both were wrong; the correct free enterprise view on this is evictionism; see on this Block (2021B).

⁹ My privatization series: Block, 2006, 2019, Block and Nelson, 2015; Nelson, and Block, 2018

economic philosophy of free markets. I would have been fired a dozen times without tenure, and even with that protection, had I refused to undergo sensitivity training.¹⁰ Hey, maybe some or all of those cancelling libertarian establishments will take me back if undergo their sensitivity training which will teach me how wonderful, ethical and magnificent are the Palestinians, the Gazans, Hamas, Hezbollah, the Houthis, the present Iranian administration.

4 MY ZIONIST AWAKENING

Nino opines: “Yet beneath this impressive scholarly output lay dormant ethnic loyalties that would eventually surface with explosive consequences.” Here, again, is his claim that it only because I am Jewish that I support Israel. This is refuted by the fact that there are many anti-Zionist Jews.

I may be a libertarian, but in this author’s opinion, my Judaism over-rode my adherence to that political philosophy. Nino states:

“The October 7, 2023, Hamas attacks triggered an ethnic awakening within Block that betrayed his libertarian commitment to non-aggression and a non-interventionist foreign policy. In his Wall Street Journal op-ed he penned with Argentine economist Alan Futerman ‘The Moral Duty to Destroy Hamas,’¹¹ Block revealed convictions that had apparently been gestating beneath his libertarian exterior for years.

“His call for ‘total, unrestrictive support’ for Israel represented a complete abandonment of libertarian non-interventionism. Block argued that ‘Hamas needs to be destroyed for the same reason and by the same method that the Nazis were,’ explicitly comparing the conflict to World War II’s total war paradigm. This was not merely policy disagreement but a fundamental rejection of the non-aggression principle that forms libertarianism’s cornerstone.”

Nino takes great umbrage with my and Futerman’s call for “total, unrestricted support for Israel.” What is so wrong, so non-libertarian, about favoring a country, a people, that was so unjustifiably, and viciously, attacked on October 7, 2023? Why is it

a “complete abandonment” of the libertarian philosophy? Nino does not vouchsafe us an answer to that important question. He merely contents himself with parroting this point.

This journalist vociferously objects to Futerman and I placing this despicable Hamas attack in the same moral category as occupied by the Nazis. Were they not both guilty of perpetrating brutal crimes? Of course, there is not any quantitative equation to be made regarding the number of deaths that took place on these two occasions. Mention of the Nazis is rather an analogy, and not an inept one. Apart from the sheer difference in numbers, the two episodes have much in common. Jews were unjustifiably attacked on both occasions. Why is it that to say this constitutes “a fundamental rejection of the non-aggression principle that forms libertarianism’s cornerstone”? Nino, once again, does not say. He limits himself to making yet another unsubstantiated charge. He refuses to enlighten us.

Could it be, perhaps, possibly, that he does not really, fully, understand the libertarian philosophy, to which some of us had contributed over the years? One searches in vain for evidence that Nino has ever before published anything on this perspective.¹²

That concludes his claim that I peeled off what turned out to be a thin veneer of libertarianism, in favor of my more basic, fundamental grounding in Judaism. But this will not do at all. It amounts to mere name calling. Nino maintains that no one who supports Israel’s behavior after that day of infamy, October 7, 2023, can possibly do so based on anything approaching libertarian theory. I do so, only, because I am Jewish, supposedly. If that does not constitute an ad hominem fallacy, there is no such thing as an ad hominem fallacy.

Note, that Nino, like Hoppe (2024) before him, relies, only, on an op ed published in the Wall Street Journal, composed of, merely, several hundred words. Both writers totally ignore a full book length publication of mine (Block, & Futerman, 2021). Futerman and I can only make a small contribution to the argument that Israel may be defended on strict libertarian grounds in

¹⁰ I violated woke strictures mentioned above

¹¹ Block and Futerman (2023)

¹² To the best of my knowledge, this is the first time he has ever written about the “L” word.



the former, we do a more complete job in the latter. Briefly, we trace disputed Israeli land claims some 3000 years ago based on the John Lockean libertarian theory of homesteading;¹³ the Arabs did indeed occupy these contested territories, but only for a matter of a few centuries. Thus, they were trespassers. There is no logical incompatibility between libertarianism and support of Israeli behavior based upon proper ownership of the terrain under dispute. Were Nino more of a scholar, he would at least have tried to refute this argument. In the event, he totally ignores it.

A word about that “triggering.” This implies that I wrote about, studied, spoke publicly, nothing at all concerning Judaism before October 7, 2023. Not so, not so. Au contraire, I have a track record which supports the very opposite conclusion.¹⁴ Nor did my defense of Israel vis a vis its many enemies start on October 8, 2023.¹⁵

Nino maintains that “Block ... betrayed his libertarian commitment to non-aggression...” He is very wide of the mark in this contention of his. I did not at all do any such thing. Rather, I took the position that the NAP and private property rights based upon initial homesteading was all on the side of the Jewish state. It was purely on the defense on the occasion of each and every war it fought; they were all initiated not by it, but by its neighbors who initiated the aggression.

The Hebrew nation has been under almost constant initiatory attack ever since its formation in 1948; before that there were pogroms against innocent Jews galore. Libertarianism is not a suicide pact. It is compatible with but does not require pacifism. Stated Benjamin Netanyahu, apropos this point, “If the Arabs put down their weapons today, there would be no more violence. If the Jews put down their weapons today, there would be no more Israel.” (Netanyahu, n.d.) The libertarians do not oppose all war; only offensive war, such as conducted by the enemies of the only

civilized country in the Middle East. The motto of LewRockell.com is “ANTI-STATE•ANTI-WAR•PRO-MARKET.” Antiwar.com bruits itself as a libertarian organization, and in many ways it is. But not in the choice of its very name. But if this is meant to articulate the libertarian vision, the middle claim is mistaken. Even Mr. Libertarian, Murray N. Rothbard, favored at least two wars: the war of secession of the thirteen colonies against Great Britain in 1776, and the war of secession of the South, against the North, in 1861. (Rothbard, 1999) The libertarian, properly, opposes offensive war, but supports defensive war.

Implicit in Nino’s “analysis” is that it is impossible, it is a logical contradiction, to be both a libertarian and a defender of Israel. But he offers not one single word as evidence for that claim. He merely asserts it. Over and over again.

Nino also looks askance at the US “interventionist” foreign policy. In this context, I presume he opposes American foreign aid¹⁶ to Israel. It cannot be denied that Israel receives more government-to-government transfers of US funds than any other single nation. However, when you consider the US monies received by all of the Arab countries put together,¹⁷ that amount given to Israel is dwarfed. Thus, less “interventionism” of this sort would help, not hurt, Israel, at least proportionately, vis a vis its enemies, present and former.

On the other hand, there is nothing in the classical liberal or monarchist versions of libertarianism that precludes US alliances with other countries. And that between it and Israel has a lot to be said in its behalf, and not only in one direction. Rather, it is a two-way street (Block, & Faran, 2025A).

5 THE GAZAN CHILDREN

Nino takes offence with the fact that I had the audacity to write an op ed (Block and Faran, 2025A) directly addressed to the children of Gaza.

¹³ Block, 1990B, 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.

¹⁴ See in this regard Block (1986, 1990A, 1996, 2002C, 2004A, 2005). Nino simply did not do his homework.

¹⁵ Block, Futerman and Farber (2020, 2021); Futerman, Farber and Block (2016).

¹⁶ When using this phrase, I must apologize to Peter Bauer (1981, 1982, 1984, 1991; Bauer, & Yamey, 1957)

¹⁷ Some of them are no longer obvious enemies of Israel since the Abraham Accords, but many of them were, before that

He maintains that my “Open Letter to the Children of Gaza” revealed depths of ethnic passion that stunned even his closest associates.” Yes, indeed, my “closest associates,” not to say decades long friends, were “stunned” and then bitterly angry at me for telling these children that they had their own parents to blame for their plight. They used them, abusively, as shields, by placing rocket launchers in hospitals, playgrounds, schools, residential areas. What is the IDF supposed to do? Sit there and take it? Continue to allow Hamas to rain death down upon Israelis, hidden behind its children? Even the Nazis did not hide behind women’s skirts and use their youngsters as shields.

Nino was offended by this statement of mine to the children of Gaz: “your parents launched a despicable, unwarranted attack on October 7.” He accuses me of “conveniently overlooking the long history of Jewish expropriation of Palestinian lands dating back to the 1880s—a campaign of extermination that the United States government has fully endorsed through its ongoing flow of military aid, economic support, and diplomatic cover. And of course, he (that is, me, the present author) didn’t mention Israel’s oppressive control over Gaza—making Gaza into an open-air prison. Who could live like that?”

Nino continues: “These positions revealed Block not as a consistent libertarian applying universal principles, but as a Jewish intellectual whose ethnic solidarity ultimately trumped philosophical commitments when forced to choose between abstract theory and tribal loyalty.”

These views of his cannot be allowed to stand. First, as before, they reveal an almost complete ignorance of the libertarian philosophy, about which he confidently pontificates. Second, is there some hidden libertarian premise of which only libertarian cognoscenti such as Nino are aware, that prevents authors from directly addressing children? Perhaps this master libertarian can point this out to me. Neophytes in this philosophy, such as I are always willing to learn from masters of this libertarian craft such as this author.

Second, even if this were true,¹⁸ it hardly justifies the massacre of some 1200 innocents. Note,

when Israel engages in assassination, it aims at military targets, including scientists working on nuclear weapons (Block, & Faran, 2025B), not civilians. The latter are impacted when they are used as shields by enemy leaders.

Third, it is not true. Many Gazans worked in Israel, earning higher wages. East Germany, in sharp contrast, was indeed an “open air prison.” When the prisoners tried to emigrate in a westward direction, they were shot. The Jewish state does no such thing regarding those who wish to depart from Gaza.

Fourth, while the East Germans who wished to move to West Germany were innocent of any crimes, the same cannot be said for the Gazans. Their celebrations, dancing in the streets, on October 8, 2023, demonstrate that virtually all of them were aiding and abetting the events of the previous day. Moreover, dozens of them engaging in suicide bombings in Israeli schools, buses, shopping malls, restaurants, etc. It is difficult on libertarian self-defense grounds, to blame the Israelis for limiting the freedom of such persons.

6 ETHNIC CLEANSING

At this point in his essay Nino cites Al Jazeera (2017) to the effect that the Israelis have engaged in “ethnic cleansing” and were responsive for the fact that almost a million “Palestinian refugees had ... been forcefully expelled from their country.” The very opposite is the case.

The reason these people became refugees stemmed not from Jewish expulsion of them. Rather, this came about due to the fact that the five invading armies in 1948, Lebanon, Syria, Iraq, Egypt and Saudi Arabia, ordered them to leave. Why? These civilians would just get in the way. If the Palestinians remained, the invaders would have had to protect them, which would reduce the slaughter of the Jews, their prime goal. (Milestones, n.d.; Marcus, 2024)

The Jews practically begged these folks to stay. According to Golda Meir (1975, pp. 267–268): “Every time I read or hear about how we supposedly treated the Arabs with such cruelty, my blood boils. In April 1948, I myself stood for hours on the shore in Haifa and literally begged

¹⁸ It is not, it is not



the Arabs of that city not to leave. Moreover, it was a scene I don't think I'll ever forget. The Haganah had just taken control of Haifa, and the Arabs began to flee — because their leaders had so convincingly promised them that this was the smartest move, and because the British generously provided them with dozens of trucks. Nothing the Haganah said or did helped — not the loudspeakers mounted on trucks, nor the leaflets we dropped on the Arab neighborhoods of the city ('Don't be afraid,' they said in Arabic and Hebrew. 'If you leave, you will bring poverty and disgrace upon yourselves. Stay in the city, which is yours and ours.') These were signed by the Haifa Workers' Council.

"And this is what British General Sir Hugh Stockwell, then commanding the army there, said: 'The Arab leaders left first, and no one lifted a finger to stop the movement that started in haste and then became a panic-stricken flight.' They were determined to go. Hundreds crossed the border in vehicles. But some went down to the seashore to wait for boats.

"Ben-Gurion called me and said: 'I want you to go to Haifa immediately and make sure the Arabs who remain there are treated properly. I also want you to try to persuade those Arabs on the shore to return. You have to make them understand they have nothing to fear.'

"So, I went immediately. I sat on the shore and begged them to go back to their homes. But I got only one answer: 'We know we have nothing to fear, but we must go. We will return.' I was completely convinced that they left not because they were afraid of us, but because they feared they might be seen as traitors to the Arab cause. In any case, I spoke until I had no strength left, and it did no good."

If it were really true that 'twas the Jews who were responsible for forcing the Palestinians to depart in a bout of "ethnic cleansing," why did hundreds of thousands of them remain? Why were they not, also, banished? And how did the Jewish state treat them and their children? They are doctors, lawyers, professors, engineers, scientists and

politicians. They are even represented in the Knesset with their own political party!

Nino neglects to mention that at around the same time, roughly the same number of Jews were exiled by the nations of the five invading armies. They feared for their lives due to increasing pogroms. Israel integrated them into its society, economy, while the Arab countries mistreated the Palestinian refugees who departed under orders from the five invading armies. They were consigned to refugee camps, where they and their children still suffer. Why? To demonstrate the supposed cruelty of the Israelis.

7 NINO AS HISTORIAN

The 1880s? The 1880s? This is as far back in history that this Middle Eastern expert goes, in his attempt to demonstrate Hebrew perfidy. What about three millennia ago and more, when there is strong evidence that the Jews were there, busily homesteading now disputed land, and thus becoming the legitimate owners of it, at least according to libertarian John Locke.¹⁹ The Muslim trespassers only arrived on the scene several centuries ago and thus cannot be considered proper owners. The most dramatic evidence for this is the that Jewish Second Temple lies below the Al Aqsa Mosque, indicating, definitively, which group of people was there first. There is evidence of Arab presence in contested land, for the first few feet down. But below that, it is turtles all the way down, Jewish turtles.²⁰ Nino ought to read a book on history, or two. Perhaps there is some hidden aspect of libertarianism, known only to world class theoreticians of this discipline such as Nino, but unknown to me, a mere beginner, that precludes going back into history to discern just property titles further than 1880. I beg Nino to instruct me on this matter.

There is such a thing in law as legislated statutes of limitations. If you seek justice after a specific number of years has passed over this limit, you are plain out of luck, legally speaking. The argument in favor of such laws is that people, after a while, want to focus on other things; they need security in their possessions. The view is that the

¹⁹ Likely, Nino has never so much as heard of this father of libertarianism

²⁰ There is archeological evidence that the Jews lived in Israel before the Moslems

past can only have a limited effect on the present, and the future.

But this legislation is incompatible with libertarianism. Suppose grandfather A stole a wristwatch from grandfather B. Grandson A is now in possession of this item. Posit that the time limitations imposed by law is 30 years. Grandson B discovers this long-ago theft 31 years later and goes to court to obtain what he rightfully owns;²¹ the court rules against him. If that is not the height, or the depth of injustice, then nothing is unjust.

The libertarian stance on this matter is called the natural statute of limitations. Possession is nine tenths of the law. The burden of proof always rests with the plaintiff, not the defendant. However, the further back you go into history, the more difficult it is to prove anything. It is my position that the archeological evidence is so overwhelming, even though it harkens back millennia, not mere centuries, that it overcomes this natural statute of limitations, and places proper ownership of contested lands with the Jewish grandson, not the Arab one.

8 HOPPE

Nino now turns for support to my old friend of some four decades Hans-Hermann Hoppe who he characterizes as “The Libertarian Contrarian Who Stood Up to Block.” Hoppe is a master of understatement and moderation who starts off his critique of my views of the Israeli situation by characterizing me as “an unhinged, bloodthirsty monster.” This, based on our disagreement over the application of the doctrine of private property rights and Lockean homesteading to the Middle East.

Just imagine his invective if we disagreed on something even more important. Civilized language might then fully fail him.

A word about this author who “stood up to me” as Nino puts the matter. Hoppe’s sole target was Block and Futerman (2023), a single, solitary Wall Street Journal op ed of a mere several hundred

words. However, as mentioned before and now so again since it is so important, I also co-authored an entire book on this subject (Block, & Futerman, 2021), with this brilliant young economist and libertarian theoretician. Hoppe entirely ignores that full-length treatment. One can be forgiven for wondering if he has ever read it.²²

Second, Futerman and I wrote a scholarly rebuttal of Hoppe (2024). Did the latter reply? To ask this is to answer it: of course not. Why condescend to a person who is “an unhinged, bloodthirsty monster?” Why argue with a person such as I who rejoices in the murder of innocent children, such as I, in his opinion.²³

Third, I have upon several occasions challenged this man to a public debate. A coward, he has refused all such invitations. This is more than passing curiously. Hoppe has done more good work, no, make that excellent work, than any other libertarian on grounding this philosophy on the argument from argument, or argumentation ethics.²⁴ I enthusiastically support him in this splendid effort of his. However, when it comes to putting his money where his mouth is, e.g., acting in accord with his own publications on the importance of argumentation, to actually engage in a debate with me, he is nowhere to be found. Instead, we find him cowering somewhere in Turkey, seemingly afraid of his own shadow. It is upon such an intellectual craven that Nino relies. Is Hoppe afraid that in an open debate the pure logic of the matter will demonstrate the error of his ways on Israel? Enquiring minds want to know. Maybe his buddy Nino can ask Hoppe about this.

Hoppe is in many ways a gifted libertarian theoretician, and Austrian economist. He is good at pontificating; he is personally eloquent. But his advocacy never stretches in the direction of *mano a mano* debates, against a competent intellectual opponent. One looks in vain in google and other such places for his public verbal disputes with anyone, on any subject pertaining to political economy. He ducks not only “unhinged, bloodthirsty monsters” like me, but everyone. In

²¹ We assume that parents pass on what they own to their children.

²² In contrast, when I criticize Hoppe, it is typically based on his journal articles or book length treatment of a subject. See Block, 1998, 2004B, 2007, 2009, 2010, 2011A, 2011B, 2021B, 2024B, 2024G; Block and

Barnett, 2010; Block, Barnett and Salerno, 2006; Block and Callahan, 2003; Block and Futerman, 2024; Gregory and Block, 2007.

²³ Several people have told me that this is the reason he gives for his refusal to debate me.

²⁴ See fn. 6, *supra*



contrast, there must be scores if not hundreds of intellectual altercations I have engaged in, with critics of libertarianism. I channel the heroic Charlie Kirk in this matter. The fraidy-cat Hoppe does not.

Nino is entirely correct in saying that I am no longer listed as a senior fellow at the Mises Institute Auburn, and that my many years of writing and speaking for them and defending them have been erased. This relationship has not only been “curtailed,” but ended. This applies to material having nothing to do with Israel, on LewRockwell.com. I deduce that they don’t much like unhinged, bloodthirsty monsters.

With this introduction to this section of Nino’s paper, we now arrive at his account of Hoppe’s (2001) in many ways excellent book.²⁵ How does this publication pertain to the Israeli situation? It has to do with “covenant communities” which have the right to “physically remove” undesirables. Nino quotes Hoppe 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,’ he declares, extending this principle to ‘advocates of alternative, non-family and kin-centered lifestyles such as, for instance, individual hedonism, parasitism, nature-environment worship, homosexuality, or communism.’” (emphasis added by present author).

Nino, oblivious to the niceties of libertarianism, does not realize what a hot potato he has uncovered herein. He makes much of the fact that since the owners of a condominium association, private store, private library and other such enterprises are entirely justified in excluding from their premises people they regard as “undesirable,” then the groups and people who have cut all ties with me are also, and equally, entitled to do so. Yes, indeed, that is true. But it is also uncontroversial. I do not claim, nor have I ever done so, that these cancellations violate libertarian law.

In my view, however, these exclusions are incompatible with the previously undeniable claim of these organizations to be scholarly; to be thought of as intellectual think tanks. Those who

wish to be thought of in that way do not embrace the leftist cancel culture. Rather, they adhere to the view that “sunlight is the best disinfectant.”

Note, Hoppe is urging that the “deplorables” be excluded not from cooperatives, condos, covenant communities and other private voluntary groups, but rather from “society” as a whole. If this means anything, it means total banishment! The logical implication here is that were the Hoppe who wrote these words in charge, gays, commies, etc., would have their properties stolen from them and forced to vacate their homes and offices. That is what banishment means; nothing more and nothing less!

If that is not a violation of libertarian principles, then nothing is a violation of libertarian principles. Nino may not recognize this, but Hoppe certainly could, would, or at least, should. Nino, who is so intent to point out incompatibilities with libertarian principles in my writings, completely misses this one written by Hoppe. During the many years when we were friends, I several times pleaded with Hoppe to not say any such thing. Banishing non-criminals from “society” is simply not on, from the libertarian perspective. In my communication with Hoppe, I characterized this statement of his as a verbal slip, similar to a typographical error. He never changed; certainly, he did not apologize for what I thought then and still think now was but a mere inadvertent error. But he did not implement my advice, from which I infer he really meant to say this. How else can we rationally interpret his refusal?

Consider what this would mean for just one of the groups that Hoppe regards as beyond the pale, homosexuals. Here is a list of eminent libertarians who also just happen to be gay: Dave Boaz, Roy Childs, Ron Hamowy, John Hospers, Chase Oliver, Tom Palmer, Jim Peron, Ralph Raico, Justin Raimondo, Will Smith, Starchild, Peter Thiel, Richard Winger.

No libertarian can doubt that these gentlemen have all made important contributions to our political economic philosophy. Here is what Rockwell (2004) had to say about one of them: “December marks the eighth anniversary of the passing of Ralph Raico, one of Murray Rothbard’s

²⁵ For my review of it, see Block (2002)

closest friends and the greatest twentieth-century historian of classical liberalism and a great libertarian theorist as well.” No words were better or more truly said. However, in uttering them, Rockwell thus places himself in an awkward position. He was the Grand Inquisitor of the Mises Institute Auburn, in excommunicating me from the organization that he founded. He did so largely based on Hoppe (2024). He very properly praises Raico to the skies. But Hoppe (2024) would banish Raico not from his own condominium residential complex, but from all of “society.” Rockwell thus has a lot of “splaining” to do. If Rockwell wants to cancel someone from his organization for taking a non-libertarian position, it should be Hoppe, not me.

Why, by the way, am I called an unhinged bloodthirsty monster?²⁶ Presumably, it is because I revel in the slaughter of innocent Gazans, particularly their women and children. That is to say, I am a supporter of Israeli war crimes and genocide on the part of the Hebrew state.

According to the always reliable of absolutely truthful statistics supplied by Hamas, the IDF has slayed some 65,000 Gazans.²⁷ Let us accept this number, arguendo. The Israeli military, the fourth most powerful in the entire world,²⁸ conquered Egypt in the 1967 war. If this colossus of power really wanted to destroy all two million Gazans, how long would it have taken them? Six hours? Maybe six minutes? Instead, the IDF acts in the exact opposite manner. Before bombing a Gazan hospital used as a cover by Hamas, it sends warning leaflets in an attempt not to destroy innocent lives, but to preserve them. The average army kills nine civilians for every enemy soldier dispatched. The IDF ratio? A startling one to one point five (Block, 2024H). They preserve the lives of Gazan non-combatants even at the cost of shedding the blood of their own warriors. The IDF has a significant advantage over Hamas troops on the ground, dealing with booby-trapped tunnels and buildings. But the former has a gigantic, not to say infinite comparative advantage over the latter from the air. Nevertheless, they all too often engage in house-to-house fighting, in an effort to

save Gazan lives. That is “unhinged?” That is “bloodthirsty?” That is “monstrous?”

Who is responsible for the deaths of the Gazans, especially their children? There are only two candidates, and three possibilities: 1. Hamas; 2. Israel; 3. Both are guilty and they share the blame.

Superficially, Israel seems most vulnerable to this charge. After all, it was the bullets and bombs of the IDF that ended the lives of these innocents. But this is a superficial analysis. Suppose a madman straps his two infants to his chest and comes running at you, knife raised, blood in his eye, yelling the threat that he is going to kill you and your family, who are sheltering behind you. You have a gun and could kill him in self-defense. But if you do so, you, his totally innocent babies will also die. You have two choices. One, allow him to murder you and your own children. This of course would be suicidal for you and your family. Even an expert libertarian such as Nino might not accept this course of action as required by this philosophy. Two, shoot him to death and his youngsters also die. If you chose the latter course of action, who is at fault for these deaths? You? He? Both are blameworthy?

Obviously, this crazy person bears full and sole responsibility for his own death and that of his progeny. He, not you, used them as a shield.

But Hamas is guilty of precisely this sort of behavior. By placing rocket and drone launchers in hospitals, schools, Mosques, residential areas, children’s playgrounds, they are the only ones responsible for, and guilty of, the demise of Gazan children. Nino should see this, even if Hoppe does not.

A picture tells a thousand words. One of the best cartoon illustrations of this situation features an Israeli and a Palestinian aiming a gun at each other. But the former is placed in front of a Jewish baby carriage, which the latter occupies space behind an Arab baby carriage. (Dershowitz, 2013)

²⁶ True confession. I like that phrase. It is even more apt at the time of this writing, during Halloween. It evinces a keen appreciation of the human condition on the part of Hoppe.

²⁷ They do not distinguish between combatants and non-combatants.

²⁸ Staff (2023). Per capita, Israel has the strongest military, bar none.



9 THE JEWS CREATED LIBERTARIANISM, AND ARE CRIMINALLY LIABLE FOR SO DOING

Saith Nino, "It's no secret that libertarian movement's development has been profoundly shaped by Jewish intellectual leadership. This pattern extends from the movement's Austrian School foundations through its contemporary institutional structure." He mentions in this regard those libertarians who were indeed Jewish. But the Austrian School was founded by Carl Menger, a non-Jew. Eugen von Bohm-Bawerk, another guy, also preceded the Jewish Mises. Nino moves too fast to Murray N. Rothbard, who was indeed Jewish, but ignores Friedrich A. Hayek, an earlier Austrian. My critic then says: "Curiously, Rothbard had more of a populist turn toward the end of his life, where he advocated for a strategy of "right-wing populism" that endorsed the presidential campaigns of David Duke and Pat Buchanan." But this mentor and friend of mine took these positions far longer than merely "toward the end of his life."

Nino mentions several Jewish libertarians who were indeed foundational for the modern movement ²⁹ such as Rothbard, Milton Friedman and Ayn Rand.³⁰ In so doing, he is trying to convert libertarianism into a quintessentially pro-Israel philosophy. Yes, the latter two were both libertarians and both pro-Israel, but the former (Rothbard, 1967) was a bitter critic of the Jewish state. Then, too, there is a whole host of non-Jewish libertarian leaders many of whom had nothing whatsoever to say about the only civilized country in the Middle East or were strong critics of this country. Ron Paul is certainly an example of the latter.

Libertarianism is no more "Jewish" than physics or mathematics are "Jewish," even though the Chosen People are disproportionately represented in all three callings.

Nino continues: "Block's passionate Zionism ultimately proved incompatible with libertarian anti-interventionism, leading him to walk away

from the intellectual community he had contributed to for over four decades."

Hey, waitasec. I did not at all "walk away" from any of the several libertarian organizations with whom I had long been associated. Rather, the very opposite is the case: they "walked away" from me. No, that is not correct. Instead, they "ran away" from me, as if I were a hot potato. Take the case of Ron Paul. I have been a friend and admirer of his for more years than either of us would like to contemplate. I am now persona non grata with his institute. But at least he will still communicate with me. Not so for many of the leaders of the other groups which have cancelled me.

Last but far from least, consider this parting shot of Nino's: "Like archaeologists uncovering layers of forgotten civilizations, the Block-Hoppe schism reveals that beneath every high-minded intellectual movement lies the bedrock of tribal identity, waiting to reassert itself when abstract principles collide with the eternal reality of us versus them."

Do you know what the favorite sport, hobby, is, in the United States? It is football. In Canada, hockey. In most of the rest of the world, it is soccer. Do you know what it is in Israel? It is archeology. The nerds in that country, along with guests from other nations, are forever digging up their soil and categorizing what they find there. In the first few feet beneath the surface, they find evidence of Arab occupation. That is to be expected, since such folks have indeed lived in the disputed territories for hundreds of years. But when they dig deeper, they uncover evidence of Jewish presence. This is due to the undeniable fact that Hebrews have occupied these lands for millennia! Perhaps the most dramatic example of this phenomenon is that the Al Aqsa Mosque lies above the Jewish Second Temple, and the first one is found even below that. This indicates as nothing else quite can, that the Jews were there first! If so, then according to the homesteading views of the libertarian John Locke (1948)³¹, the

²⁹ However, according to Rothbard, the ancient Chinese philosopher Lao Tzu was "the first libertarian intellectual." (Rothbard, 2014)

³⁰ She rejected that label, preferring Objectivist, but Nino is correct in his categorization. Curiously, Nino overlooks the Jewish Robert Nozick.

³¹ No Jew, he!

Jews, not the Palestinians or any other Arabs, are the rightful owners of the terrain under dispute.

10 CONCLUSION

Yes, condominium associations and private think tanks, have every right to ban anyone they wish from their electronic or physical premises; to disassociate themselves from anyone they wish. However, these organizations fashion themselves in addition to property rights holders, in addition to bearing the rights of free association, also as intellectual enterprises. We have all rejected the left's cancel culture, for using the wrong pronouns, etc. But now we find these groups adopting a similar policy. No. Intellectuals do not cancel anyone. Anyone at all. They debate them.

The list below is that of individuals (some of whom would not have attached the word 'Libertarian' to themselves – because the term had not yet been invented in their era), but who nevertheless espoused philosophies and foreign (and economic) policy beliefs that aligned word perfect with today's Ron Paul Libertarianism and could thus be labelled the 'Founding Fathers of Libertarianism':

Adam Smith, John Locke, Thomas Paine, Thomas Jefferson, Frédéric Bastiat, Lysander Spooner, Henry David Thoreau, Alexis de Tocqueville, Carl Menger, Eugen von Böhm-Bawerk, Friedrich von

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Wieser, Joseph Schumpeter, Friedrich Hayek, Hans-Hermann Hoppe. Lew Rockwell and countless others.

As you can see, there is NOT a single Jew among them.³²

Yes, Jews at 2% of the US population are wildly overrepresented amongst libertarians, but the same is true of pretty much any other intellectual discipline: physicists, chemists, doctors, dentists, lawyers, mathematicians, chess grandmasters, Nobel Prize Winners, etc. Nino's strange attempt to paint libertarianism as a quintessentially Jewish enterprise is thus highly problematic. But I give him credit for one thing: creativity. His is the first attempt to do any such thing of which I am aware.

Methinks this quote from Golda Meir is very appropriate to Mr. Nino. She said: "When peace comes we will perhaps in time be able to forgive the Arabs for killing our sons, but it will be harder for us to forgive them for having forced us to kill their sons. Peace will come when the Arabs will love their children more than they hate us." (Meir, 1973)

In like manner, I say of this critic of mine, his hatred of Jews, Israel, and me as a spokesman for both, has overcome his love of truth, if he ever had any of the latter in the first place, that is.

³² Source: comment section: (Nino, 2025A)



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ACCESS TO FINANCE IN THE ROMANIAN ENTREPRENEURIAL ECOSYSTEM: INSIGHTS FROM FINANCIAL PROFESSIONALS

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ABSTRACT

Access to finance remains a critical challenge for small and medium-sized enterprises (SMEs) in emerging economies, where institutional support and financial infrastructure are often underdeveloped. As in many European countries, SMEs in Romania play a central role in employment and value creation; however, they face persistent barriers in securing adequate financial resources for survival, growth, and innovation. This study investigates the perceptions of Romanian financial professionals - both from banking and non-banking institutions - regarding SMEs' access to finance, aiming to identify perceptual patterns and their demographic and institutional determinants. Based on a survey of 74 financial professionals, the research employs several statistical techniques to uncover latent dimensions and segment respondents into coherent perceptual profiles. Three distinct profiles emerged: Optimists (confident in finance as a catalyst), Moderates (balanced but cautious), and Skeptics (cautious about finance's role in early-stage entrepreneurship). The type of institution and locality size significantly influenced perceptions, while professional experience and education had limited impact. A notable finding is the divergence between the generally positive perception of finance's role in SME development and the skepticism regarding its capacity to stimulate new business creation, suggesting the presence of systemic barriers. The study offers a practical framework for tailoring financial products and public policies to the perceptual and institutional profiles of financial professionals, contributing to more effective support mechanisms and a more inclusive entrepreneurial ecosystem.

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1 INTRODUCTION

Access to finance remains one of the major challenges for small and medium-sized enterprises (SMEs), especially in emerging economies where entrepreneurial ecosystems are still consolidating and institutional support is often fragmented. In Romania, SMEs contribute significantly to employment and value creation, yet they frequently face difficulties in obtaining the financial resources needed for launching, expanding, or innovating.

According to the SAFE 2024 report (European Commission, 2025; European Central Bank, 2025), access to finance is no longer a top concern for most SMEs in the European Union, with only 6% identifying it as their main issue - similar to 2023 and significantly down from 17% in 2009 (European Commission, 2023). However, nearly 40% of firms still report increased interest rates, and one-third of those planning growth in the next 2–3 years cite high costs or prices as the main limitation to accessing finance. However, in Romania, the situation remains more challenging: 10% of SMEs consider financing a major issue, and the loan rejection rate is among the highest in the EU (19%, compared to 7% EU average). Moreover, only 50% of Romanian SMEs received the full amount requested, versus 64% in Eastern Europe. These figures confirm that while financing conditions have improved overall, structural barriers persist in certain member states, especially for growth-oriented and younger firms.

In this context, the perceptions of financial professionals—both from banking and non-banking sectors—are essential. The way they understand available funding sources, access barriers, and the impact of finance on entrepreneurial development influences institutional decisions and shapes public policies. In a rapidly changing economic environment, aligning support strategies with the vision of those facilitating access to finance is crucial.

This study analyzes, based on a questionnaire applied to financial professionals in Romania, their perceptions regarding SMEs' access to finance. It investigates preferences for traditional and alternative sources, perceived barriers, and the influence of demographic and institutional factors on these opinions. The results provide a

segmented and contextualized view of how financial actors perceive the role of finance in entrepreneurial development, with direct implications for designing financial products and public policies.

The paper is structured into five main sections: following this contextual introduction, we present a review of the relevant literature, a detailed methodology, and the analysis of results with an integrative discussion that links our findings to existing literature. Finally, we formulate conclusions and recommendations for public policies and institutional practices, with emphasis on adapting financial solutions to the identified perceptual profiles.

2 LITERATURE

Access to finance is widely recognized in academic literature as a fundamental element for SME development (Badulescu, 2013), influencing their capacity to innovate, expand, and withstand economic challenges. Berger and Udell (1998) emphasized the role of private capital markets and bank credit in the financial growth cycle of small firms, highlighting difficulties related to collateral requirements and credit history, while Badulescu and Simut (2012), analyzing banks' behavior toward SMEs during crisis periods, pointed out a tendency to restrict lending due to perceived risk.

Rao et al. (2021), in a systematic review of SME financing literature, noted the evolution of this topic across regions and methodologies, underlining that although traditional sources remain dominant, alternative channels - such as crowdfunding and peer-to-peer lending—are gaining ground, especially in the context of digitalization and the need for financial inclusion. In this regard, Sharma (2025) and Romero Alvarez et al. (2025) argue that these forms of financing can stimulate innovation and reduce dependence on classical banking institutions. At the institutional level, OECD (2024, 2025) provides a comparative overview of SME access to finance across member countries, highlighting significant disparities in the availability of credit, guarantees, and venture capital.

Public policies play a crucial role in improving SME access to finance, influencing the availability of resources, the typology of financial instruments,

and the sustainability of interventions. Evidence from Dvouletý, Srhoj, & Pantea (2021) indicates that public policies have a considerable positive effect on SME performance, particularly in terms of business continuity, employment, capital formation, and revenue generation. Allocating public financial support on a competitive basis has proven to be a key determinant of performance, with its effectiveness varying by firm size and age, and with positive effects observed especially among younger SMEs (Chiappini & Pomet, 2023).

At the European Union level, between 2014 and 2020, the European Regional Development Fund (ERDF) supported over 800,000 SMEs, yet a report by the European Court of Auditors (2022) highlighted the lack of a strategic approach and the predominant use of grants over repayable instruments. This orientation led, in some cases, to negative effects on competitiveness by distorting the market and selectively favoring certain firms. OECD (2025) confirms these findings, stressing the need for better alignment between national strategies and European funds, as well as the efficient use of blended financial instruments. In this context, Crawford, Cui, and Kewley (2023) emphasize the importance of clarifying policy objectives and rigorously evaluating their impact on SME performance, while Prasannath et al. (2024) argue that government policies can positively influence entrepreneurial orientation and SME performance, provided they are sector-specific and coherently implemented.

Moreover, European initiatives such as the Capital Markets Union Action Plan (European Commission, 2015) aim to reduce financial fragmentation and facilitate SME access to capital markets. However, the implementation of these measures at the national level - particularly in Romania - faces challenges related to administrative capacity, absorption rates, and alignment with the real needs of entrepreneurs. Herte et al. (2021), analyzing the interaction between access to finance and SME innovation capacity, highlights the importance of proximity to scientific infrastructure and a supportive institutional environment.

Thus, the literature emphasizes that the effectiveness of access to finance depends not only on the availability of resources but also on how they are distributed, regulated, and adapted to the specific needs of SMEs. An integrated approach is needed - one that combines diverse financial instruments with coherent public policies and a deep understanding of the entrepreneurial ecosystem.

3 METHODOLOGY

This study is based on the analysis of data collected through a questionnaire administered to a sample of financial professionals in Romania between January and March 2025. The main objective of the research was to identify perceptual patterns regarding SMEs' access to finance and to explore the relationship between these perceptions and respondents' demographic characteristics.

The sample included 74 respondents employed in banking and non-banking financial institutions, holding various positions such as unit branch managers, credit analysts, financial consultants, EU funds specialists, and corporate relationship managers. Their professional experience ranged from under 5 years to over 20 years, allowing for a relevant comparative analysis based on seniority, position, and institution type.

The questionnaire included questions related to: perceptions of the effectiveness of traditional and alternative financing sources; the role of access to finance in SME development, new business creation, and entrepreneurial spirit; and preferences regarding the types of financial instruments used in practice. Responses were recorded on a five-point Likert scale, ranging from "to a very small extent" to "to a very large extent."

Three complementary statistical methods were used to analyze the data: Fisher's exact test, selected to identify significant associations between demographic variables under conditions of uneven distribution; exploratory factor analysis (EFA), useful for reducing complexity and extracting latent dimensions of perception; and K-means clustering, applied to segment respondents into homogeneous perceptual profiles, relevant for differentiated interpretation of

results and the formulation of tailored recommendations.

Textual responses were converted into numerical scores to enable statistical processing, and internal validation was performed by checking the consistency of extracted factors and the stability of clusters. The interpretation of results was guided by the professional and institutional profiles of the respondents, with emphasis on significant perceptual differences, aiming to understand the mechanisms behind financial professionals' views and to support the development of targeted recommendations for improving SME access to finance.

4 RESULTS AND DISCUSSION

4.1 Demographic Associations Regarding Perceptions of Access to Finance

The analysis of associations between respondents' demographic characteristics and their perceptions of the role of access to finance was conducted using Fisher's exact test for three key dimensions: the contribution of finance to SME development (Q8 – "To what extent do you believe access to finance contributes to SME development?"), the stimulation of new firm creation (Q10 – "To what extent do you believe access to finance stimulates the creation of new firms in Romania?"), and the encouragement of entrepreneurial spirit (Q14 – "To what extent do you believe a good relationship with the bank and easy access to finance stimulate entrepreneurial spirit in Romania?").

The results reveal significant differences based on institution type and locality size, while other variables, such as job position, professional experience, or education level, did not generate statistically significant differences.

For question Q8, significant associations were found with institution type ($p = 0.020$) and locality size ($p = 0.017$). Professionals from banking institutions tend to have a more favorable perception of finance's role in SME development compared to those from non-banking institutions. This difference may reflect both organizational culture and the level of exposure to diverse financial instruments. Additionally, respondents

from large or very large cities perceive the contribution of finance more positively, which can be explained by the presence of more developed entrepreneurial ecosystems and a broader financial offering.

In contrast, for question Q10, no significant associations were identified with any of the demographic variables analyzed. This homogeneity of responses suggests a shared, relatively uniform perception regarding systemic difficulties in supporting early-stage entrepreneurship. Regardless of experience, position, or institution type, financial professionals appear to be aware of the structural limitations affecting access to finance for start-ups.

For question Q14, a significant association was again observed with institution type ($p = 0.029$). This result reinforces the idea that the institutional environment influences perceptions of finance's role in entrepreneurial dynamics. Banking institutions, by the nature of their activity, may have a more optimistic view of the impact of the client–bank relationship in stimulating entrepreneurial initiative.

Figure 1 presents a synthetic representation of these associations between demographic characteristics (rows) and perception questions (columns: Q8 – SME Development, Q10 – Firm Creation, Q14 – Entrepreneurial Spirit), where lower p-values (darker red) indicate stronger statistical significance.

The heatmap reveals that institution type and locality size are the most influential variables, with p-values of 0.020 and 0.017, respectively, for Q8, and 0.029 for Q14. These findings confirm that organizational context and urban environment shape perceptions more strongly than individual attributes such as position, experience, or education.

This detailed analysis supports the idea that perceptions regarding access to finance are shaped primarily by institutional and urban context, while other individual characteristics have a more limited influence. These findings provide a solid foundation for designing differentiated policies tailored to the professional and geographic profiles of actors involved in SME financing.

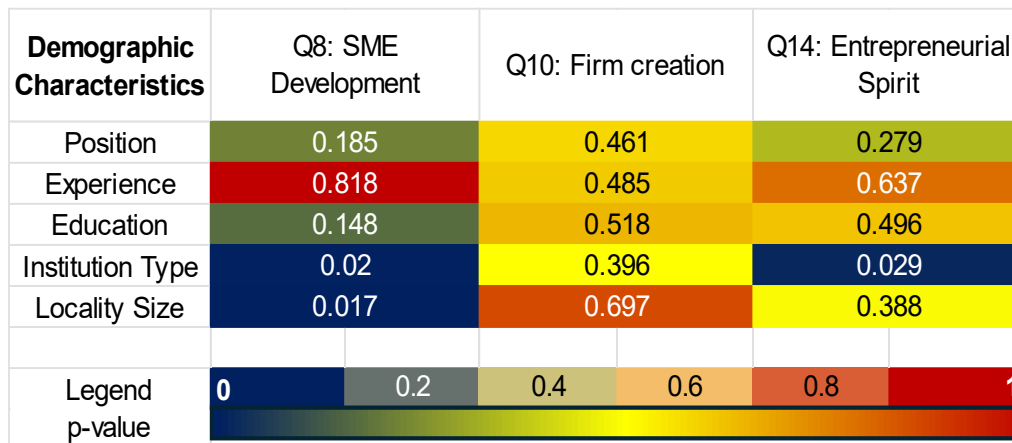


Figure 1. Statistical significance of associations between demographic characteristics and perceptions of access to finance
Source: Authors' analysis based on questionnaire responses

4.2 Latent Dimensions of Perception (EFA) and Perceptual Segmentation (Clustering)

To explore the underlying structure of financial professionals' perceptions regarding access to finance, an exploratory factor analysis (EFA) was applied to responses for three key items: Q8 (contribution to SME development), Q10 (stimulating firm creation), and Q14 (encouraging entrepreneurial spirit). Responses were coded on a five-point Likert scale and processed using Principal Component Analysis (PCA) with varimax rotation to enhance interpretability.

The EFA revealed two latent dimensions. The first factor reflects an integrated perception of finance as a driver for SME growth and entrepreneurial

development. Moderate negative loadings across all three items suggest a generally favorable, though not highly enthusiastic, attitude toward the role of finance in supporting business consolidation and expansion.

The second factor captures a distinct orientation toward firm creation. The strong negative loading for Q10 indicates skepticism about the ability of financial access to stimulate new ventures, while the positive loading for Q14 suggests some appreciation for the relational aspect of banking in fostering entrepreneurial spirit.

This structure confirms that perceptions cluster around two conceptual axes: one emphasizing the overall impact of finance on the entrepreneurial ecosystem, and another highlighting caution about its role in early-stage entrepreneurship.

Table 1. Factor Loadings for Perceptions of Access to Finance

Question	Loading on Factor 1	Loading on Factor 2
Q8 – SME Development	-0.33	-0.01
Q10 – Firm Creation	-0.30	-0.38
Q14 – Entrepreneurial Spirit	-0.35	+0.13

Source: Own processing based on questionnaire data

Based on factor scores, a K-means clustering analysis identified three perceptual profiles. The first cluster, Optimists, exhibits consistently high evaluations across all dimensions, signaling strong confidence in finance as a catalyst for SME growth and entrepreneurship. The second cluster, Moderates, reflects balanced perceptions with

slight caution regarding the relational influence of banks. The third cluster, Skeptics, combines positive views on SME development with clear skepticism about finance as a driver for new firm creation, suggesting awareness of systemic barriers such as bureaucracy and insufficient guarantees.

Table 2. Average Perceptions of Access to Finance (Q8, Q10, Q14) by Cluster

Cluster	Q8: SME Development	Q10: Firm Creation	Q14: Entrepreneurial Spirit	General Interpretation
1	4.83	4.21	4.79	Optimists – generally, a favorable perception
2	4.08	3.96	3.54	Moderates – balanced, slightly reserved
0	4.25	2.33	4.21	Skeptics – positive on development, skeptical on initiation

Source: Authors' analysis based on questionnaire responses

The cluster averages presented in Table 2 highlight these differences numerically, providing a clear picture of how each group prioritizes development versus start-up support.

Cluster 1 – Optimists: Respondents with a highly favorable perception of the role of access to finance across all three dimensions. They view finance as an essential catalyst for SME development, firm creation, and entrepreneurial spirit.

Cluster 2 – Moderates: Respondents with a balanced attitude, showing slight reservation

regarding the impact of the bank–client relationship on entrepreneurial spirit. They acknowledge the importance of finance but are more cautious in evaluating its effects.

Cluster 0 – Skeptics: While they appreciate the role of finance in SME development and in supporting entrepreneurial spirit, they express clear skepticism about its ability to stimulate new firm creation. This profile may reflect a realistic perception of existing systemic barriers to early-stage entrepreneurship.

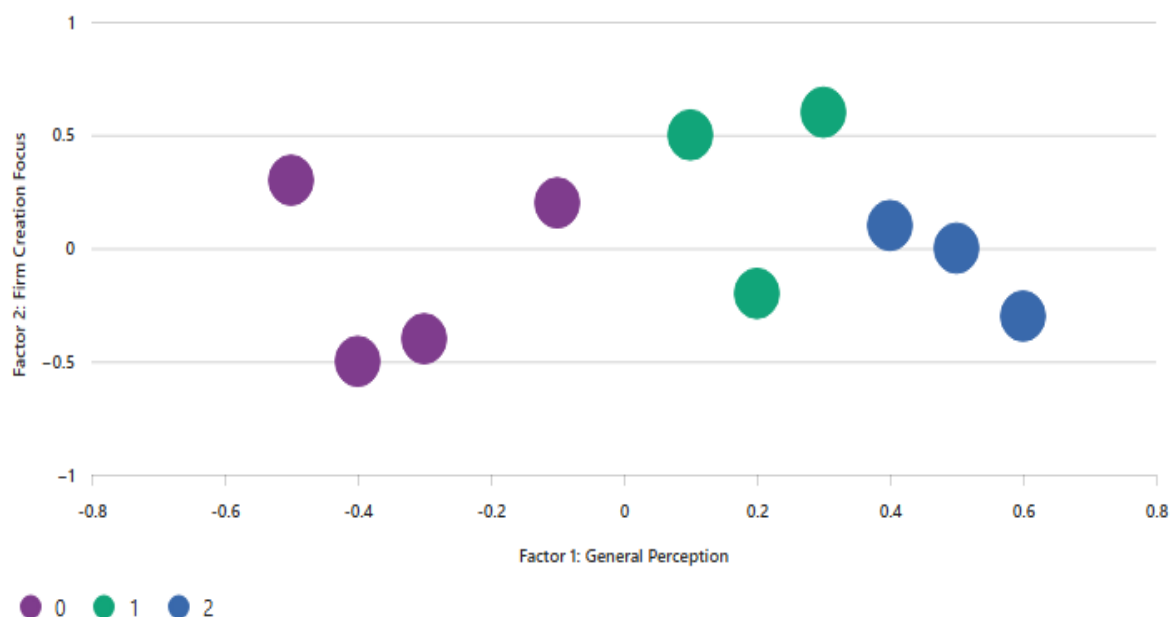


Figure 2. Distribution of Respondents in Factorial Space (PCA) According to Perceptions Regarding Access to Finance

Source: Authors' analysis based on questionnaire responses

Figure 2 presents the perceptual map of respondents in the PCA space, segmented into three clusters: Optimists (Cluster 1), Moderates (Cluster 2), and Skeptics (Cluster 0). The spatial distribution highlights clear differentiation:

Optimists occupy the upper-right quadrant, indicating strong positive perceptions across all dimensions; Moderates cluster near the center, reflecting balanced but cautious attitudes; Skeptics are positioned toward the lower-left,

signaling skepticism about finance as a driver for new firm creation despite recognizing its role in SME growth.

This visualization underscores the heterogeneity of perceptions and the need for tailored policy interventions. For example, the “Optimists” group can be mobilized as partners in promoting innovative financial products, while “Moderates” may benefit from trust-building measures, and “Skeptics” require deeper interventions to overcome perceived barriers.

4.3 Integrative Discussion

The integrative analysis highlights the significant influence of institutional and urban context on perceptions regarding access to finance, confirming existing literature that emphasizes the role of regional financial ecosystems and organizational culture (OECD, 2025; European Commission, 2023). In particular, professionals from banking institutions and large cities tend to express more favorable views on the role of finance in SME development and in fostering entrepreneurial spirit.

On the other hand, the widespread skepticism regarding finance’s ability to support new firm creation points to the existence of systemic barriers - such as bureaucracy, insufficient guarantees, and high costs - that affect early-stage entrepreneurship, regardless of respondents’ profiles. These results align with prior research documenting structural constraints in SME financing across Europe (European Court of Auditors, 2022).

The perceptual segmentation into three profiles - Optimists, Moderates, and Skeptics - provides an applicable framework for differentiated policy design. Optimists can be engaged in promoting innovative financial solutions, Moderates may benefit from trust-building and transparency measures, while Skeptics require structural interventions aimed at reducing perceived risks and improving accessibility. These findings contribute to the foundation of more effective and inclusive strategies for supporting entrepreneurship through tailored financial mechanisms.

CONCLUSIONS

This study deepens the understanding of how financial professionals perceive access to finance for SMEs in Romania, within a context marked by economic transformation and institutional challenges. By applying statistical methods - Fisher’s exact test, exploratory factor analysis, and clustering - the research revealed not only the distribution of opinions but also the latent structure of perceptions, offering a segmentation that is practically applicable.

The results confirm that perceptions are not uniform but vary according to institutional affiliation and geographic context. The type of institution proved to be a key factor in shaping attitudes toward the role of finance, while locality size also influenced views on SME development. Other demographic variables, such as experience or education, had a limited impact. These findings highlight the importance of organizational culture and regional ecosystems in forming financial behavior.

Three perceptual profiles emerged - Optimists, Moderates, and Skeptics - each with distinct attitudes toward financing and entrepreneurship. This typology provides a useful framework for tailoring interventions: innovative products and partnerships for Optimists, trust-building and transparency for Moderates, and risk-reduction mechanisms for Skeptics. A notable insight is the favorable perception of finance in supporting SME consolidation and entrepreneurial spirit, contrasted with clear reservations about its ability to stimulate new business creation. This suggests systemic barriers - bureaucracy, insufficient guarantees, and high costs of loans - that limit the effectiveness of financial instruments for start-ups.

The study’s limitations include the relatively small sample size and uneven distribution across institution types, which may introduce bias. The self-reported nature of data also affects accuracy. Future research should expand the respondent base to include entrepreneurs, fintech representatives, and consultants, and adopt mixed methods for richer insights. Longitudinal studies could track how perceptions evolve under regulatory, economic, or technological changes, while exploring the role of digital finance in reducing access barriers.

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BLOCKCHAIN IN SMALL-SCALE LOGISTICS: OPERATIONAL AND STRATEGIC BENEFITS, AND IMPLEMENTATION CHALLENGES FOR MSMEs

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Sustainable logistics.

ABSTRACT

The integration of blockchain technology into micro and small logistics enterprises (MSLEs) presents an opportunity for enhanced transparency, traceability, and operational efficiency. Traditionally perceived as suitable only for large-scale systems, blockchain is increasingly becoming feasible for resource-constrained environments. This paper examines technical, economic, and organizational aspects of blockchain implementation within MSLEs, supported by literature analysis, real-world case studies (TradeLens, TE-FOOD, Modum, Slync.io), and simulated applications for two model enterprises — PickupPoint and LastMileCo. The research highlights the value of blockchain in automating delivery confirmation, securing digital invoicing, and improving data consistency across transport and warehouse systems. The study also identifies practical challenges, including cost barriers, integration complexity, regulatory uncertainties, and the need for technical upskilling. These are addressed through stepwise implementation strategies and modular adoption approaches. Findings indicate that even minimal-scale blockchain deployment can lead to measurable gains, with return on investment estimated at 6–18 months. The paper concludes with recommendations for industry adoption and policy development, advocating for regulatory sandbox environments and incentives tailored to the logistics SME context. Blockchain should be seen not merely as a technical tool, but as a strategic enabler of resilient and digitally mature supply chain operations.

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1 INTRODUCTION

1.1 Significance of the Topic

Although digitalization is a widespread phenomenon, its impact on micro, small, and medium-sized enterprises (MSMEs) has only recently entered the spotlight, among both researchers and government institutions. The pace and success of adoption vary across sectors and countries. Entities that adapted effectively have demonstrated notable, sometimes exceptional, results. Others, less prepared for the transition, face increased risks of stagnation or decline.

Studies conducted by the World Trade Organization indicate that MSMEs, despite representing the vast majority of businesses globally, remain underexamined. Their operational needs and technological capacities are often overlooked, underestimated, or dismissed (Bogavac et al., 2019).

The precise number of MSMEs active in transport and warehousing is undefined. Estimates place their share in the EU between 5–7% of total MSMEs—including businesses that manage logistics internally. The subset offering third-party logistics services is likely smaller: 2–4% in developed economies. In urban areas, particularly within e-commerce environments, the share may rise to 6–8%, depending on local demand and the presence of large operators.

Within this sector, micro and small logistics enterprises, whether operating as internal support units or external service providers, play an increasingly important role in modern supply chains. Blockchain technology is recognized as a potentially transformative solution in this context. Its core attributes—transparency, decentralization, and secure record-keeping—may strengthen operational reliability.

This paper explores how blockchain's scalability and adaptability can meet the diverse organizational capacities of MSMEs. It examines associated technical, financial, and workforce-related challenges.

In a rapidly evolving market shaped by shifting consumer expectations, the logistics capabilities of micro and small enterprises are essential for

sustaining competitiveness. It is therefore necessary to examine how MSMEs are positioned within logistics flows, what specific value they contribute, and what challenges they encounter.

1.2 The Role of Logistics in Micro and Small Enterprises

Large logistics companies offer scale and standardized infrastructures. However, micro, small, and medium-sized enterprises (MSMEs) contribute to supply chains through flexibility, specialized expertise, and rapid adaptation to local conditions. Micro and small firms often identify market gaps—particularly in last-mile delivery, niche sectors, and rural areas—where large operators struggle to perform efficiently (Čekerevac et al., 2024).

Their presence in urban zones and familiarity with local markets enable them to:

- Respond quickly to demand fluctuations and ad-hoc delivery requests
- Provide specialized services (e.g., pharmaceutical transport, spare parts, cold chain logistics)
- Form outsourcing partnerships with larger companies for warehousing, distribution, and returns processing

Compared to large operators, MSMEs typically operate with limited resources. Nonetheless, their organizational agility allows them to adjust more easily to market changes. They adopt mobile apps for delivery tracking, route optimization software, and basic ERP/TMS modules.

Digital logistics platforms and tools, such as visual shipment verification methods like QR codes and e-confirmations, help reduce transport costs, accelerate processing, and improve reliability. In doing so, MSMEs sustain a competitive edge and cultivate long-term relationships with end customers and business partners, especially in the last-mile segment (Dvorak et al., 2024).

1.3 Technological Acceleration and Digitalization in MSME Logistics

The rapid evolution of information technologies has sparked the emergence of new business models, ranging from local process optimizations to the strategic transformation of global supply

chains. Logistics stakeholders, including micro and small enterprises (MSMEs), increasingly rely on smart systems, modular tools, and digital interoperability.

In practice, MSME digitalization typically involves the following components:

- GIS tools and digital mapping for resource planning and allocation (Čekerevac et al., 2010),
- IoT sensors for real-time tracking of temperature, humidity, location, and shipment conditions
- Smart contracts and blockchain layers for secure delivery records, reduced complaints, and automated invoicing
- AI algorithms for route optimization and predictive vehicle maintenance
- API integrations between TMS, ERP, and an external courier service¹, enabling automated data exchange across software components.

Despite these opportunities, MSMEs face multiple challenges:

- Integrating new digital services with existing ERP/TMS systems
- Ensuring data protection and compliance with local and EU regulations
- Limited in-house IT personnel and reliance on external technical support
- Upfront costs for digital transition and infrastructure maintenance

By adopting modular and affordable digital solutions—such as SaaS models and open-source platforms, MSMEs can gradually digitize operations, improve efficiency and competitiveness, and lay the groundwork for continued technological advancement.

1.4 Research Objectives

The primary objective of this paper is to explore the intersection between blockchain technology and the logistics needs of micro and small enterprises (MSEs), whether they operate as part of broader supply chains or manage logistics independently.

A specific focus is placed on evaluating the potential benefits blockchain may offer to the MSE sector, including the following areas:

- Enhancing shipment tracking and reducing administrative costs through recordkeeping automation
- Increasing data security and protecting against manipulation and information loss
- Implementing smart contracts to automate transactions and delivery confirmations
- Analyzing case studies of successful blockchain applications in small logistics companies.

Through this analysis, the paper seeks to identify practical blockchain implementation models in MSE logistics and to highlight technical, financial, and organizational challenges associated with the digital transformation process.

To achieve these objectives, a systematic review of existing literature was conducted, applying standard procedures characteristic of structured review studies—as presented in the following methodological framework.

1.5 Methodology

This study was conducted using methodological procedures commonly applied in review-based academic research. The employed methods included the search, selection, analysis, and synthesis of relevant literature.

The research covered academic databases such as Google Scholar, IEEE Xplore, SpringerLink, and MDPI. Due to the specificity of the topic, relevant websites focused on blockchain applications in the MSME sector were also examined.

To enhance search efficiency and source classification by thematic relevance, the authors utilized artificial intelligence (AI) tools to assist in query formulation, abstract screening, and preliminary literature selection.

The search process was based on keywords such as “logistics,” “blockchain,” and “small and medium-sized enterprises.” Selected papers were

¹ API – Application Programming Interface; TMS – Transport Management System; ERP – Enterprise Resource Planning

included based on thematic relevance, methodological quality, and publication date. Most of the sample consists of publications from the past five years, supplemented by previous works by the authors in the fields of MSMEs, blockchain, and logistics.

The collected material was critically analyzed using academic standards for source validity, reliability of findings, and relevance to the defined research problem. Information was organized and synthesized through thematic analysis, which identified key domains, recurring patterns, and a conceptual framework that integrates current knowledge.

For concise presentation, certain findings are displayed in tabular format to facilitate comparison and readability. Based on the analysis, the authors identified existing gaps in literature and proposed directions for future research, with particular emphasis on the development of small-scale logistics enterprises within the MSME sector.

1.6 Research Question

This study builds on existing research and practical examples to provide a structured overview of blockchain technology's potential in the small logistics enterprise sector.

To guide the analysis, a research question and a working hypothesis have been formulated.

Central research question:

How can blockchain technology contribute to the improvement of logistics processes in micro and small enterprises, and what are the key implementation challenges in this context?

Working hypothesis:

Blockchain technology has the potential to significantly enhance the efficiency and transparency of logistics operations in micro and small enterprises. However, successful implementation requires overcoming specific technical, organizational, and regulatory challenges.

This hypothesis will be examined through literature review, case studies, and thematic analysis of potential implementation models.

2 LITERATURE REVIEW

2.1 Digitalization and Logistics Automation in MSMEs

Digitalization has become a key driver of transformation in both society and the economy. Its implementation in micro, small, and medium-sized enterprises (MSMEs) significantly influences business models, particularly within logistics operations. In this context, numerous studies have examined the degree of digital adoption among MSMEs and its impact on business performance (OECD, 2024; Sagala & Ori, 2024; Kahveci, 2025; Bogavac, 2019).

One of the most notable contributions in this field is the analysis of digital maturity among MSMEs using the IDSME Index. Within this framework, Bogavac and Čekerevac (2019) identify two core sub-dimensions:

- *The use of digital technologies* includes indicators such as website ownership, social media presence, electronic recordkeeping, adoption of B2B and B2G e-commerce models, cloud computing, decision-support tools, and automation systems.
- *Electronic commerce* covers indicators such as online sales, e-commerce activity, transaction volume, and cross-border digital trade.

Interestingly, research indicates that the degree of digitalization among MSMEs is not necessarily correlated with a country's economic development. For instance, in 2018, Qatar achieved a Global Connectivity Index (GCI) score of approximately 71—equal to Italy—despite having a GDP per capita nearly twice as high (Schwab, 2018). A similar trend was observed in 2024, when both countries scored 54.4 and shared 23rd place in the Global Digitalization Index (GDI) Country Rankings (Huawei, 2024; WPR, 2025).

Beyond economic indicators, research suggests that factors such as tradition and prior digital experience play a critical role in the acceptance of digital transformation. Globally, Asia has emerged as the most prepared region for deep digital reform, while the United States leads innovation in digital technologies. By contrast, Europe remains more conservative, progressing through

incremental changes (Bogavac & Čekerevac, 2019).

Several authors emphasize the convergence between advanced manufacturing and digital technologies—a process that has driven major innovations in logistics systems. This convergence has led to significant innovations in logistics systems, including megalogistic, macrologistic, and micrologistic systems. (Didenko et al., 2021; Küpper et al., 2022)

The integration of intelligent sensors, referred to as "smart sensors" in the scientific community, represents a major advancement in logistics system capabilities. These sensors are equipped with self-recovery mechanisms, built-in electronics, and microprocessors. They also include digital interfaces that support network protocols for communication. They can be embedded into wireless or wired sensor networks, enabling the creation of social–cyberphysical systems (Mendling et al., 2020; Valebnikova et al., 2019). Technologies such as IoT, production automation, digital design, virtualization, cloud computing, mobile communications, unmanned aerial systems, AI, big data analytics, robotics, and 3D printing are considered among the most influential factors shaping modern logistics

systems (Savaglio, et al., 2020; Park, 2017; Tu, 2018; Wu et al., 2013).

Advanced manufacturing technologies, such as automated design, flexible manufacturing centers, robots, and automated storage systems, are increasingly connected into single flexible production systems. These systems can ultimately be integrated into computerized enterprises or logistics systems, enhancing productivity, creating new markets, and enabling innovative business models (Borremans et al., 2018).

Digital transformation in logistics is a multifaceted process, involving the introduction of digital technologies across various stages of production chains and management structures. Automation has evolved to include informatization and digitization, forming the foundation for transformation at micro-, macro-, and mega-logistic scales.

Efficiency across these frameworks is crucial and evaluated using a range of indicators—technological, economic, social, and environmental. Notable impacts include job creation, improved working conditions, cost transparency, and adaptability to external shifts (Anderson, 2025; van Dooren & Galema, 2018; Olmstead, 2024)



Figure 1. *Issues in Traditional Logistics Processes*

Source: (Anderson, 2025)

Traditional approaches to logistics operations pose a variety of challenges under current conditions. The most prominent issues are illustrated in Figure 1. Digitalization-related problems are perceived as the most pressing, with ratings well above 90%. Nearly all respondents identified inefficient route management, lack of real-time shipment tracking, manual data processing, and inventory management as critical concerns. Poor warehouse management remains

notable as well, rated at 78%, though it ranks lowest on the problem scale. These findings suggest that adopting digital solutions can substantially improve business performance, especially for small firms that lack access to expensive systems and stand to benefit most from technological advancements.

Literature also highlights risks associated with digitalization. For example, Sørensen (2018)

noted that digitalization may introduce competition-related risks, such as collusion enabled through algorithms and AI. Gallipoli and Makridis (2017) observed that digital technologies are shifting market structures, expanding service sectors while diminishing industrial ones. Sauter (2019) warned of risks linked to digital dominance, including the potential for unfair treatment of competitors, suppliers, and consumers. Tero Sotamaa, Arto Reiman, and Osmo Kauppila (2025) emphasized risks for MSMEs stemming from underutilized production capacities, outdated equipment, customer complaints, lack of innovation, and logistical shortcomings. Their review underscores the importance of a multidimensional approach to managing risks and capitalizing on opportunities, ultimately enhancing business continuity and long-term success.

In today's landscape, sustainability has become a central theme across industries, including logistics. As pressure mounts to reduce greenhouse gas emissions and conserve natural resources, a key question emerges: how can digitalization and automation contribute to sustainable logistics?

One pathway is through operational optimization. For instance, route optimization algorithms can reduce fuel consumption and emissions. Likewise, robotic systems for warehousing and sorting can lower energy use and spatial requirements.

Additionally, digitalization and automation foster sustainability through innovation. The development of autonomous vehicles, for example, may lead to reduced emissions. Similarly, predictive demand algorithms can help minimize waste.

However, digitalization and automation are not a "magic wand" for sustainability. While they offer numerous benefits, they also introduce new challenges, such as increased energy consumption from expanded use of digital technologies.

Therefore, achieving sustainability through digitalization and automation requires balancing benefits with risks. This means continuously monitoring the environmental impact of operations, adapting to new technologies in sustainable ways, and actively seeking methods to reduce ecological footprints.

2.1 Blockchain in Logistics Chains

The use of blockchain technology in logistics processes among micro and small enterprises (MSEs) is becoming increasingly relevant, driven by the demand for transparent, efficient, and decentralized systems for tracking and management.

Key areas of blockchain application within logistics chains include:

- Traceability and Transparency
 - Enables real-time tracking of goods and origin
 - Essential for combating counterfeits and ensuring quality control
- Smart Contracts
 - Automate transactions and delivery conditions
 - Reduce the need for intermediaries and accelerate processing
- Inventory and Warehouse Management
 - Improve record accuracy and reduce manual input errors
 - Enhance coordination between supply chain actors
- Data Verification and Security
 - Data immutability and decentralization build trust
 - Particularly important for MSEs lacking advanced IT systems
- Sustainability and Waste Reduction
 - Support emissions tracking and resource flow monitoring
 - Enable energy efficiency documentation and recycling metrics

Fernández Moreno and colleagues (2025) conducted a detailed bibliometric analysis of blockchain applications in logistics. The goal was to explore thematic evolution, identify major research trends, and forecast future directions.

Using SciMAT software and co-word analysis, they examined studies published from 2016 to March 2023. Their results revealed eight dominant thematic clusters:

- Blockchain (the most prominent)
- Security
- Sustainability
- Implementation Challenges
- Industry 4.0
- Traceability

- Circular Economy
- Smart Contracts (gaining traction in recent years)

Through longitudinal mapping and strategic diagrams, the authors illustrated how these topics evolved across three study periods. Their analysis concluded that blockchain can improve operational efficiency, lower costs, and strengthen data security, though successful implementation depends on resolving technological, organizational, and regulatory challenges. The study offers a clear snapshot of current research directions and paves the way for developing theoretical frameworks and practical solutions for blockchain in logistics chains.

Aslam et al. (2024) found that empirical, data-driven research is vital for understanding technology adoption. Their study reviews blockchain applications in logistics using a comprehensive theoretical approach. Blockchain's core features—decentralization, transparency, and real-time information sharing—position it as a critical enabler for logistics modernization.

They integrated the Fit-Viability Model (FVM) and Task Technology Fit (TTF) theory to demonstrate how blockchain enhances logistics performance and sustainability. Data from 576 logistics managers were analyzed using partial least squares (PLS) regression, revealing how blockchain improves alignment, resilience, integration, and sustainability across logistics operations. Their research maps blockchain attributes to specific logistics challenges, helping managers implement solutions more strategically. However, the study's scope is limited to logistics and excludes other supply chain functions and emerging technologies such as AI, IoT, cloud computing, and robotics. Future research should expand to include cost analysis and adoption barriers and replicate findings across diverse regions.

Berneis, Bartsch, and Winkler (2021) conducted a comprehensive systematic review focused on blockchain's economic benefits and its application in luxury and high-value supply chains. While prior success was mostly associated with cryptocurrency, a growing number of researchers and practitioners are recognizing blockchain's potential for supply chain optimization.

Despite extensive theoretical literature, the authors identified a lack of published case studies, raising questions about actual value creation and practical feasibility. Their work also offers an introduction to blockchain fundamentals, including the origin of Bitcoin, core technical attributes, and the function of smart contracts.

Their cluster analysis outlined key application concepts, especially for high-value goods, where blockchain's advantages are maximized under low trade volume and high transparency demands, provided confidentiality risks remain manageable. The study presents an idealized logistics process for luxury supply chains, giving managers insights into real-world benefits, current gaps, and implementation opportunities.

Ultimately, the authors argue that blockchain's primary advantage over traditional distributed databases lies in its ability to eliminate intermediaries and centralized control through decentralized architecture. However, high hardware and energy requirements are justified only when transparency benefits outweigh those costs. Their findings highlight the need for further empirical validation, particularly within the MSE logistics sector, where case-based evidence remains limited.

2.2 Regulatory Aspects and Implementation Barriers

The adoption of blockchain technology in the logistics sector among micro and small enterprises (MSEs) faces numerous regulatory challenges. Legal frameworks in many countries are still evolving, making alignment with national and international regulations increasingly complex. One of the most pressing issues is compliance with financial regulations, including invoicing, transaction reporting, data protection, and anti-money laundering measures. Blockchain-based systems must not only meet but potentially exceed the standards of traditional platforms, particularly about speed, efficiency, and regulatory alignment.

Beyond legal considerations, the growing automation of business processes introduces a range of ethical dilemmas. Algorithms and robots are increasingly tasked with making operational decisions, prompting critical questions around responsibility: Who bears the consequences of

machine-made decisions—the developer, the system user, or the organization itself?

Equally important is the issue of fairness. Algorithmic systems are used in decision-making that directly affects employees, customers, and partners. It is essential to ensure that these systems do not discriminate based on personal attributes. A third challenge is algorithmic transparency. So-called “black box” models, which produce decisions without human interpretability, raise concerns about reliability and accountability.

In digitally integrated logistics operations—where vast amounts of goods and data are processed daily—privacy protection has become a core business component. This applies both to personal user data and sensitive corporate information. The high volume of digital exchange increases the risk of misuse, making it imperative to implement robust security protocols, conduct regular system audits, and apply proactive security principles starting in the product and service design phase.

Employee education is just as critical. Every member of the organization must be equipped to identify potential threats and respond

appropriately. A culture of cybersecurity and data protection must be embedded in all aspects of MSE operations—not as an add-on, but as a fully integrated organizational value.

3 BLOCKCHAIN INTEGRATION IN SMALL-SCALE LOGISTICS

Micro and small logistics enterprises typically operate with limited infrastructure, localized distribution networks, and fragmented documentation systems. In such contexts, adopting blockchain requires a tailored approach that avoids unnecessary complexity and focuses on measurable value.

A key principle guiding this study is modular integration—the idea that SMEs do not need full-spectrum blockchain architectures but can selectively adopt components aligned with their operational priorities. Depending on their scale, technical readiness, and business model, enterprises may implement functionalities such as timestamping, delivery verification, smart contracts, IoT data logging, or document tokenization. This modularity allows for incremental adoption without disrupting existing workflows.

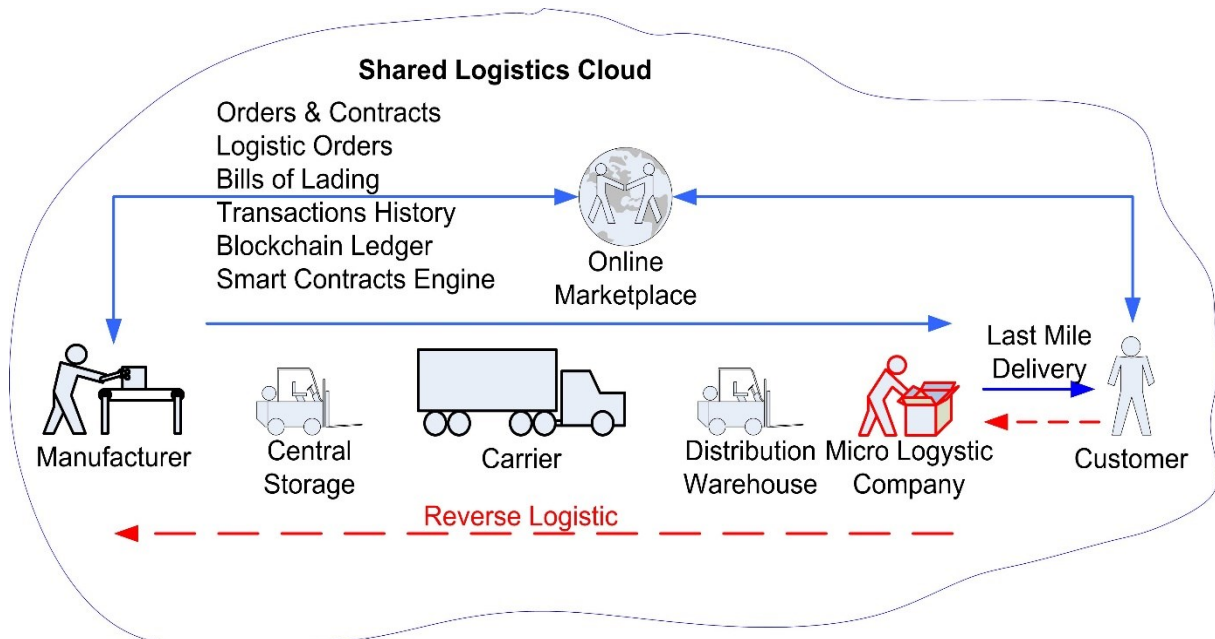


Figure 2. Shared Logistics Cloud — Functional architecture

Source: Adapted from (Novikova, 2019)

To illustrate how this layered approach can be visualized and segmented across logistics workflows, Figure 2 provides an overview of key blockchain modules grouped by business

functions. The illustration serves as a conceptual map, guiding SMEs in identifying which components best match their operational scope and digital maturity.

The system includes two main functional layers:

- Business Logic Layer:
 - Orders & Contracts: Digital management of purchase orders and commercial agreements
 - Logistic Orders: Instructions and dispatch requests for shipment processing
 - Bills of Lading: Accompanying documents for goods from dispatch to delivery
- Infrastructure Layer (Blockchain-Based):
 - Transactions History: A transparent and complete record of all business events
 - Blockchain Ledger: Distributed and immutable transaction registry
 - Smart Contracts Engine: Automated execution of business rules and contractual conditions

The order flow begins with the Customer entity and progresses through the following stages:

1. Online Marketplace – A digital platform aggregating customer requests and initiating orders
2. Manufacturer – Entity confirming the order and preparing goods for dispatch
3. Central Storage – Facility for consolidation or distribution
4. Carrier – Transport service managing physical delivery
5. Distribution Warehouse – Regional unit for sorting and routing
6. Micro Logistic Company – Enterprise responsible for final-mile delivery
7. Customer (End-User) – Final recipient of goods

Solid blue lines represent the directional flow of goods and information within the logistics process. Communication between actors is bidirectional, enabling direct data exchange at any point in the system.

The dashed red line labeled Reverse Logistics depicts the return flow of goods in case of complaints, product returns, or recycling—moving from the end-user back to the manufacturer.

All entities (except the end-user) are connected to the central cloud, which allows for direct participation in:

- Document exchange

- Smart contract execution
- Shipment status tracking
- Creation of a single authoritative version of business truth.

In addition to creating a single version of truth, blockchain consistently delivers three operational benefits for micro and small logistics enterprises:

- *Transparency*, enabling traceable and auditable delivery records
- *Security*, ensuring data integrity and controlled access within distributed systems; and
- *Automation*, streamlining repetitive workflows through smart contracts and event triggers.

These benefits are not uniform across use cases, but they serve as a foundational framework referenced throughout the simulations and implementation strategies in Sections 4 and 5.

3.1 Potential Applications of Blockchain in Micro Logistics

Micro logistics enterprises typically operate at the final stage of the logistics chain and maintain the closest contact with customers, as shown in Figure 2. Small businesses such as local retailers and delivery services increasingly rely on digital invoicing and shipment tracking. Blockchain offers not only enhanced transactional security but also new collaboration models, automation capabilities, and trust among stakeholders.

3.1.1 Security and Integrity of Digital Invoices

Micro enterprises often rely on manual, centralized systems for invoice dispatch and storage, leaving them vulnerable to errors and fraud. Blockchain adoption can address these risks by providing:

- *Immutability and cryptographic protection*: Each invoice registered on the blockchain receives a unique timestamped record that cannot be altered or deleted, preventing unauthorized changes to amounts, dates, or recipient information. This approach strengthens fraud prevention and builds trust with customers and suppliers. (Piankov, 2023)
- *Reduced intermediaries and cost savings*: Smart contracts embedded in invoices allow payment conditions—such as 15-day payment terms or early-payment discounts—to be executed automatically, eliminating the

need for third parties like banks or payment processors. This reduces transaction fees and delays. (Davies, 2025)

- *Micro-payments and tokenization:* Blockchain supports token-based micro-payments, ideal for parcel-based services or digital transactions. Platforms like dexFreight—a peer-to-peer delivery network—use tokenized assets for collateral and courier payments, accelerating liquidity for small shippers and carriers. (Daley & Urwin, 2023)

3.1.2 Real-Time Shipment Tracking Transparency

Local deliveries require precise and reliable tracking that traditional databases often fail to provide. Blockchain enables micro enterprises to benefit from:

- *IoT integration and smart contract automation:* Chronicle, for example, combines IoT sensors and blockchain to record shipment conditions—temperature, humidity, GPS location—and instantly notifies stakeholders via smart contracts. This allows small businesses to monitor sensitive goods (e.g., food, pharmaceuticals) without investing in proprietary servers or costly licenses. (Daley & Urwin, 2023)
- *Distributed shipment status registry:* Platforms like CargoLedger and Oracle Intelligent Track and Trace maintain all status updates—from

pickup to handover to final delivery—on a permissioned blockchain. All participants (retailers, couriers, consumers) share access to a single “source of truth” with cryptographically secured, tamper-proof records. (Oracle, 2024; Cargoledger, 2025)

- *Faster dispute resolution:* When a customer reports a problem (e.g., damaged parcel, delay), all relevant data—scan timestamps, route logs, sensor records—are instantly accessible on the blockchain. This shortens investigation times and streamlines complaint processing, saving time and money for micro firms.

One of the most promising pairings within SME logistics is the combination of smart contracts and IoT devices. When sensors (e.g., RFID, GPS, temperature) feed real-time data into blockchain networks, smart contracts can automatically execute predefined actions, such as confirming delivery, releasing payments, or flagging anomalies. This integration creates a trusted environment for autonomous transactions and event-driven workflows, especially in contexts requiring traceability, responsiveness, and minimal human intervention.

3.1.3 Smart Contracts and Task Automation

Smart contracts on blockchain platforms enable automated execution of key operations and facilitate decentralized process control.

Table 1. *Smart Contract Applications in Micro-Scale Logistics*

Function	Benefits for Micro Enterprises	Example
Automated Payments	Instant payment upon delivery confirmation without bank delays	TradeLens partners use smart contracts for rapid financial data exchange, cutting transit time by 40% (Novikova, 2019)
Service Contracting	Automated signing and execution of agreements with couriers	MuleChain P2P network uses MCX tokens as collateral for delivery agreements between sender and courier (Daley & Urwin, 2023)
Data Consensus	Single version of truth without a central authority	Guardtime blockchain in maritime logistics maintains transaction integrity and prevents data tampering (Daley & Urwin, 2023)

3.1.4 Implementation Pathways

Blockchain deployment in micro and small logistics enterprises faces several key challenges:

- Limited IT development resources
- Need for specialized knowledge of distributed architectures

- Integration with existing ERP, WMS, or TMS systems
- Costs associated with node setup and network maintenance

Without a dedicated technical team, any new technology requires learning, piloting, and process adaptation. Micro enterprises typically succeed

best through collaboration with Blockchain-as-a-Service (BaaS) providers or within permissioned networks, starting with small-scale pilots and gradually expanding usage.

Recommended implementation phases include:

1. *Business Case Analysis*: Identify specific operational challenges (e.g., return tracking, temperature monitoring).
2. *Small-Scale Pilot Project*: Test blockchain tracking on a selected route or product type to evaluate feasibility.
3. *Vendor or Accelerator Selection*: Choose between consulting BaaS providers or joining logistics consortia. Micro firms may form local consortium blockchains to co-finance infrastructure, share costs, and reach critical mass. Services like Azure Blockchain or IBM Food Trust allow micro-operators to quickly adopt blockchain functions without in-house development, paying per transaction volume. (Daley & Urwin, 2023)
4. *Training and Process Adaptation*: Include all relevant personnel and define new procedures and KPIs.
5. *Gradual Integration and Expansion*: Begin with a single use case (e.g., digital invoicing) and extend to shipment tracking and contract

automation. Once a pilot succeeds, the enterprise can scale blockchain deployment across operations and increase node participation.

3.2 Blockchain Scalability in MSME Logistics

Small logistics enterprises are typically engaged in regional transportation and operate mid-sized warehouses. Many of them already provide last-mile delivery services, especially in urban and metropolitan areas, where flexibility and local market knowledge offer advantages over large-scale systems.

In addition to internal and external transport and warehousing operations (including potential repackaging), these businesses increasingly handle inventory management, contract verification, and decentralized tracking.

Compared to micro enterprises, small firms manage more diverse logistics flows, coordinate with multiple partners, and face greater demands for technical interoperability. Core distinctions between micro and small enterprises in the context of logistics and blockchain application are shown in Tables 2 and 3.

Table 2. *Operational Capacity and Logistics Complexity*

Aspect	Micro Enterprises (1–9 employees)	Small Enterprises (10–49 employees)
Number of employees	1–9	10–49
Logistics scope	Limited to local deliveries and warehousing	Regional distribution, multiple delivery points
Technological infrastructure	Minimal (Excel, phone, GPS)	Basic ERP/WMS systems, mobile apps
Type of services	Last-mile, courier, and ad hoc transport	Warehousing, distribution, contract-based logistics

Table 3. *Blockchain Application Parameters*

Element	Micro Enterprises	Small Enterprises
Technical readiness	Low – often no internal IT staff	Moderate – potential for engaging external consultants
Blockchain solution type	Plug-and-play tools, mobile apps	Modular systems, smart contracts
Application focus	Delivery verification, receipt confirmation	Inventory management, partner agreements
Investment capacity	Limited – dependent on grants or open-source tools	Capable of pilot projects and interoperability testing
Need for decentralization	Low – typically direct end-user interaction	Higher – multiple supply chain actors involved

These differences stem from distinct strategic approaches:

- Micro enterprises prioritize simple mobile tools that offer basic transparency (e.g., QR codes for delivery confirmation, blockchain timestamping without dedicated infrastructure). As such, they are well-suited for experimental, low-budget blockchain applications that solve specific problems, such as proof of delivery.
- Small enterprises can support more complex operations, such as smart contracts for automated post-delivery payments, multi-

point tracking, and integrated partner coordination (e.g., with distributors and warehouses). They are positioned to lead interoperable solutions that connect multiple stakeholders and foster standardization within regional logistics networks.

A synthesized matrix showing how blockchain functionalities can be applied based on enterprise size—from micro to large firms—is presented in Table 4. The matrix includes specific examples of available tools and software providers, matched to business scale² and implementation feasibility.

Table 4. Matrix of Blockchain Functionalities with Example Tools

Functionality	Micro Enterprises (1–9)	Small Enterprises (10–49)	Medium & Large Enterprises (50+)
 Timestamping & Verification	OpenTimestamps (free timestamp service), OriginStamp (web API)	BlockCerts (digital document seals), POA Network (private Ethereum)	IBM Blockchain Platform (Hyperledger Fabric), Amazon Managed Blockchain
 Smart Contracts	Remix IDE + Ganache (local testing), Truffle Suite	Quorum (JP Morgan), BlockApps STRATO	R3 Corda, Hyperledger Fabric, SAP Blockchain Framework
 Product Tracking	TE-FOOD Mobile (QR delivery app), Provenance (cloud tracking)	VeChainThor, IBM Food Trust Lite	Project Provenance, Microsoft Azure Blockchain + IoT
 Tokenized Access & Documents	IPFS + Textile, Pinata Cloud	Filecoin Gateway, Access Protocol	Microsoft Confidential Consortium Framework, ConsenSys Mesh
 Decentralized Partner Network	Akasha Network, 3Box (Web3 profiles)	Kaleido (Hyperledger B2B), Lumedic (Corda for healthcare)	Baseline Protocol (ERP–Ethereum), TradeLens (Maersk–IBM)
 Document Storage & Exchange	Pinata / Infura IPFS (free up to 1 GB), Textile Powergate (IPFS + Filecoin backup)	Storj DCS (decentralized cloud storage), Sia (flexible payment model)	Cofound.it (tokenized digital assets), Kaleido Marketplace (enterprise-grade IPFS + blockchain integration)
 Financial Tracking & Micro-Payments	BTCPay Server (open-source crypto POS), Coil (content micro-payments)	Stripe + Polygon Bridge (fiat–crypto micro-payments), Request Network (automated blockchain invoicing)	RippleNet (real-time interbank transfers), Symbiont Assembly (complex financial transactions)

Building upon the functional framework illustrated in Figure 2, Table 4 helps enterprises identify suitable blockchain tools according to their

operational capacity, thereby supporting strategic adoption planning across scales.

² The author maintains no commercial or financial ties with the manufacturers of the software mentioned. All references to digital tools are provided solely for

informational purposes and do not constitute a commercial endorsement.

To demonstrate how this mapping translates into real-world implementations, Section 4 presents two proof-of-concept simulations. The first targets the micro-enterprise PickupPoint, selecting only lightweight modules—dynamic QR-code timestamping and basic smart-contract payment triggers—to match its minimal infrastructure. The second focuses on the small enterprise LastMileCo, combining smart contracts, IoT tracking, and client portal into an integrated architecture. These scenarios will show how SMEs can pick and implement the most relevant blockchain components from the matrix to suit their operational needs and resource constraints.

4 COST-BENEFIT ANALYSIS

This section explores the following aspects:

- Initial costs of blockchain implementation
- Long-term benefits—cost reduction, data security, delivery efficiency
- Case studies of successful implementations in small logistics firms
- Simulations of blockchain adoption within micro and small enterprises.

4.1 Initial Costs of Blockchain Implementation

Deploying blockchain technology in micro and small logistics enterprises requires thoughtful investment planning, factoring in technical, organizational, and human resource demands. Although the initial investment may seem challenging, the growing availability of modular and SaaS solutions allows for relatively affordable adoption, even for the smallest players.

Key cost components include:

- *Consulting services*: Process analysis and solution tailoring to MSME environments
- *Digital infrastructure development*: Servers, cloud hosting, API integrations

- *Application customization*: QR code integration, data verification tools, developer engagement, testing, and UX design³.
- *Employee training and operational adjustment*: Usage protocols and security education
- *Technical system integration*: Compatibility with existing tracking platforms.

Estimated investment ranges:

- *Micro enterprises*: €3,500–5,000
- *Small enterprises* (wider operational scope): €18,000–27,000
- *Open-source pilot solutions*: €5,000–25,000
- *Enterprise-grade platforms* (e.g., Quorum⁴ and Hyperledger Fabric⁵: 30.000–100.000 EUR, because both platforms require specialized knowledge and technical infrastructure.

These figures include:

- Licensing and support (e.g., ConsenSys Quorum with SLA agreements)
- Module development (e.g., delivery confirmation, shipment tracking, audit trail)
- System integration (TMS, WMS, ERP via API or middleware)
- Security configuration (identity management, encryption, access control)
- Documentation and training
- Testing and production deployment

The implementation time frame is estimated at 4-12 months, depending on the complexity of the system.

Many MSMEs opt for SaaS blockchain solutions (e.g., Baseline, Kaleido, IBM Blockchain Platform), subscribing to monthly plans (typically €300–1,000), which helps bypass high upfront costs and accelerate rollout.

³ *User Experience (UX) design* refers to the intentional structuring of user–system interaction to ensure it is intuitive, efficient, pleasant, and functionally effective.

⁴ *Quorum* is a modified version of the Ethereum blockchain designed for enterprise use, featuring support for private transactions and consensus

mechanisms such as Raft and Istanbul BFT. (Banerjee, 2024)

⁵ *Hyperledger Fabric* is a modular blockchain platform developed under the Linux Foundation, well-suited for permissioned logistics networks. It supports Chaincode (smart contracts) and offers fine-grained access control. (Arpit, 2024; Hyperledger Foundation, 2025)

4.2 Long-Term Benefits for MSMEs in Logistics

Despite the initial costs, blockchain offers numerous long-term and sustainable benefits for logistics-focused MSMEs. It supports smoother goods flows, reduces downtime between delivery phases, and ensures more reliable data exchange. Smart contracts facilitate transaction automation, while decentralized shipment verification enhances trust and transparency.

Core benefits include:

- *Operational cost reduction:* Delivery confirmation automation, error minimization, and intermediary elimination
- Data security and error-proofing
- Accelerated payment processing
- Improved delivery efficiency

Beyond the operational efficiencies and technical innovations, blockchain adoption brings subtle but meaningful shifts in the business landscape of MSME logistics. As systems grow more transparent and transactions become verifiable in real-time, trust between clients and service providers naturally deepens. Regulatory compliance also becomes more attainable—not through added complexity, but through the seamless traceability of goods. Enterprises gain the ability to demonstrate the origin and movement of products with clarity, reinforcing both consumer confidence and institutional accountability.

Over time, these improvements translate into measurable financial outcomes. Case data indicate that for successfully deployed blockchain systems, the return on investment typically ranges from 6 to 18 months, depending on the business model and level of digital integration. In this context, blockchain emerges not only as a technological upgrade but as an economically sustainable and competitive choice for the MSME sector, particularly as it navigates the demands of digital transformation.

4.3 Empirical Case Studies

In the MSME context, implementations that demonstrate the scalability and adaptability of blockchain solutions within small logistics systems show the greatest potential for operational transformation. Literature and case studies

highlight real-world applications in local courier services, distribution hubs, and warehouses, where QR codes linked to blockchain records are used to automate deliveries and confirmations.

One particularly notable simulation involves a microenterprise that employs a mobile app and a unique verification code to confirm both the receipt and release of parcels, eliminating manual recordkeeping, reducing errors, and accelerating communication with the seller.

4.3.1 Application of the TradeLens Platform in MSMEs

In his graduate thesis, Šeatović (2025) examines how TradeLens—a blockchain solution jointly developed by Maersk and IBM—can be adapted to the needs of micro and small logistics actors. Although originally designed for large global supply chains, the author identifies specific functionalities that, with appropriate customization, enable MSMEs to:

- Verify deliveries using timestamps and digital signatures
- Exchange documents transparently and in real time
- Automate invoicing through smart contracts

The study suggests that this "lightweight" approach—selectively integrating only the core TradeLens services—can reduce development costs and expedite blockchain adoption in small-scale environments (Šeatović, 2025).

Although TradeLens processed more than 70 million containers and over 4 billion logistics events during its operational period, TradeLens was officially discontinued on March 31, 2023, as confirmed by IBM's support portal. The decision was first announced by Maersk and IBM in November 2022, citing strategic misalignment and lack of full industry adoption (Maersk, 2022; IBM, 2023).

Key reasons for its termination included a lack of commercial viability, limited industry cooperation, and hesitancy from competitors toward a platform controlled by a dominant sector player (Cecere, 2022; Haselhorst, 2024).

Nevertheless, TradeLens remains a relevant example of blockchain infrastructure, whose conceptual and functional components can be adapted to the MSME context, especially through modular strategies and open-source technologies.

4.3.2 Application of TE-FOOD: Blockchain in Local Food Logistics

Launched in 2016, TE-FOOD implemented a public blockchain system for food traceability in Vietnam, with a focus on micro and small enterprises—including farms, slaughterhouses, distributors, and retail stores. The system aims to record every critical event in the supply chain using immutable blockchain entries, while mobile scanners and QR codes printed on packaging allow seamless interaction for end-users.

Key system components include:

- IoT/QR integration for logging product movement at each supply chain node
- Decentralized ledger capturing HACCP checkpoints and transport events (Pham, et al., 2023)
- A web portal for MSMEs offering shipment history overview and deviation alerts

Operational impact in Vietnam:

- More than 2,400 farms and 6,000 distributors onboarded
- Product recall time reduced from seven to two days
- Consumer trust improved and complaint rates lowered by 30%, attributed to visible audit trails

Estimated implementation costs (average projections):

- Basic package (mobile app + QR printing): €8,000–12,000
- Additional modules (IoT sensors, API integrations): +€5,000
- Monthly SaaS subscription: ~€150

This case illustrates how MSMEs in the agri-food sector can leverage blockchain to increase transparency, security, and operational efficiency, without the need for complex infrastructure investments.

4.3.3 Case Study: Chronicled and IoT Integration

Chronicled, founded in 2014 in San Francisco, combines blockchain with IoT sensors (RFID, GPS, temperature) to:

- Record transport conditions (temperature, humidity, location) in an immutable ledger

- Automate ownership transfer confirmations via smart contracts
- Provide a robust audit trail for small courier firms

This implementation reflects the sensor-driven automation model described in Section 3.1.2, wherein IoT data triggers smart contract execution, enabling secure, event-based logistics coordination. This approach offers Micro, Small, and Medium Enterprises (MSMEs) secure records of storage and shipment conditions, while leveraging the smart contract–IoT integration framework described in Section 3.1.2 to trigger automatic payment upon verified delivery, reducing disputes and accelerating cash flow. Based on a consensus blockchain and distributed IoT nodes, the system exemplifies a modular strategy for adopting advanced technologies in small environments, validating selective integration of large-scale solution components to optimize SME implementation costs and risks. (Daley & Urwin, 2023)

Additional benefits for MSMEs include (MediLedger, 2025; Pribich & Cooper, 2023):

- Access to an existing consortium without capital expenditure, through subscription and transaction fees
- Hyperledger Fabric-based architecture (Hyperledger, 2018) that allows selection of only the modules relevant to the SME business model
- API integrations with leading ERP/PLM systems, reducing technical implementation time and cost
- A web portal and mobile application tailored for end users (distributors, pharmacies), featuring a simple interface for reviewing shipment history, reporting, and performance tracking

To achieve rapid, scalable deployment, MediLedger adopted a cloud-native, high-availability architecture and partnered with a DevOps team (Kelly, 2025). This collaboration reduced client onboarding time from days to 1–2 hours, eliminated implementation errors, and produced reusable Infrastructure-as-Code modules. The architecture is cloud-migration ready (e.g., AWS), and dedicated technical

support further strengthens solution agility and scalability for SMEs.

4.3.4 Modum Case: Monitoring Pharma Shipments

Modum, a Swiss startup founded in 2016, integrates temperature and humidity sensors with Ethereum blockchain verification (Modum, 2017). Their plug-and-play devices enable small logistics firms to (Huang et al., 2019):

- Monitor and record environmental conditions in real time
- Automatically generate immutable compliance reports for regulators
- Integrate sensor data into existing TMS/WMS via REST APIs
- Minimize risks of product recalls and losses due to improper transport

Focusing initially on pharmaceutical deliveries—where SMEs handle sensitive products locally and regionally—Modum operationalizes the smart contract–sensor framework described in Section 3.1.2. Sensor readings are continuously matched against predefined thresholds, and compliance actions are triggered automatically, minimizing manual oversight. Key advantages for SMEs include:

- A scalable model requiring no proprietary blockchain infrastructure
- Easy sensor installation and companion mobile app
- Compliance with EU GDP regulations for drug transport

This example illustrates how SMEs in the agri-food and pharma sectors can leverage blockchain for regulatory alignment, automated transactions, and operational efficiency—without heavy infrastructure investments.

4.3.5 Case Study: Slync.io for SME Logistics

Slync.io, a Dallas-based startup launched in 2017, marries blockchain with artificial intelligence to provide small and medium logistics firms with:

- Real-time visibility of domestic and international shipments
- Automation of repetitive operational workflows
- Congestion prediction and route optimization

The platform leverages a distributed ledger for immutable event logging, while an AI layer

aggregates and analyzes data to produce timely alerts and trigger automated corrective actions. This hybrid solution allows SMEs to elevate digitalization and transparency without building complex, in-house infrastructure, while benefiting from lower integration costs and faster deployment (Daley & Urwin, 2023). Research shows that such blockchain-AI convergence can significantly reduce errors and delays, boosting operational efficiency.

Despite its innovative promise, Slync.io failed. Between 2019 and 2022, the company generated only \$1.7 million in revenue against cumulative losses exceeding \$80 million (Sunset, 2024). In 2023, founder and CEO Chris Kirchner was arrested for financial misconduct (Dooley, 2024), leading to a loss of investor confidence and inability to secure further funding. By October 2023, Slync.io ceased operations and entered liquidation. This cautionary tale underscores the necessity of transparent governance and sustainable business strategies, especially for tech startups targeting the SME sector.

These case studies confirm that blockchain can deliver tangible benefits to the SME logistics sector, whether through direct sensor-triggered automation (as discussed in Section 3.1.2) or broader AI-integrated workflows, provided implementations follow a selective integration approach.

4.4 Proof-of-Concept Simulations

Following the modular structure outlined in Figure 2 and applied through the tool matrix in Table 4, the following subsections present two simulations:

- A detailed case study for the microenterprise *PickupPoint*
- A conceptual implementation model for the small enterprise, *LastMileCo*

Together, these simulations assess the applicability of TradeLens-inspired modular principles in concrete, small-scale operational settings.

4.4.1 Sources Informing the Simulation

The simulations were constructed using technical and economic sources that explain blockchain–QR code principles and support preliminary cost estimation. These include:

1. *Technical principles of blockchain-linked QR codes:*

- a. Casandra (2025) describes how QR codes can be linked to blockchain records to enable transparency and verification, particularly in logistics. The approach uses dynamic QR codes that reference hashed blockchain transactions.
- b. MyMap.AI (2025) explains identity and product status verification via QR technology, directly applicable to micro-logistics operations.

2. *Cost estimation frameworks:*

- a. Open-source development tools (e.g., Solidity, React Native, Polygon SDK) and commercial platforms with published pricing (e.g., Infura, Polygon.io) offer SMEs clear access to technical specifications and costs. Solidity and React Native are open-source, while Infura and Polygon.io provide paid APIs. Polygon also maintains open-source modules such as zkEVM, available under permissive licenses. (Infura, 2025; Polygon, 2025)
- b. Application and smart contract development costs were estimated based on freelance blockchain mid-level developer rates in the EU (€15–30/hour) (Index, 2025). SMEs may source developers globally to optimize pricing.
- c. SaaS blockchain infrastructure providers (Alchemy, Moralis, QuickNode) offer scalable pricing models, with estimated costs for micro enterprises around €100/year. (Alchemy, 2025; Moralis, 2025; QuickNode, 2025)

4.4.2 Simulation Methodology for SMEs in Logistics

The simulations employ a modular, proof-of-concept methodology to model blockchain implementation tailored to SME logistics workflows.

For the microenterprise, the simulation assumes:

- Use of a mobile app, QR codes, and manual event registration
- Operations within a single warehouse or distribution point, staffed by a few employees handling a limited volume of daily shipments
- Blockchain is used for transparent delivery logging and smart contract-triggered payment after QR scanning

For the small enterprise, the simulation expands the scope:

- Integration of the blockchain layer into an existing TMS/WMS system via API
- Operations across multiple facilities with digital bills of lading (e-BL) and IoT-based event automation
- Smart contracts enabling dynamic invoicing, environmental condition monitoring, and regulatory audit trails

Common steps across both scenarios include:

1. Shipment registration (identity creation on blockchain)
2. Receipt and scanning (QR code or RFID tag)
3. Ownership transfer confirmation (smart contract activation)
4. Verification and audit via client/operator-facing interface

These models reflect operational capacity and implementation feasibility at two scales. The next case study applies the methodology to the *PickupPoint* microenterprise.

4.4.3 Simulation: Micro Enterprise “PickupPoint”

PickupPoint is a local mini shop that receives parcels from couriers and hands them over to final customers.

Before blockchain implementation:

- Courier delivers a package; staff manually scans and logs it into a physical record
- Customer receives an email/SMS with pickup code and time
- Upon pickup, the staff verifies the code (and possibly ID) and manually confirms delivery to the seller, triggering payment authorization
- If unclaimed, the parcel is returned through the courier, following the same process in reverse

Blockchain-enabled workflow:

1. Each parcel is assigned a dynamic QR code linked to a hashed public blockchain transaction (e.g., on Polygon)
2. Upon arrival, the staff scans the QR; the mobile app generates a “received” event published to the blockchain with unique metadata

3. Customer scans QR and inputs a one-time PIN; app verifies receipt, checks the PIN, and posts “picked-up” event
4. Smart contracts automatically notify the seller and logs income for the microenterprise

Technical setup and estimated costs:

- Frontend: Mobile app built with React Native
- Backend: Node.js with REST API for blockchain interaction
- Blockchain layer: Polygon for low-cost transactions; access via Infura or RPC
- Smart contract: Written in Solidity for event logging

Table 5. Estimated Blockchain Implementation Costs for PickupPoint

Item	Cost Estimate
Development & integration (2–4 weeks)	€2,000–3,500
UI design (1–2 weeks)	€1,000–1,500
Blockchain infrastructure (annual)	~€100 subscription
Training & support	~€400
Total initial investment	€3,500–5,000

Projected Return on Investment (ROI): Estimated at 6–9 months, based on projected reductions in dispatching time, customer service labor, and delivery errors. Calculations assume an average transaction value of €18, ~150 successful deliveries per month, and a 30% drop in customer complaints and dispatch rework.

This investment level is accessible for micro enterprises and activates the core blockchain benefits summarized in Section 3, particularly transparency and error reduction within delivery workflows.

4.4.4 Simulation: Small Enterprise “LastMileCo”

LastMileCo is a regional delivery company with 15 couriers and three warehouses, operating last-mile logistics, “from warehouse to doorstep.”

Blockchain integration includes:

- Smart contracts deployed on Quorum or EVM-compatible platforms such as Hyperledger Besu, defining delivery and payment conditions triggered upon status “delivered”

- IoT and GPS tracking to record delivery paths, with each key event registered on the blockchain and timestamped
- Client portal providing automated access to delivery history, recipient digital signatures, and auto-generated delivery confirmations

Table 6. Technical Architecture and Estimated Blockchain Implementation Costs for LastMileCo

Item	Estimated Cost
Smart contract and backend development	€8,000–12,000
IoT integration (RFID/GPS sensors)	€5,000–8,000
Enterprise blockchain node (SaaS with SLA support)	~€6,000/year
Client-facing web portal	€3,000–5,000
Staff training and process adaptation	€2,000
Total initial investment	€18,000–27,000

Return on Investment (ROI): Estimated at 12–18 months, reflecting reduced delivery disputes, fewer failed shipments, and accelerated billing, cutting average invoice clearance from 15 to 7 days. Calculations follow the same transaction-level ROI model established in the PickupPoint scenario (Section 4.4.3), scaled to LastMileCo’s enterprise size, infrastructure, and delivery volume.

These simulations validate the feasibility of selecting and integrating blockchain modules as mapped in Figure 2, reaffirming that even small enterprises can benefit from targeted adoption strategies.

5 RECOMMENDATIONS FOR MICRO AND SMALL ENTERPRISES

Amid growing demands for logistics process digitalization, micro and small enterprises (SMEs) face the challenge of balancing operational efficiency with financial sustainability. While blockchain adoption may appear technically demanding, there are well-defined scenarios in which it delivers tangible value at reasonable investment levels. On the other hand, it remains a complex and potentially costly endeavor.

Therefore, when developing a blockchain implementation strategy, SMEs should consider:

- *Business volume* – Is the current transportation volume sufficient to justify a blockchain investment?
- *Implementation costs* – Affordable options exist, but long-term viability must be evaluated
- *System integration* – Will blockchain be compatible with current transport management software?
- *Regulatory context* – Are there legal barriers to using blockchain in the logistics sector?

If blockchain is determined to be both justified and necessary, enterprises must carefully plan implementation phases and anticipate key challenges.

5.1 Phased Implementation Strategy

Before committing to a full-scale blockchain deployment, micro and small enterprises should assess their operational priorities against specific digital functionalities. This assessment can be guided by modular frameworks such as the one presented in Figure 2, which organizes blockchain components by logistics function and enterprise scale.

To avoid technological and organizational shocks, SMEs should adopt blockchain gradually through the following phases:

- i. *Business process analysis and needs identification*: Map logistics workflows to pinpoint inefficiencies, bottlenecks, or trust gaps, such as goods intake, quantity verification, and delivery confirmation.
- ii. *Pilot project initiation*: Define goals and test blockchain within a limited scope (e.g., one

location, route, or product cycle). Open-source platforms such as Ethereum Lite or Hyperledger Sandbox allow cost-effective prototyping.

- iii. *Integration with existing software*: Connect the blockchain layer with systems like TMS, WMS, or ERP using standardized APIs or middleware, without major architectural modifications.

- iv. *Employee training and operational adaptation*: Successful implementation depends on users' understanding and using the system effectively. Training should cover logistics operations (storage, confirmation, verification) and security protocols (encryption, private keys, access control).

- v. *Scaling across broader environments*: If the pilot proves successful, the system can be expanded to multiple warehouses, production lines, IoT nodes for automated asset tracking, and external partner integration.

5.2 Key Challenges and Mitigation Strategies

Although blockchain adoption is viable for logistics-focused SMEs, they may encounter several implementation barriers. The most common challenges and recommended strategies are outlined in Table 7. SMEs that adopt blockchain with a clear objective, phased functionality expansion, and proper employee support can achieve not only operational improvements but also a competitive edge in digitally transformed logistics environments.

Table 7. Key Blockchain Implementation Challenges and Mitigation Strategies

Challenge	Recommended Strategy
 High initial investment costs	Use open-source platforms and SaaS subscriptions to reduce upfront expenses
 Limited technical expertise	Partner with IT firms, outsource developers, and leverage educational guides
 Integration with existing software	Apply modular architectures, API connectors, and consulting packages for compatibility
 Legal and regulatory uncertainty	Monitor EU guidelines on digital records and consult legal experts in tech law
 Employee resistance to new technologies	Involve staff in the pilot phase, provide customized training, and use familiar interfaces (e.g., mobile apps with visual confirmations)

6 CONCLUSION

The adoption of blockchain technology by micro and small logistics enterprises represents a strategic shift toward greater reliability, transparency, and operational efficiency. Although blockchain is often seen as a solution for large corporate systems, the simulated implementations at PickupPoint and LastMileCo demonstrate that resource-constrained operators can execute rational, cost-effective deployments.

Based on our analysis of technical requirements, organizational change, and cost frameworks, blockchain is most justified when an enterprise:

- Manages high-value or sensitive goods requiring indisputable authenticity and traceability
- Collaborates with multiple external partners and needs a neutral, tamper-proof event registry
- Seeks to automate core processes such as delivery confirmation, service billing, or digital signing
- Encounters inconsistent records across legacy systems (TMS, ERP) and needs an interoperability layer
- Aims to eliminate manual errors and miscommunications inherent in paper-based workflows

Under these conditions, blockchain should be viewed not merely as a technical add-on but as a foundational infrastructure that ensures reliable record-keeping, accelerates contract execution, and enhances supply-chain reputation.

Our modular models confirm that even small-scale operations can integrate blockchain affordably and with controlled risk, paving the way for broader digital transformation in the logistics sector.

Key decision factors for pursuing blockchain include:

- *Business domain:* Is the enterprise engaged in digital transactions, contracts, or logistics processes that benefit from unified, verifiable data?
- *Implementation cost:* Do available open-source or SaaS options provide a measurable return relative to business goals?

- *Regulatory environment:* Are there industry-specific or national regulations affecting blockchain-based records and e-signatures?
- *Technical support capacity:* Can the enterprise manage a blockchain system internally, or must it rely on external expertise, impacting budget and sustainability?

These criteria not only guide evaluation but also form the bedrock of a sustainable digital-transformation strategy tailored to the resources, needs, and compliance requirements of small firms.

7 PROPOSALS FOR FUTURE DEVELOPMENT AND REGULATORY REFORM

The preceding analysis confirms that blockchain can function as a viable solution for micro and small logistics enterprises. However, its broader adoption will depend not only on technical feasibility but also on sustained research efforts and thoughtful regulatory adjustments.

On the research front, several directions merit particular attention. First, tailored ROI models must be developed to reflect the operational realities of SMEs. These models should account for resource constraints, gradual implementation strategies, and sector-specific dynamics. In parallel, the evaluation of hybrid architectures—those that combine blockchain and IoT—could unlock new efficiencies in traceability and automation. Attention to user experience design is also crucial. For low-tech operational environments typical of many SMEs, simplified and intuitive interfaces may significantly boost staff adoption and mitigate resistance.

Equally valuable is comparative technological analysis. By examining platforms such as Polygon and Hyperledger, researchers and practitioners can help small firms navigate the landscape of available tools and identify solutions best suited to their scale, interoperability needs, and cost structures.

Among the most promising opportunities lies blockchain's application in Environmental, Social, and Governance (ESG) reporting. Through measurable and verifiable data, SMEs can demonstrate alignment with sustainability, ethics, and transparency goals. Such reporting offers

more than just internal insight; it empowers stakeholders, including investors, partners, regulators, and the public—to make informed assessments about the enterprise's integrity and strategic direction.

From a regulatory standpoint, establishing sandbox environments would allow SMEs to test blockchain applications under relaxed compliance constraints. Such frameworks would reduce legal risk and encourage innovation without compromising oversight. National and international laws must also evolve to formally recognize blockchain-authenticated digital confirmations, such as delivery receipts, invoices, and certificates of origin. This recognition should build upon existing global standardization efforts, including ISO TC 307, IEEE initiatives, and the Blockcerts protocol.

Data protection remains a critical concern, particularly for SMEs lacking in-house legal teams. Clear guidelines must be established to govern the treatment of sensitive information across distributed networks. Furthermore, targeted incentive schemes—such as public grants, tax credits, or cooperative infrastructure programs—could play a decisive role in making technological transition both attainable and sustainable.

Taken together, these proposals offer an actionable roadmap for integrating SMEs into the emerging landscape of digital logistics. Rather than passive adopters of new technologies, micro and small enterprises are poised to become co-creators of a logistics ecosystem defined by transparency, resilience, and long-term sustainability.

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FIREWALL-BASED DEFENSE STRATEGIES AGAINST MAN-IN-THE-MIDDLE ATTACKS

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ABSTRACT

Firewalls serve as the first line of defense against Man-in-the-Middle (MITM) attacks, which compromise the confidentiality, integrity, and authenticity of digital communication. This paper presents a structured taxonomy of core MITM techniques, including ARP poisoning, DNS spoofing, HTTPS degradation (also known as SSL stripping), and session hijacking, as well as specialized variants targeting cloud services, web browsers, mobile applications, and IoT devices. Particular attention is given to vulnerabilities in VPN infrastructures, where centralized traffic decryption creates high-value targets, and to weaknesses in IoT ecosystems stemming from unvalidated certificates and outdated factory configurations. The analytical-comparative methodology integrates a literature review, statistical assessment of the economic impact of MITM incidents, and a practical demonstration of advanced firewall capabilities using Linux iptables/nftables configuration. The paper outlines both fundamental and advanced features of modern firewall solutions, including ACL rules, stateful inspection, application-layer filtering, DNS filtering, TLS inspection, and integration with IDS/IPS systems. Illustrative examples from widely used applications highlight the strengths and limitations of these measures. The findings emphasize that while firewalls are essential, they are not sufficient on their own. Effective protection requires a multilayered architecture that combines DNS encryption, strict TLS certificate validation, anomaly detection, and continuous user education to significantly reduce the risks and economic consequences of MITM attacks in contemporary digital networks.

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1 INTRODUCTION

1.1 Fundamentals of Hacking and Hacker Motivation

Hacking encompasses all unauthorized methods of interacting with information systems, where actors—commonly referred to as hackers—seek to access, modify, or steal data beyond the permissions granted by system owners. Hackers are ethically categorized into three groups: black-hat (malicious), white-hat (ethical), and gray-hat (ambivalent). While they may share tools and techniques, their motivations and objectives differ significantly. Skill levels range from advanced malware developers to so-called “script kiddies” who exploit known vulnerabilities without deep technical understanding.

Motivations for hacking include data harvesting, impersonation for fraudulent activities such as DDoS attacks, destructive intent aimed at system disruption, and personal thrill-seeking or challenge-driven behavior. The legal framework surrounding hacking is complex, involving issues such as data ownership versus system ownership, privacy concerns, and ambiguous boundaries of lawful online conduct. Hackers are subject to legal consequences for unauthorized actions.

Hacking techniques span from physical device theft to sophisticated network-based attacks that exploit open ports, backdoors, and social engineering tactics such as phishing¹ and credential spoofing. Even software “Easter eggs”² left by developers can be repurposed for malicious use. One of the most impactful forms of hacking is the Man-in-the-Middle (MITM) attack, which is the central focus of this paper and is examined in detail in Section 3.

Successful hacking requires deliberate planning, considering the attacker’s goals, profitability, chosen methods (mass versus targeted attacks), and potential consequences. Effective attacks

demand substantial effort and are rarely instantaneous.

1.2 Financial Motivation

Cyberattacks result in substantial financial losses, including direct theft, remediation costs, and ongoing security expenditures. As early as 2011, hackers reportedly generated over \$12.5 billion in illicit revenue, with corporations suffering significant financial damage. Despite advancements in cybersecurity, the scale of losses has continued to grow.

For example, the average cost of a data breach in 2024 reached \$4.88 million per organization, marking a 10% increase compared to \$4.45 million in 2023. Interestingly, this figure declined by 9% in 2025 to \$4.44 million, which may suggest improved defensive measures or a shift in attacker focus on smaller organizations. (IBM, 2025).

According to Verizon’s 2025 Data Breach Investigations Report (2025), several key findings stand out:

- 30% of security breaches involved third parties, doubling from the previous year, with root causes including system vulnerabilities and operational disruptions.
- The number of attackers exploiting vulnerabilities for initial access rose by 34% year-over-year.
- Organizations remediated 54% of perimeter vulnerabilities, while nearly half remained unresolved.
- 44% of analyzed incidents involved ransomware, representing a significant increase from prior reports.

The emergence of AI tools such as ChatGPT in late 2022 triggered an explosion of phishing campaigns. Within six months, phishing volume increased more than fortyfold compared to previous periods (SOCRadar, 2024). Before AI

¹ Phishing refers to an attempt to steal sensitive information—such as usernames, passwords, credit card numbers, or bank account details—for misuse or resale. Disguised as a trusted source with an enticing request, the attacker lures victims into deception, much like a fisherman uses bait to catch a fish.

² Software Easter eggs are hidden features, messages, or content intentionally embedded by developers, not

part of the official functionality. They are often humorous, nostalgic, or playful, and typically require a specific sequence of actions to be revealed. Examples include typing “do a barrel roll” in Google Search, which rotates the page, or entering “about:robots” in Mozilla Firefox to display a whimsical message about robots.

adoption, phishing emails were often grammatically flawed and easily detectable. ChatGPT enabled attackers to generate grammatically correct, stylistically convincing messages that appeared to originate from colleagues, banks, or IT support. This led to higher success rates. Moreover, AI can produce hundreds of phishing message variants per second, and attackers now deploy scripts that combine ChatGPT with automated email delivery systems.

In 2021, the average cost of a cyber incident exceeded €670,000 per hour of active attack duration, while the number of compromised accounts surpassed one billion (AAG, 2025).

According to CVEdetails.com, which tracks publicly disclosed CVE identifiers, over 40,000 vulnerabilities were reported in 2024, and more than 30,000 were registered in the first seven months of 2025 (CVEdetails, 2025). Based on analysis using tools like CVEmap and data from the GitHub community, it is estimated that 35–45% of these vulnerabilities had publicly available proof-of-concept (PoC) exploit code, making them technically accessible for exploitation. These vulnerabilities were or could have been leveraged in various attack types, including ransomware, phishing, supply chain compromise, privilege escalation, remote code execution, and zero-day exploitation.

The Hackmanac Cyber Threat Report 2024 estimated the average financial impact of a cyberattack at approximately \$5 million, encompassing ransom payments, technical remediation, reputational damage, and business interruption (Hackmanac, 2024). However, this average varies widely depending on the target: while large organizations may suffer multimillion-dollar losses, individuals and small businesses often experience lower—but still significant—damage.

According to the NETSCOUT Threat Intelligence Report, the first half of 2024 saw an average of 41,000 DDoS attacks per day, totaling approximately 7.5 million attacks—a 30% increase compared to the same period in the previous year (NETSCOUT, 2024).

2 METHODOLOGY

In alignment with the research objectives, the following research questions were formulated:

RQ1: Is the firewall a viable tool for mitigating MITM attacks?

RQ2: If so, how can a properly configured firewall, in combination with a multilayered security architecture, effectively reduce the risk of MITM attacks in modern digital environments?

The study employed an analytical-comparative methodology, combining theoretical analysis, case studies, and technical demonstrations. The methodological framework was structured around the following components:

- Analysis of MITM attack techniques and their variants
- Comparison of traditional and advanced firewall functionalities
- Case studies of MITM scenarios in the context of Viber and WhatsApp applications
- Comparative assessment of VPN³ and Tor⁴ infrastructures with respect to security resilience
- Statistical overview of the financial impact of MITM incidents
- Demonstration of iptables rules in a Linux environment as a practical configuration example

The literature review encompassed academic databases such as Google Scholar, IEEE Xplore, SpringerLink, and MDPI, supplemented by specialized technical sources focused on firewall configuration. Due to the complexity of the topic,

³ A VPN (Virtual Private Network) is a technology that enables secure, encrypted communication between a user and a remote network over the public internet. By using a VPN, all network traffic is routed through a protected channel, ensuring data confidentiality, integrity, and anonymity

⁴ Tor (The Onion Router) is a decentralized network and software bundle that enables anonymous communication over the internet. It uses multi-layered encryption and routes traffic through a series of randomly selected relay nodes, effectively concealing the user's identity and location. (Dingledine, et al., 2004)

artificial intelligence tools were employed to optimize query formulation, abstract screening, and preliminary selection of relevant publications.

Inclusion criteria for sources were based on thematic relevance, methodological rigor, and publication date. Most of the analyzed works were published within the last five years, alongside prior publications by the author in the field of MITM attacks.

The collected material underwent critical analysis in accordance with academic standards for source validation, reliability assessment, and relevance to the defined research problem. The information was organized through thematic analysis, which identified key security domains, recurring patterns, and a conceptual framework that integrates existing knowledge.

For clarity and comparative purposes, selected findings were presented in tabular format. Based on the conducted analysis, gaps in the existing literature were identified, serving as a foundation for the formulation of conclusions and recommendations.

3 MAN-IN-THE-MIDDLE ATTACKS

3.1 Introduction to MITM Attacks

MITM attacks represent a distinct class of cyber intrusions in which an attacker covertly positions themselves between two communicating parties with the intent to intercept, redirect, or alter transmitted data. These attacks pose a direct threat to the confidentiality, integrity, and authenticity of digital communication—affecting both corporate infrastructures and end-user environments.

Common vectors for MITM scenarios include unsecured Wi-Fi networks, DNS record

manipulation (DNS spoofing, also known as DNS cache poisoning), removal of encryption layers in TLS/SSL protocols (SSL stripping⁵), and session hijacking. With the proliferation of cloud technologies, the Internet of Things (IoT), and Bring Your Own Technology (BYOT⁶) practices, MITM attacks have become increasingly prevalent. Adversaries exploit weaknesses in encryption, authentication mechanisms, and network protocols to gain unauthorized access and manipulate data flows.

3.2 Technological Foundations of MITM Attacks

MITM attacks have existed long before the advent of computers and can be likened to a malicious postal worker intercepting letters between two parties. Modern MITM attacks rely on sophisticated techniques that exploit vulnerabilities in security protocols. Particularly problematic are implementations of SSL/TLS protocols, where administrative complexity often results in one-way authentication—leaving room for attackers to impersonate legitimate entities.

In a typical MITM scenario, the attacker intercepts communication, inserts themselves as an intermediary between the communicating parties, and manipulates message content. For example, they may alter invoice payment details to redirect funds to their own account.

The most common MITM techniques include (OWASP, 2025):

- ARP cache poisoning⁷
- DNS spoofing
- Session hijacking, including side-jacking, evil twin attacks, and packet sniffing
- SSL session hijacking

The technological basis of MITM attacks is extensively discussed in Čekerevac et al. (2017a). Therefore, this paper presents only a schematic

⁵ SSL stripping is a technique in which an attacker intercepts HTTPS requests and redirects them to the unencrypted HTTP version of the target site. By removing the encryption layer, the attacker gains access to plaintext data, enabling the theft of sensitive information such as login credentials, session tokens, and personal details.

⁶ Bring Your Own Technology (BYOT) je strategija ili praksa koja omogućava zaposlenima, studentima ili saradnicima da koriste svoje lične uređaje i tehnologije

(laptopove, pametne telefone, aplikacije, cloud servise itd.) za pristup organizacionim resursima, mrežama i podacima.

⁷ ARP cache poisoning, also known as ARP spoofing, is a type of cyberattack that targets vulnerabilities in the Address Resolution Protocol (ARP)—a protocol that maps IP addresses to MAC addresses within a local area network (LAN). Commonly used tools for this purpose include Ettercap, Scapy, Cain & Abel, Bettercap, and MITMf

flow of a representative attack, highlighting the directional flow of information. Figure 1 illustrates how an attacker, positioned between two victims, intercepts and modifies communication, thereby compromising the integrity of transmitted data.

Figure 1 illustrates a typical MITM attack scenario:

- **Victim A** initiates communication by sending a “Hello” message, which the attacker intercepts and forwards to **Victim B** without modification, creating the illusion of a direct connection.
- **Victim B** responds by sending their public key (“Public key B”), which the attacker intercepts and replaces with their own key (“Public key MITM”) before relaying it back to **Victim A**.

- When **Victim A** sends an invoice (“Invoice A”), the attacker modifies the content and forwards the altered version (“Changed invoice”) to **Victim B**.
- Ultimately, **Victim B** completes a payment to the wrong address (“Money paid to the wrong address”), believing they are communicating with a legitimate partner.

This schematic highlights the core stages of an MITM attack: interception, manipulation, and exploitation of communication. The attacker seamlessly integrates into the communication channel, leaving both parties under the false impression that they are interacting directly.

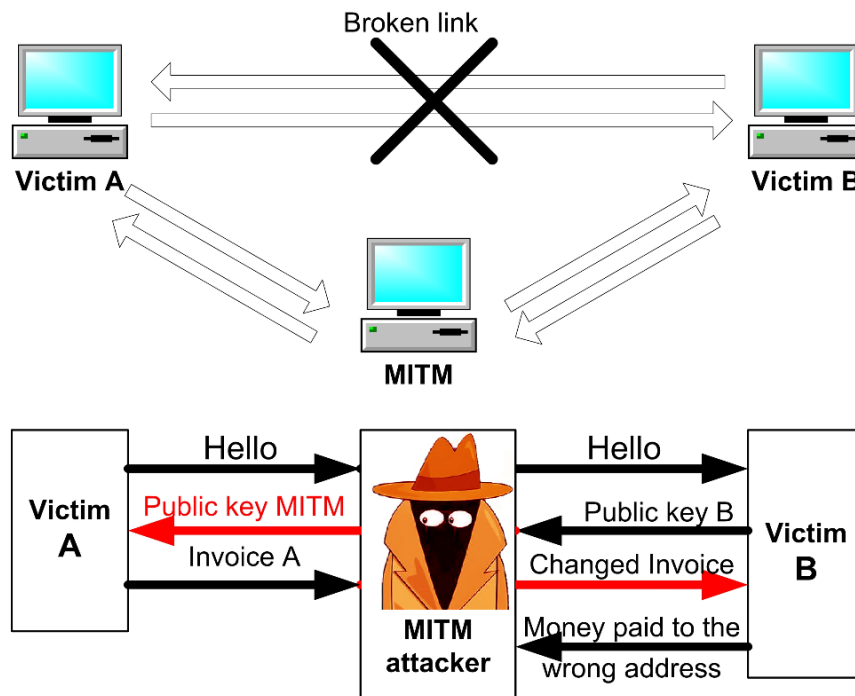


Figure 1. Schematic representation of an MITM attack: interception and manipulation of messages between two victims.

Source: Cekerevac et al. (2017a)

An illustrative example of such exploitation involves intercepting FTP credentials using tools like dsniff, which allow attackers to capture usernames and passwords transmitted in plaintext—opening the door to further network compromise.

3.3 Evolution of MITM Attacks

With the advancement of technology, MITM attacks have evolved into several specialized forms:

- **MIT-cloud (MITC):** Exploitation of session tokens in cloud services to gain unauthorized access.
- **MIT-mobile (MITMO):** Interception of mobile authentication codes (mTAN) transmitted via SMS.
- **MIT-app (MITA):** Injection of self-signed certificates to intercept data exchanged through mobile or desktop applications.
- **MIT-IoT:** Targeting IoT devices that fail to validate SSL certificates, enabling credential theft and unauthorized control.

Note: Although similar in name, Man-in-the-Browser (MITB) attacks are not technically classified as MITM attacks. MITB exploits occur locally within the user's web browser via malware, without intercepting network traffic between the client and server.

3.4 MITM Attacks in the Context of IoT Devices

Internet of Things (IoT) devices are particularly vulnerable to MITM attacks due to limited computational resources, lack of regular updates, and weak encryption protocols. These attacks are typically executed locally over Ethernet or Wi-Fi networks, leveraging ARP poisoning, DNS manipulation, and HTTPS interception through self-signed certificates or tools such as SSLstrip.

Many smart devices still fail to validate TLS/SSL certificates, allowing attackers to intercept credentials and compromise connections using tools like Ettercap, Evilgrade, dsniff, and Cain & Abel (Vahab, 2025). According to OWASP, "Insecure Data Transfer and Storage" remains one of the most widespread IoT vulnerabilities, as a significant number of devices do not verify certificate trust chains and often rely on outdated cryptographic libraries.

Bluetooth Low Energy (BLE), commonly found in smart locks, thermostats, and security cameras, exhibits a high rate of vulnerability. Hlapisi (2023) reports that 70–80% of tested BLE models are susceptible to cloning, passive data interception, and unauthorized device takeover. These recent findings confirm and expand upon earlier observations by Spring (2016), underscoring the urgent need for stricter certificate validation mechanisms and regular firmware updates (Wattlecorp, 2025; Hlapisi, 2023).

Distributed Denial-of-Service (DDoS) and related Denial-of-Service (DoS) attacks accounted for approximately 60–64% of all attacks targeting IoT devices in 2016, according to reports by McAfee and OWASP (McAfee, 2016). Billions of IoT devices remain continuously connected to poorly monitored networks, making them ideal targets for botnet recruitment, spam distribution, and credential theft. Notable examples include attacks on smart hubs and refrigerators that transmit unencrypted data.

IoT devices are frequently shipped with insecure factory settings, default passwords, open

interfaces, outdated firmware, and a lack of update mechanisms, which make them highly susceptible to exploitation. Connected vehicles are also vulnerable, as demonstrated in the 2015 Jeep Cherokee incident, where remote hacking led to the recall of 1.4 million cars (Čekerevac et al., 2017).

3.5 VPN Infrastructure as a Potential MITM Attack Vector

Public hotspot networks—especially those that are open and unsecured—are classic environments for executing MITM attacks. However, due to their limited range and physical accessibility, such attacks typically target local or narrowly defined user groups. In contrast, VPN infrastructure, which serves as a centralized conduit for encrypted traffic from many users, presents a far broader surface for potential compromise.

Although VPN services are commonly perceived as privacy-enhancing security mechanisms, their architecture inherently requires that all traffic be decrypted on the server side before being forwarded to its destination. If a VPN provider were malicious or compromised, it could intercept, modify, and analyze user traffic—creating conditions for a sophisticated MITM attack. Particularly vulnerable are unencrypted protocols, unvalidated certificates, and unchecked DNS requests.

Given the level of trust users place in VPN services, it is essential to select solutions that offer transparent policies, open-source codebases, independent security audits, and technical safeguards that minimize the risk of abuse—whether by the provider itself or in the event of a breach. Security is further enhanced when VPN providers undergo external verification by independent organizations. One such example is the Mobile Application Security Assessment (MASA) conducted on the Mullvad VPN service (Mullvad, 2025).

In the context of communication security, it is critical to distinguish between two foundational concepts:

- *Infrastructure trust:* VPN services operate on the assumption that the provider is trustworthy, does not log user activity, refrains from third-party cooperation, and is technically capable of securing user traffic. However, users have no direct control over these

- assurances—trust is external and often unverifiable.
- *Technical assurance of security:* The Tor network, although slower, is based on a decentralized model with multilayered encryption (onion routing), where no single node knows the complete transmission path.

Security is not dependent on trust in individual entities but on the architecture itself. While the exit node may be a point of surveillance, preceding layers protect the user's identity.

A comparative overview of VPN and Tor architectures is presented in Table 1.

Table 1. VPN vs. Tor — Security Considerations

Aspect	VPN	Tor
Speed	Faster, suitable for streaming and daily tasks	Slower due to multilayered routing
Privacy	It depends on the provider	Embedded in the system architecture
Resistance to MITM Attack	Vulnerable if the provider is compromised or cooperates with third parties	Stronger resistance; exit node remains a weak point
Visibility and Control Over Communication*	Limited user autonomy	Greater anonymity, but less granular control
Suitability for Daily Use	High	Lower, but valuable for specific use cases

Source: Author

* Note: In this context, “visibility and control over communication” refers to the user's ability to influence security parameters, understand network architecture, and manage their own level of privacy and anonymity. With VPNs, this autonomy is constrained by trust in the provider, whereas Tor offers greater technical independence.

3.6 Strategies in MITM Attacks: Adversaries vs. Victims

In the context of MITM attacks, strategic thinking is not exclusive to defenders—attackers also develop sophisticated approaches to evade detection and maximize effectiveness. Understanding the tactics employed by both sides enables a more precise definition of security requirements and facilitates more effective defense mechanisms.

3.6.1 Adversarial Self-Preservation Strategies

Attackers typically adopt a range of measures to minimize the likelihood of exposure:

- Operating remotely and frequently changing physical locations
- Utilizing publicly accessible or disposable devices
- Conducting financial transactions via cash or prepaid instruments to reduce traceability
- Employing anonymization tools (e.g., VPN, Tor) and automated scripts to hinder attribution.

3.6.2 Defensive Strategies for Victims

While complete elimination of MITM attacks remains challenging, risk can be significantly reduced through the implementation of the following measures:

- Designing network architectures with security as a foundational principle
- Deploying security-oriented network topologies
- Regularly updating operating systems and software
- Using firewalls and strong encryption mechanisms (e.g., SSL/TLS certificates)
- Implementing static ARP entries to prevent ARP poisoning
- Avoiding connections to unsecured Wi-Fi networks and using tools such as HTTPS Everywhere
- Applying DNSSEC and intrusion detection systems to mitigate DNS spoofing attacks
- Promoting digital literacy and cultivating a culture of cybersecurity awareness among users

Organizations, particularly smaller ones with limited resources, often need to reassess their security practices or engage external protection services. Key challenges include threat awareness and timely detection of attacks.

The use of public key cryptography (PKC) and digital certificates issued by trusted Certificate Authorities (CAs) is essential for reliable device identification and secure communication. However, compromise of root keys, the highest-level trust anchors, can jeopardize the entire system. This underscores the importance of the root of trust⁸ concept within trusted computing modules. Although cryptographic methods provide foundational protection, their effectiveness is significantly enhanced when combined with properly configured firewall systems, which will be examined in detail in the following section.

Users are advised to disable automatic network connections, avoid opening suspicious links and attachments, and refrain from performing device modifications such as *jailbreaking* or *rooting*, to reduce the risk of MITM attacks.

Given the increasing interconnectivity of devices and the complexity of modern network environments, MITM attacks represent not only a technical challenge but also a significant security and economic risk—particularly in the context of digital business transformation.

Due to their frequency and ability to compromise critical communication flows, MITM attacks occupy a prominent position among cyber threats. The following subsection presents their financial impact through statistical indicators collected over the past five years.

3.7 Economic Impact Assessment of MITM Attacks

MITM attacks represent a technically sophisticated form of cyber threat, capable of covertly intercepting communication, stealing credentials, and manipulating sessions and transactions. Their destructiveness extends

beyond direct financial damage, undermining systemic trust in digital infrastructures.

Within the broader spectrum of cyberattacks, MITM occupies a prominent position—both in terms of frequency and economic impact. According to available data, MITM accounts for approximately 19% of successful online attacks, with an estimated annual cost of \$2.4 billion (Astra Security, 2023). In the domain of Wi-Fi exploitation, MITM techniques contribute to as much as 35% of incidents, making them one of the most prevalent attack vectors in wireless environments. Additionally, 50% of MITM incidents result in credential theft, with over one million passwords compromised monthly, highlighting a serious risk to user identities and enterprise security systems.

Manufacturing enterprises are particularly vulnerable due to extensive use of IoT devices, automated systems, and often inadequately secured network configurations. MITM attacks are increasingly combined with automation and artificial intelligence, enhancing their efficiency and reducing the need for direct attacker involvement.

For a more comprehensive overview, Table 2 presents a comparative analysis of MITM and other dominant cyberattack types observed between 2021 and 2025

Despite often being overlooked in public discourse, MITM attacks carry high strategic significance. Their ability to integrate with other vectors—such as phishing—and to target communication flows makes them particularly dangerous in the context of digital transformation and industrial automation.

Compared to ransomware attacks, which generate immediate financial damage, MITM attacks operate more quietly yet systemically undermining authentication, data integrity, and user trust. For this reason, it is essential to develop layered defense strategies, including end-to-end (E2E) encryption, network segmentation, anomaly detection, and user education.

⁸ Roots of trust refer to foundational components within hardware or software infrastructures that are considered inherently reliable. In the context of a Trusted Platform Module (TPM), these include

cryptographic keys and mechanisms that initiate core security operations such as firmware verification, data encryption, and system authentication.

Table 2. Types of Cyberattacks: Characteristics, Prevalence, and Financial Impact (2021–2025)

Attack Type	Typical Target	Prevalence (2021-2025)	Annual Cost	Dominant Vector	Data Theft Share	Source(s)
MITM	Communication, passwords, sessions	High (19% of online attacks)	\$2.4 billion	AI, phishing, Wi-Fi	50% of MITM incidents involve credential theft	(Wabuge, 2023)
Phishing	User data, credentials	Very high (3.4 billion phishing emails per day)	\$3.1 billion (estimated)	Email, links	41% of incidents begin with phishing	(Palatty, 2025), (SSL Insights, 2025), (APWG, 2025)
Ransomware	Systems, databases	Declined from 66% in 2023 to 59% in 2024, rising again in late 2024	\$20B (2021); \$57B (2025); avg. \$3.9M per incident	Encryption, extortion	Medium (60% involve data loss)	(Okoruwa & Chapman, 2025), (Morgan, 2025) (Threat Hunter Team, 2025)
DDoS	Service availability	Moderate, rapidly increasing (4× growth Q4 2022 vs Q4 2021)	\$1.6 billion	Botnets	Low	(StormWall, 2025), (Smith, 2025)
Supply-chain	Software chains, update systems	Rising (431% increase)	Difficult to estimate	Compromised updates	Variable	(Morgan, 2023), (Snape, 2025)
SQL Injection	Databases	Moderate	Localized damage	Automated code	Low	(Jackson, 2024), (Citakovic, 2023)

Source: Author

4 FIREWALL

The implementation of robust network security measures forms the foundation of protection against Man-in-the-Middle (MITM) attacks, with the network firewall serving as the first line of defense between the user's internal network and external threats. To assess its functional value within MITM scenarios, first, it is essential to examine attack techniques, analyze the core and advanced capabilities of modern firewall solutions,

and demonstrate the application of recommended security measures through case studies.

Firewalls based on traditional packet-level filtering—such as port, IP address, and protocol inspection—are often ineffective in detecting compromised sessions when attackers utilize permitted and encrypted communication channels. A standard Layer 3/Layer 4 (L3/L4)⁹ firewall without TLS inspection enabled can observe only metadata (IP address, port, Server

⁹ L3 and L4 refer to the network and transport layers of the OSI model, respectively, and are commonly used as the basis for traffic filtering in standard firewalls. L3

filtering typically involves IP-based rules, while L4 filtering targets protocols such as TCP and UDP. (Kaspersky, 2025)

Name Indication¹⁰), but not the validity of certificates. The client within the application or operating system performs the certificate validation. For further details, see Section 4.2.2.

A properly configured firewall is not merely a nominal security measure—it represents the critical distinction between formal protection and actual system resilience. The following configuration strategies are designed to identify and block suspicious activities commonly associated with Man-in-the-Middle (MITM) attacks.:

1. Access Control Lists (ACLs)
 - Precisely define who can access which resources, under what conditions, and through which protocols.
 - Enforce a default-deny policy, blocking all traffic that is not explicitly permitted.
2. Stateful Inspection
 - The firewall analyzes not just individual packets but the entire session context.
 - Detects unauthorized attempts to inject packets into active sessions—a hallmark of MITM behavior.
3. Layer 7 Filtering (Application Layer)
 - Enables deep inspection of protocols such as HTTP, DNS, and FTP.
 - Blocks modified requests, unauthenticated responses, and anomalous traffic patterns.
4. Spoofing and ARP Manipulation Protection
 - Prevents IP address spoofing and ARP table tampering—common vectors in MITM scenarios.
 - Includes anti-spoofing rules and ARP monitoring mechanisms.
5. Logging and Alerting
 - A well-configured firewall logs access attempts, failed connections, and suspicious patterns.

- Can trigger real-time alerts to administrators or forward events to a SIEM¹¹ system.
6. Regular Rule and Firmware Updates
 - Firewall rules must be continuously adapted to emerging threats.
 - Firmware updates ensure protection against known vulnerabilities and maintain system integrity.

4.1 Firewall Operation

Before analyzing firewall functionality, it is important to understand that a port, in the context of networking, represents a logical identifier that enables multiple applications on the same device to communicate with the network simultaneously. A port is not a physical entry point, but rather a software-defined channel that the operating system uses to route incoming data to the appropriate application. The application then utilizes system resources—such as the processor, memory, and other components—to process the received data.

The data handling process unfolds as follows:

- A network packet arrives at the network interface (e.g., Ethernet card).
- The packet is forwarded to the operating system's TCP/IP stack.
- The operating system uses the transport layer to identify the destination port and delivers the data to the application registered for that port.
-
- The application processes incoming data and, when necessary, utilizes the processor to execute tasks.

To receive data, the application must be actively running, configured for network communication, and authorized by the operating system. During this process, the firewall may either block or allow access to the designated port based on predefined security rules. Once registered to a

¹⁰ SNI (Server Name Indication) is an extension of the TLS protocol that allows the client to specify the domain name it wishes to access during the TLS handshake. This enables servers to present the appropriate certificate for the requested domain, particularly in environments hosting multiple domains on a single IP address

¹¹ SIEM (Security Information and Event Management) systems are centralized platforms for managing security-related information and events within IT environments. Their primary function is to collect, analyze, and correlate data from various sources—such as network devices, servers, applications, and user accounts—to detect threats, anomalies, and security incidents in a timely manner.

specific port, the application begins accepting incoming connections.

Several characteristic scenarios are presented in Table 3.

Table 3. Examples of Port Usage by Applications

Application	Typical Port(s)	Persistent Listening?
Web server (e.g., Apache)	80 (HTTP), 443 (HTTPS)	Yes, if running
Email server (e.g., Postfix)	25 (SMTP)	Yes, if active
Web browser (e.g., Chrome)	Dynamic ports	No — initiates outbound connections only
Torrent client	6881–6889 (historically); dynamic ports now	Da, ako je pokrenut

Source: Author

Table 4. Port Classification in TCP/IP Networking

Port Type	Range	Purpose
Dobro poznati portovi	0–1023	Standard services (HTTP, HTTPS, FTP, SSH, DNS...)
Registered ports	1024–49151	Applications not part of the OS but widely recognized
Dynamic/private ports	49152–65535	Privremeni portovi za klijentske konekcije (ephemeral)

Source: Author

TCP/IP supports a total of 65,536 ports, which are divided into three categories as shown in Table 4.

In practice, only a relatively small number of ports are actively used.

- Servers rely on well-known ports to provide services, such as 80 (HTTP), 443 (HTTPS), 21 (FTP), 22 (SSH), 25 (SMTP), and 53 (DNS), among others (see Table 4).
- Clients use dynamic ports to initiate connections. For example, when a client opens a website, its device selects a port from the range 49152–65535 to communicate with the server on port 443.

On average, fewer than 100 ports are actively used on most systems, while the remaining ports remain closed or inactive.

In the best security practices, the following measures are recommended:

- Close all unused or unknown ports to minimize the attack surface.

- Log all access attempts, including failed connections and unauthorized probes.
- Deploy an Intrusion Detection System (IDS¹²) to monitor unusual activity patterns and detect potential threats in real time.

One may ask: *what happens when a packet arrives at a non-standard port, such as 54321?*

Port 54321 falls within the IANA-defined range for dynamic and private ports and is not standardized for any well-known service (e.g., 80 for HTTP or 443 for HTTPS). In practice, such ports may be used by custom applications, experimental services, or—more critically—by malicious software, including backdoor communication channels.

Several outcomes may occur when a packet targets a non-standard port, such as 54321:

1. The port is closed (not permitted by firewall rules):
 - The firewall automatically drops the packet or responds with an ICMP¹³

¹² IDS (Intrusion Detection System) and IPS (Intrusion Prevention System) are security mechanisms designed to identify, analyze, and respond to suspicious activity within network traffic.

¹³ An ICMP message (Internet Control Message Protocol) refers to a control-level network packet used to signal communication issues between devices on an IP network.

- message (*reject*) indicating the port is unreachable.
- The packet never reaches the operating system; the firewall intercepts the attempt.
- 2. The port is open, but no application is listening:
 - The operating system may ignore the request or return an error (e.g., TCP RST).
 - If the firewall operates in passive mode, an attacker may infer that the port is open, posing a potential security risk.
- 3. The port is open, and an application is active, but unprotected:
 - An attacker may attempt to exploit vulnerabilities in the application.
 - If the firewall does not inspect content, this may lead to buffer overflows, remote code execution, or even MITM attacks if the application uses insecure authentication mechanisms.

The firewall—or its operating system-integrated component—serves as the first layer of defense. Following this, the operating system maintains an

internal table of active ports and the applications that have registered to use them. When a network packet arrives:

1. The operating system analyzes the port number specified in the packet.
2. It checks whether any application is actively listening on that port.
3. If a registered application is found, the data is forwarded accordingly.
4. If no application is listening, the packet is either discarded, or a response is sent indicating that the port is unavailable.

A properly configured firewall can respond to incoming packets in several ways:

- *Drop*: Silently discards the packet before it reaches the operating system, without sending any response.
- *Ignore*: Passively disregards the packet, offering no acknowledgment or feedback to the sender.
- *Reject*: Actively denies the packet and returns an ICMP message indicating that the port or service is unavailable.

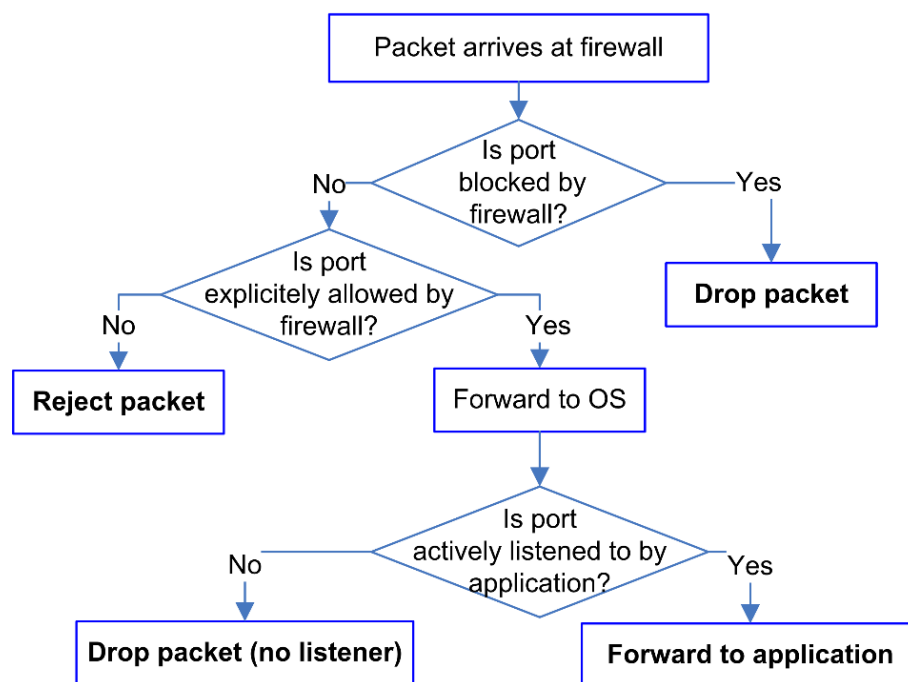


Figure 2. Packet Processing Flow

Source: Author

Practical Example

Figure 2 illustrates the decision-making algorithm for a network packet arriving at a port, e.g.,

54321—highlighting the interaction between the firewall and the operating system (OS)

Two primary scenarios are possible at the firewall level:

- If the port is open on the firewall, but no application is listening:
 - The firewall allows the packet to pass through.
 - The OS discards the packet due to the absence of a registered application on that port.
 - The OS may respond with an ICMP “port unreachable” message (for UDP) or a TCP segment with the RST flag (for TCP)
 - If the port is blocked by the firewall:
 - The packet never reaches the OS.
 - The firewall may silently drop the packet or explicitly reject it with a response.
- The outcome depends on the configuration of both layers—the firewall acts as the first gatekeeper, while the operating system serves as the second.
- The diagram visualizes the packet processing flow through the following decision-making stages:
- Firewall decisions: allow, block, or reject the packet
 - Operating system decisions: based on whether an application is actively listening on the targeted port
 - Outcome: drop, reject, or forward to the application.
- A comparative overview of TCP and UDP protocol behavior in response to incoming packets is presented in Table 5.

Table 5. Comparative Analysis: TCP vs UDP

Characteristic	TCP (Transmission Control Protocol)	UDP (User Datagram Protocol)
Protocol type	Connection-oriented	Connectionless
Reliability	High — includes acknowledgment and retransmission	Low — no acknowledgment
Flow and error control	Yes	No
When no application is listening	OS sends TCP RST (reset)	OS sends ICMP Port Unreachable
Firewall behavior (drop)	Silently discards packet without response	Same — silent discard
Firewall behavior (reject)	May send TCP RST	May send ICMP message
Typical applications	Web servers, email, SSH, FTP	DNS, VoIP, video streaming
Speed	Slower due to control mechanisms	Faster, but less reliable
MITM vulnerability	Higher if used without encryption	Higher due to a lack of control mechanisms

Source: Author

In cases where an attacker attempts to probe port availability, system behavior depends on the protocol used:

- TCP: If a connection attempt is made to port 22 (SSH) and no application is actively listening, the operating system responds with a TCP RST (reset). This may signal to the attacker that the port exists but is inactive.
- UDP: If a packet is sent to port 53 (DNS) and no application is active, the operating system may respond with an ICMP Port Unreachable message—provided the firewall allows such responses.

Such responses may have security implications. TCP RST and ICMP messages can enable an attacker to map the network using tools as *nmap*. For this reason, many systems implement a firewall drop policy—silently discarding packets without any response—to reduce the likelihood of exposing active network services.

Depending on the requirements and security policy of the administrative team, two primary strategies are available for handling port behavior when no application is actively listening: silent dropping (*drop*) and active rejection (*reject*). These options are summarized in Table 6.

Table 6. Defining iptables Rules for the Linux Firewall — Simulating TCP and UDP Behavior When No Application Is Listening

Policy	Linux Code Snippet
DROP (silent discard)	# TCP packets to port 22 (SSH) are silently dropped <code>iptables -A INPUT -p tcp --dport 22 -j DROP</code>
	# UDP packets to port 53 (DNS) are silently dropped <code>iptables -A INPUT -p udp --dport 53 -j DROP</code>
REJECT (active denial)	# TCP packets to port 22 are rejected with TCP RST <code>iptables -A INPUT -p tcp --dport 22 -j REJECT --reject-with tcp-reset</code>
	# UDP packets to port 53 are rejected with ICMP Port Unreachable <code>iptables -A INPUT -p udp --dport 53 -j REJECT --reject-with icmp-port-unreachable</code>

Source: Author

The listed commands are entered directly into `iptables`, the interface that manages the *netfilter* mechanism within the Linux kernel. Each command:

- Adds a rule to the INPUT chain (incoming traffic)
- Defines behavior for a specific port and protocol (TCP/UDP)
- Takes effect immediately and influences network traffic in real time

If the rules are not saved, they will be lost upon system reboot. The current configuration can be reviewed using the following command:

```
iptables -L -n --line-numbers
```

To ensure persistent firewall rules across system reboots, it is recommended to install the following package:

```
sudo apt install iptables-persistent
```

When using the `iptables-persistent` package, firewall rules are automatically stored in:

```
/etc/iptables/rules.v4 (for IPv4)
```

```
/etc/iptables/rules.v6 (for IPv6)
```

To enhance system security, it is recommended to set the default policy to DROP, which blocks all incoming and forwarded traffic unless explicitly allowed:

- `iptables -P INPUT DROP`
- `iptables -P FORWARD DROP`
- `iptables -P OUTPUT ACCEPT`
- (or DROP, depending on policy),

Next, rules for permitted services—such as SSH (port 22) and HTTP (port 80)—can be added:

- `iptables -A INPUT -p tcp --dport 22 -j ACCEPT`
- `iptables -A INPUT -p tcp --dport 80 -j ACCEPT`

Additionally, it is recommended to allow traffic from the loopback interface and already established connections:

- `iptables -A INPUT -i lo -j ACCEPT`
- `iptables -A INPUT -m state --state ESTABLISHED,RELATED -j ACCEPT`

When using `iptables` directly, rules are not saved automatically. To persist with the current configuration, they must be manually saved:

```
iptables-save > /etc/iptables/rules.v4  
(Debian/Ubuntu systems)
```

To manage firewall rules across system reboots, administrators may use different tools depending on the Linux distribution:

- `iptables-persistent` is commonly used in Debian and Ubuntu-based systems. It saves the current rule set and restores it automatically during startup.
- `firewalld` is the preferred solution in distributions such as Fedora, CentOS, and RHEL. It provides a dynamic firewall management interface and supports zone-based configurations.

The choice of tool depends on system architecture, administrative preferences, and compatibility with existing security policies.

4.1.1 Note on *nftables* in Modern Distributions

Although this text uses *iptables* to illustrate firewall rule definitions, modern Linux distributions—such as Fedora, Debian, and Ubuntu 22.04+—default to using *nftables* as the underlying backend. In many cases, *iptables* commands are internally translated into *nftables* rules through a compatibility layer

For example, blocking access to port 22 using *iptables* (Nickfetrat, 2024):

```
iptables -A INPUT -p tcp --dport 22 -j DROP
```

The equivalent *nftables* command would be:

```
nft add rule inet filter input tcp dport 22 drop
```

This *nftables* example uses the unified *inet* table. By leveraging the *inet* family, rules are automatically applied to both IPv4 and IPv6 protocols—eliminating the need for duplication.

To persist *nftables* rules across reboots, use:

```
nft list ruleset > /etc/nftables.conf  
sudo systemctl enable nftables
```

On systems where *iptables* is still active, both interfaces may be used in parallel. However, transitioning to *nftables* is recommended due to its improved flexibility, performance, and native IPv6 support.

Regardless of whether *iptables* or *nftables* is used, proper firewall configuration remains a cornerstone of network security. By combining local and network-level rules, administrators can precisely control application access, minimize exposure to threats, and ensure stable system operation.

4.1.2 Note on Application Behavior During Software Installation

When installing new software, applications typically request permission to access the network. The operating system checks whether a local firewall is active. If so, the user is prompted with a dialog box asking: “Allow this application to access the network?”

If the user grants permission, the operating system automatically adds the corresponding rule to the local firewall, enabling the application to utilize network resources. The local firewall (e.g., Windows Firewall or *iptables*) governs the application's access to specific ports. The network firewall (e.g., on a router or gateway) may further filter traffic to external servers.

For example, applications such as WhatsApp and Viber use dynamic ports for outbound connections (typically in the range 50000–60000), but connect to predefined servers. It is important to note that the application does not “bypass” the firewall—it uses system APIs to request network access. If the firewall denies the connection, the application will be unable to establish communication.

4.2 How Firewalls Mitigate MITM Attacks?

Man-in-the-Middle (MITM) attacks often begin by exploiting vulnerabilities at the application layer, where an attacker targets the port used by a vulnerable application. If protection is insufficient, the attacker may:

- Execute malicious code
- Gain control over the application
- Indirectly access the processor and system resources

The firewall plays a critical role in preventing such scenarios. Through well-defined access policies, inspection of application-layer protocols, and integration with threat detection systems, the firewall can identify unauthorized access attempts and block them before the system is compromised.

The following section explores the firewall as the first line of defense against MITM attacks.

4.2.1 Firewall Defense Against MITM Attacks

A properly configured firewall can play a significant role in preventing Man-in-the-Middle (MITM) attacks. Its effectiveness depends on the direction of traffic and the point of potential compromise. In the context of MITM protection, two primary categories are distinguished:

- **Inbound MITM:** This type of attack involves unauthorized attempts to access the user's network from external sources, typically through open ports or vulnerable services. A

firewall equipped with well-defined inbound traffic rules and active packet inspection can effectively block such connections.

- A firewall with support for *stateful inspection* does not merely analyze individual packets—it monitors the entire session state, including IP addresses, ports, protocols, and communication flows. This enables dynamic decision-making regarding traffic legitimacy. The firewall can block unauthorized access attempts that do not belong to established sessions, including spoofed packets and injection attempts aimed at redirecting or manipulating the communication stream.
- **Outbound MITM:** In this scenario, an application on the user's device attempts to connect to a compromised external server. A firewall with DNS filtering, reputation-based lists, and TLS inspection capabilities can identify and block suspicious IP addresses, domains, or invalid certificates—preventing the establishment of harmful communication.
- In outbound MITM protection, stateful inspection allows the firewall to track the flow of outbound sessions and detect unusual connection attempts to compromised servers. Combined with TLS inspection, reputation filtering, and DNS analysis, this functionality significantly increases the chances of timely detection and blocking of malicious traffic.

It is important to note that firewalls cannot detect compromise within encrypted sessions, as such

traffic appears to be legitimate. When HTTPS is used, an attacker must rely on forged certificates—forcing techniques such as SSL stripping or certificate spoofing. Due to these limitations, firewalls are often integrated with advanced threat detection and prevention systems (IDS/IPS), which will be discussed in the following section.

4.2.2 Firewall with IDS/IPS Gives Enhanced Protection

A firewall operates primarily as a statistical filter—focused on traffic rules and port-level control, but without visibility into packet content. However, when combined with intrusion detection and prevention systems (IDS/IPS), it becomes possible to identify anomalies within network traffic, including:

- Irregularities in the TLS handshake
- Unusual or suspicious DNS queries
- Attempts at ARP spoofing

This layered approach significantly improves the system's ability to detect and respond to Man-in-the-Middle (MITM) threats. Table 7 illustrates the relationship between firewall functionality and MITM mitigation strategies.

By combining firewalls with IDS/IPS systems, organizations achieve layered traffic analysis and proactive protection against MITM attacks. This significantly reduces the risk of compromise—even within encrypted communication channels.

Table 7. Firewall and MITM Protection Overview

Element	Role in MITM Defense
Firewall	Blocks unauthorized connections, but cannot inspect encrypted MITM traffic
IDS/IPS	Analyzes traffic and detects anomalies
TLS/SSL	Prevents MITM if certificates are properly validated
User	If certificate warnings are ignored, MITM attacks may succeed

Source: Author

5 MITM SCENARIOS

5.1 Recent Examples of MITM Attacks

The study by Čekerevac et al. (2025) presents a comprehensive overview of MITM attacks that occurred between 2007 and 2023. These cases will not be analyzed in detail here. Instead, the focus is placed on attacks that emerged in late

2023 and beyond. It is important to note that the exact percentage of MITM incidents varies depending on the source.

Arad (2024) reports that MITM attacks accounted for 23% of identity-related cyber incidents in 2024. According to the *Microsoft Digital Defense Report* (2024, p. 39), the intensity of password-based

attacks reached a rate of 7,000 attempts per second.

5.1.1 Salt Typhoon Attack on the U.S. Telecommunications Companies

In 2024, the hacker group Salt Typhoon, reportedly linked to China (Krouse, McMillan, & Volz, 2024), conducted a sophisticated MITM attack targeting major U.S. telecommunications providers, including AT&T, Verizon, Lumen Technologies, and T-Mobile (Kapko, 2025; Lyons, 2024; Israel & Young, 2025).

The attack was executed covertly, enabling unauthorized access to communication metadata—such as phone numbers, IP addresses, and timestamps (but not necessarily the content of calls or messages). This breach compromised the privacy of numerous users, including government officials and political campaign staff.

In response, the U.S. government established a dedicated incident response task force, while affected companies intensified collaboration with security agencies to strengthen infrastructure protection (Jaikaran, 2025).

5.1.2 Cozy Bear Attack on TeamViewer SE

In June 2024, German company TeamViewer SE—known for its remote monitoring and management (RMM) software used by managed service providers (MSPs) and IT departments to control servers, workstations, network devices, and endpoints—reported a breach of its corporate IT network by the Russian hacker group Cozy Bear (also known as APT29).

Access was gained through legitimate user credentials, although the method by which attackers obtained them was not disclosed. TeamViewer emphasized that its corporate IT systems are strictly segregated from the production environment of its remote access software, thereby preventing the attack from spreading to customer data. (Jones, 2024; Langley, 2024)

While the remote access product itself was not compromised, attackers accessed sensitive internal communications. The incident highlighted vulnerabilities in corporate IT infrastructure and the risks posed by advanced persistent threats

(APTs) such as Cozy Bear. (Lakshmanan, 2024; Poireault, 2023)

5.1.3 Terrapin Attack on the SSH Protocol

In December 2023, researchers from Ruhr University Bochum discovered a vulnerability in the SSH protocol known as the *Terrapin Attack* (CVE-2023-48795). This flaw enables an MITM attacker to manipulate the initial messages of an SSH session using a technique called prefix truncation, which interferes with the negotiation of security extensions and silently downgrades session protection. (Palo Alto, 2024)

The attack specifically targets algorithms such as ChaCha20-Poly1305 and CBC with Encrypt-then-MAC, allowing the attacker to disable protections against keystroke timing attacks. According to unofficial estimates, nearly 11 million publicly accessible SSH servers were exposed to this risk (Toulas, 2024; Popovici, 2024).

Mitigation requires simultaneous updates on both the client and server sides, as unilateral patching is insufficient. Developers introduced a Strict Key Exchange option, which resets sequence counters and prevents packet injection during the unencrypted portion of the handshake. Additionally, a scanning tool for vulnerable hosts was released and made available via GitHub. (Mizrahi & Zohar, 2023; Ojha, 2023)

5.1.4 Iranian Hackers and the U.S. Presidential Campaign

In August 2024, Iranian hackers affiliated with the intelligence unit of the Islamic Revolutionary Guard Corps (IRGC) launched a spear-phishing attack targeting the presidential campaign of former President Donald Trump. The attack resulted in the compromise of a senior campaign official's account, enabling MITM interception of communications and the theft of sensitive documents. These documents were later leaked to the media via an anonymous account, including a research dossier on vice-presidential candidate JD Vance (Sharma, 2024).

According to a report by Microsoft, the Iranian actors used spoofed forwarded messages containing links that redirected traffic through attacker-controlled domains, thereby gaining access to confidential data (Sharma, 2024). U.S. agencies, including the FBI, CISA, and ODNI, confirmed Iran's involvement in attempts to

compromise both major presidential campaigns—Trump's and the Biden-Harris team. (Kochi, 2024)

The incident raised concerns over foreign interference in the U.S. electoral process. In response, the campaign strengthened its cybersecurity protocols and initiated cooperation with federal authorities to investigate the breach. The attack underscored the urgent need for enhanced digital protection in political campaigns (Aijaz, 2025).

5.1.5 OpenSSH Client Vulnerability CVE-2025-26465

In February 2025, researchers from the Qualys Threat Research Unit (2025) discovered a vulnerability in the OpenSSH client—CVE-2025-26465—which enables an MITM attack when the VerifyHostKeyDNS option is enabled. Due to a coding flaw, certain return codes from the host key verification function were improperly handled, allowing an attacker to impersonate a legitimate server and compromise the integrity of the SSH session.

The vulnerability affects versions 6.8p1 through 9.9p1, and was particularly active on systems such as FreeBSD, where the VerifyHostKeyDNS option was enabled by default from September 2013 to March 2023. The attacker could exploit this flaw by exhausting the client's memory and manipulating DNS responses, causing the client to incorrectly trust a malicious host key.

OpenSSH-a developers released a patch—version 9.9p2—on the same day, addressing the issue. The fix was confirmed in the NVD database entry for CVE-2025-26465 (NIST, CVE-2025-26465 Detail, 2025). However, the incident raised broader concerns about security defaults in widely used SSH clients (Abbasi, 2025).

5.1.6 MITM Attacks via Malicious Wi-Fi Networks and DNS Spoofing

Throughout 2025, there has been a notable increase in MITM attacks within public network environments, particularly through evil twin Wi-Fi networks and DNS spoofing. Attackers deployed rogue access points that mimicked legitimate networks in cafés, hotels, and airports,

intercepting user communications and harvesting sensitive data such as passwords and credit card numbers. These attacks proved especially effective due to weak encryption protocols and the automatic reconnection of devices to known SSIDs¹⁴ (JumpCloud, 2025).

Security experts emphasized the need for user education and broader adoption of VPN solutions in public networks to mitigate these risks. DNS spoofing enables attackers to redirect traffic by injecting false DNS records, often leading users to malicious websites that appear legitimate (Rawat, 2025).

In 2024, a surge in incidents was observed where attackers positioned themselves functionally between the user and the target system—aiming to gain unauthorized access, monitor communications, modify content, or exfiltrate confidential data.

To illustrate the broader spectrum of MITM scenarios—which extend beyond simple traffic interception to include compromised software components, proxy phishing techniques, and session token abuse—the following section presents controlled simulations of such attacks.

5.2 Use of ICMP Protocol in MITM Attack Initialization

The Internet Control Message Protocol (ICMP) is a fundamental component of network communication, primarily designed for error signaling and diagnostics (Postel, 1981). Although not inherently malicious, ICMP can be weaponized during the preparatory phase of Man-in-the-Middle (MITM) attacks—especially when combined with techniques such as ARP spoofing and routing manipulation (MITRE ATT&CK, Adversary-in-the-Middle [T1557], n.d.-a).

In MITM scenarios, ICMP messages are used to trigger legitimate network reactions that allow the attacker to position themselves between two communicating parties. For example, by sending an ICMP Echo Request to a target device, the attacker may provoke an ARP request, creating an opportunity to inject a forged ARP reply and

¹⁴ The SSID (Service Set Identifier) is a sequence of up to 32 alphanumeric characters that uniquely identifies a specific Wi-Fi network (Nicole, 2025). It functions as the

network's name, allowing devices to distinguish between multiple wireless access points within range.

redirect traffic. This technique enables the attacker to silently intercept, modify, or forward packets without raising suspicion among end users (SANS Institute, 2020).

Additionally, ICMP Redirect messages—if not blocked at the firewall level—can be exploited to manipulate routing paths, redirecting traffic to compromised nodes. While modern operating systems and network devices often ignore ICMP Redirects by default, their presence in poorly secured or misconfigured networks poses a significant security risk (MITRE ATT&CK, n.d.-b).

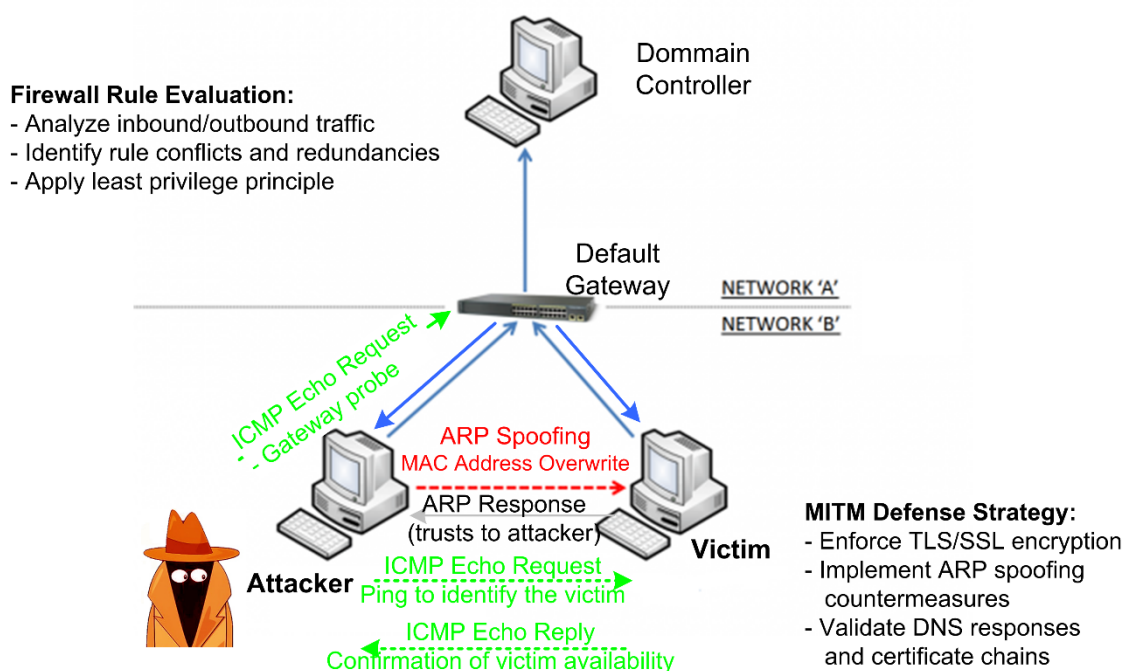
The misuse of ICMP in MITM preparation highlights the need for precise firewall rules that govern not only TCP and UDP traffic, but also ICMP messages—particularly those capable of triggering unintended network behavior. In this context, it is recommended to explicitly filter ICMP Redirect messages and monitor anomalous ICMP patterns that may indicate an attempt to establish a MITM position.

The diagram in Figure 3 illustrates the following stages:

- **Phase 1 – ICMP Echo Request/Reply:** Represented by arrows between the attacker and the victim, this phase initiates network activity.

- **Phase 2 – ARP Exchange:** ICMP communication triggers an ARP request from the victim, creating an opportunity for manipulation.
- **Phase 3 – Spoofed ARP Reply:** The attacker sends a forged ARP response, positioning themselves between the victim and the gateway.
- **Phase 4 – MITM Positioning:** Bidirectional arrows indicate interception and forwarding of packets.
- **Phase 5 – ICMP Redirect:** Shown as an additional arrow toward a compromised node, this phase reflects route manipulation. By sending an ICMP Redirect message, the attacker can permanently reroute traffic from the compromised host, establishing a stable MITM position without relying further on ARP spoofing.

These stages collectively illustrate how ICMP and ARP protocols can be sequentially exploited to establish a MITM position. The diagram highlights the attacker's strategic use of legitimate network mechanisms to silently intercept and manipulate traffic, underscoring the critical importance of protocol-level visibility and precision in defensive configurations.



MITM Initialization Diagram Based on ICMP and ARP Spoofing

Source: Author based on (CoreLabs Team, 2020)

This visualization clarifies the technical logic of the attack and highlights key intervention points—particularly through firewall rules, ARP monitoring, and ICMP filtering.

5.3 Simulation of a DNS Spoofing Attack on Viber

MITM attacks via DNS spoofing pose a serious threat to applications that rely on unencrypted DNS queries and insufficient TLS certificate validation. The following scenario illustrates how an attacker can compromise communication between a user and Viber servers under real-world conditions.

5.3.1 Environment

Consider a user accessing Viber on a laptop or smartphone while sited in a café and connected to public Wi-Fi. The network appears legitimate but is deployed by an attacker using a tool such as *Wi-Fi Pineapple* to create a rogue access point. With utilities like *Ettercap* or *dnsspoof*, the attacker redirects DNS queries to a malicious DNS server that returns forged responses.

5.3.2 Attack Flow

1. The attacker sets up a rogue Wi-Fi access point using a familiar SSID (e.g., “Café_Free_WiFi”), creating the illusion of legitimacy.
2. The user’s device automatically connects, unaware that the network is under attacker control.
3. All DNS requests sent by the user (e.g., for `api.viber.com`) are intercepted and replaced with spoofed IP addresses pointing to the attacker’s server.
4. The Viber application attempts to establish a TLS connection with the server but unknowingly communicates with the attacker.
5. The attacker presents a forged TLS certificate mimicking the legitimate Viber server.
6. If the application fails to properly validate the certificate, the connection is established, and the MITM attack succeeds.

7. If Viber detects an invalid certificate, the connection is terminated, and the user receives a warning, which may be ignored.

5.3.3 The Role of the Firewall in This Scenario

A firewall can play a significant role in mitigating this type of attack, but its effectiveness depends on the level of configuration and the presence of additional security layers.

A firewall can help if:

- It implements DNS filtering (e.g., via Pi-hole or DNS-over-HTTPS¹⁵), preventing interception and manipulation of DNS responses.
- It blocks unknown IP addresses and unauthenticated TLS handshakes¹⁶ using advanced inspection mechanisms.
- It operates in conjunction with IDS/IPS systems that detect anomalies in DNS traffic and attempt to spoof certificates.

Firewall cannot help if:

- It allows unrestricted outbound traffic, enabling connections to malicious destinations.
- DNS queries are sent unencrypted (standard UDP port 53), making them easy to intercept.
- It lacks TLS inspection—in which case the firewall only sees that the connection is “allowed,” without visibility into certificate content.

Table 8 summarizes the firewall’s protective capabilities against MITM attacks in the context of a DNS spoofing scenario targeting the Viber application.

TLS validation represents the critical point of protection—without it, all other layers (firewall, DNS filtering, IDS/IPS) can be bypassed. If the application fails to verify the certificate, or if the user ignores a warning about an invalid certificate, the attacker can successfully impersonate the server and gain full control over the communication.

¹⁵ The DNS over HTTPS protocol (commonly abbreviated as DoH) is formally defined in RFC 8484 (Hoffman & McManus, 2018)

¹⁶ During the TLS handshake, cryptographic parameters are negotiated, certificates are exchanged, and a secure channel is established between the client and server.

Table 8. Protection Against MITM Attacks Targeting the Viber Application

Element	Protects Against MITM?	Note
Firewall	Partially	Requires DNS filtering and TLS inspection
DNS over HTTPS	Yes	Prevents interception of DNS queries
TLS Validation	Critically important	If the application ignores certificate errors, MITM attack succeeds
User	Not effective if warnings are ignored	Human factors are often the weakest link

Source: Author

5.4 Hypothetical MITM Scenario Involving WhatsApp

1. The user connects to a public Wi-Fi network.
2. The attacker deploys a rogue access point using a Wi-Fi Pineapple device.
3. WhatsApp attempts to establish a connection with its server.
4. The attacker intercepts the traffic and attempts to inject a forged TLS certificate.
5. A standard Layer 3/Layer 4 firewall can read the Server Name Indication (SNI) during the TLS handshake, but without TLS inspection, it cannot verify the certificate chain—allowing

the forged certificate to pass undetected. Many applications, especially end-to-end encrypted services like WhatsApp, implement certificate pinning, which prevents TLS interception and limits firewall-level inspection capabilities.

6. WhatsApp detects the invalid certificate and terminates the connection.

Although the attack scenarios for Viber and WhatsApp are similar in intent, there are significant differences in their defensive architecture. Key distinctions are summarized in Table 9.

Table 9. Comparison of MITM Resistance in Viber and WhatsApp Applications

Aspect	Viber	WhatsApp
TLS Version	TLS 1.2/1.3 with inconsistent validation	TLS 1.3 with PSK for session resumption
Certificate Validation	Allows error bypassing in some versions	Strictly terminates connection on untrusted certificates
SNI Validation	SNI - not validated in certain versions	SNI checked before encryption
Resistance to Fake Certificates	Lower — accepts generic certificates	High — verifies CN/SAN and issuing authority
Updates and Patching	No publicly documented MITM-related CVEs	Rapid vulnerability fixes, e.g., CVE-2021-24027 (NIST, CVE-2021-24027 Detail, 2024)

Note: This table is based on publicly available statements and reports as of August 2025. For the most recent information, consult official security advisories.

Source: Author

5.5 Simulation of a Potential MITM Attack on Port 443

If a firewall allows unrestricted inbound traffic on port 443 without additional inspection, an MITM

attacker may exploit this configuration using TLS stripping¹⁷ to intercept and manipulate communication. In this scenario:

- The user attempts to access an HTTPS website (e.g., <https://example.com>)

¹⁷ TLS stripping is an advanced MITM technique that prevents the automatic upgrade from HTTP to HTTPS,

thereby keeping the user in an unencrypted communication mode.

- The attacker intercepts the request and responds with an HTTP version of the site (<http://example.com>)
- The user unknowingly communicates over an unencrypted HTTP connection
- The attacker maintains a separate HTTPS session with the legitimate server and relays data, acting as a transparent intermediary
- Block unencrypted requests directed at encrypted destinations (e.g., via HSTS policy enforcement¹⁸)
- Alert administrators to TLS session manipulation attempts.

The diagram in Figure 4 illustrates the flow of a TLS stripping attack within an MITM scenario on port 443, highlighting the attacker's ability to downgrade secure connections and intercept sensitive data.

A properly configured firewall would:

- Detect unauthenticated certificates and downgrade attempts

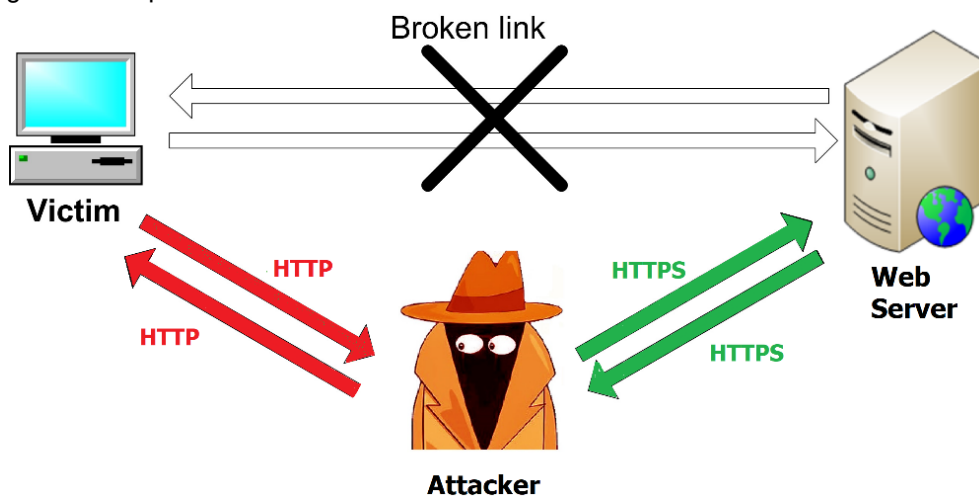


Figure 4. TLS Stripping Attack Flow in an MITM Scenario over Port 443

Source: Author

The attack unfolds as follows:

1. Victim attempts to access a website
 - The user types `example.com` - into the browser without specifying `https://`.
 - The browser sends an initial request over HTTP (port 80), as no HSTS policy is cached.
2. - Attacker intercepts the HTTP request
 - Positioned in an MITM role (e.g., via a rogue Wi-Fi access point), the attacker captures the request.
 - Instead of allowing the browser to upgrade to HTTPS, the attacker keeps the communication on HTTP.
3. - Attacker establishes an HTTPS session with the server
 - The attacker connects to `example.com` via HTTPS (port 443).
4. Attacker decrypts and converts the response to HTTP
 - The server responds with encrypted content, such as a login form.
 - The attacker presents the user with an unencrypted version of the site — visually identical, but insecure.
 - The user sees the form and enters credentials, unaware that the page is served over HTTP.
5. - Victim submits data via HTTP-a
 - Login credentials are transmitted in plaintext to the attacker.
 - The attacker forwards them to the server over HTTPS — the server remains unaware that the user was deceived.

The victim made two critical errors: connecting to a malicious hotspot and failing to enter the full

¹⁸ HTTP Strict Transport Security (HSTS) is a web server security policy that protects users from downgrade attacks and traffic interception (MITM). It

enforces the use of HTTPS by instructing browsers to communicate exclusively over encrypted channels when interacting with a specified domain.

https:// prefix. Had the initial request been explicitly HTTPS, the browser would have established a secure session directly with the server. The attacker would not have been able to view or modify the content, as the traffic would have been encrypted from the outset. TLS stripping would have been ineffective unless the attacker possessed a valid certificate, which is extremely difficult without compromising a certificate authority (CA).

Recommended countermeasures are:

- Always enter the full URL with https://
- Use a VPN when connected to public networks
- Prefer websites that implement HSTS policies and maintain valid TLS certificates
- Enable HSTS and browser-level HTTPS-Only Mode.

6 CONCLUSION: FIREWALL AND PROTECTION AGAINST MITM ATTACKS

Based on the analysis conducted, it can be concluded that a firewall can be effectively utilized in defending against MITM attacks—providing a positive answer to the first research question (RQ1).

Furthermore, the analysis addresses the second research question (RQ2): In MITM scenarios such as DNS spoofing, firewall protection can play a significant role in safeguarding users—provided it is properly configured and integrated into a broader security strategy.

This leads to the following conclusions:

- *The firewall is not self-sufficient:* Basic access rules and port filtering alone are insufficient to prevent sophisticated MITM attacks.
- *DNS filtering and DoH:* These mechanisms prevent interception and manipulation of DNS queries, eliminating one of the most common MITM vectors.
- *TLS validation is critical:* Applications must rigorously verify server certificates—without this, an attack may succeed even with firewall protection in place.
- *Advanced firewall features* (e.g., IDS/IPS, TLS inspection, network segmentation) enable anomaly detection and the blocking of suspicious traffic.
- *The human factor remains a persistent vulnerability:* Ignoring certificate warnings or connecting to unknown networks can undermine technical safeguards.
- The firewall can be an effective tool against MITM attacks, but only as part of a multi-layered security architecture that includes:
 - Encrypted DNS queries
 - TLS certificate validation
 - Anomaly detection
 - User education

In the context of applications employing end-to-end encryption—such as Viber—the firewall can help prevent access to rogue servers, but it cannot replace the internal security mechanisms of the application itself.

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THE FUNCTIONAL AND INVESTMENT ROLE OF ARTIFICIAL INTELLIGENCE IN THE FINANCIAL SECTOR

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ABSTRACT

The study aims to shed light on the applications and impact of artificial intelligence in the field of financial operations (my usage – investment), by examining the effect of this variable on the current financial industry and its role in enhancing the value of technology companies that choose to invest in it. To achieve the study's objectives, the Autoregressive Distributed Lag (ARDL) model was used over the period from March 2019 to June 2025 on key indicative metrics. The study concluded that there is a weak transitional effect in the extension of the equilibrium relationship from the short term to the long term between the use and development of artificial intelligence, represented by the STOXX Global AI Innovators index, and the AltFi Fintech financial index. It was also found that investment in artificial intelligence technologies (through the STOXX Global AI Innovators index) significantly influences the increase in market value of technology companies listed on the Nasdaq Composite index, regardless of the investment horizon. The study, therefore, recommends periodic evaluations of the effects and integration of AI in both micro and macro finance.

enhancing operational and employment capacities through technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) in the modern financial industry. As a result, the financial application and utilization of AI in this field have taken successive strides in their current direction, aiming to create value stemming particularly from smart innovations. Based on the above, the following research question (RQ) can be posed:

1 INTRODUCTION

The financial sector is one of the fields that has witnessed numerous rapid and significant developments in recent decades. Within this context, innovation has played a fundamental role in driving these changes, contributing to the provision of a diverse range of emerging financial products and technologies. These include

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RQ: To what extent can the use and investment in artificial intelligence affect the financial sector?

1.1 Studying Importance and Objectives

The current phase is witnessing modern trends toward the application of artificial intelligence in the financial sector, where the integration and adaptation of the financial industry with what is known as the Fourth Industrial Revolution has opened wide horizons for specialists to explore approaches to using AI technologies in the field of finance and business. This highlights the significance of the profound transformations that have affected the financial industry. Therefore, the research aims to address various aspects related to the development of AI applications and their impact on current financial transactions.

1.2 Study Methodology

This topic was addressed using the descriptive analytical method to review and analyze the most significant developments in the investments and applications of artificial intelligence in the financial sector. Additionally, an empirical study was conducted using several indicators that support this theme, aiming to highlight the impact of AI applications and investment in their technologies within the financial field.

1.3 Study Hypotheses

To address the research question of this study, the following hypotheses (H) were formulated:

- H₁:** There is a transitional impact of the use of artificial intelligence in the financial sector, from the short to the long term.
- H₂:** Investment in artificial intelligence technologies has an impact on increasing the market value of major technology companies, regardless of the investment horizon.

2 THE USE OF ARTIFICIAL INTELLIGENCE IN FINANCE

Artificial intelligence-based technologies offer numerous opportunities for the financial sector, witnessing unprecedented growth in recent years within the contemporary financial industry, extending into both traditional and modern financial channels.

2.1 The Concept of AI

Artificial intelligence is the simulation of human intelligence and an attempt to understand its nature through the functioning of computer programs (Majed, 2018). It is the ability to replicate human behavior, thought processes, and working patterns, such as learning, thinking, and exploration (*Artificial Intelligence*, 2021). The use of artificial neural networks allows data analysis, trend and pattern recognition, and the extraction of fundamental rules (Al-Suhayti, 2024). In other words, it embodies the machine's ability to simulate the human mind in how it operates, thinks, discovers, and learns from past experiences (Osoba & Welser IV, 2017).

2.2 The Fourth Industrial Revolution and AI

The Fourth Industrial Revolution was built upon the foundations and principles of the Third Industrial Revolution, particularly through the advancement of emerging technologies. It is characterized by the integration of physical, biological, and digital technologies, alongside the use of artificial intelligence and the application of nanotechnology (Bourana & Benechick, 2022). In other words, it refers to systems of electronically controlled machines (smart machines connected to the Internet) and is often described using terms such as the Digital Industrial Revolution, the Artificial Intelligence Revolution, and the Internet of Things Revolution (Baadi, 2022).

- **The Fourth Industrial Revolution (early 21st century):** It has relied on the outcomes of internet applications, the development of remote sensing devices, 3D printing, smart robotics, emerging digital technologies, autonomous vehicles, nanotechnology, biotechnology, materials science, energy storage, quantum computing, and creative computers (*The Future of Knowledge: A Foresight Report 2019*, 2019).
- **The shift of major economies toward the Made in strategy:** The Fourth Industrial Revolution has led many major economies to develop long-term strategies to achieve their intended goals (i.e., the Fourth Technological Revolution). As a result, the Made in strategy for the said countries has gained significant importance. For example, in 2015, during its

12th Five-Year Plan, China launched the Made in China 2025 strategy ("Made in China 2025," 2018). This plan is like Germany's Industry 4.0 strategy adopted in 2012, Japan's plan from 2015, and France's Industry of the Future initiative launched in 2015 (Goulard, 2017), all of which aim to take the lead in innovation. In recent decades, the goal of dominant and emerging economies to control global wealth has increasingly relied on expanding their investments in smart technologies (Arora & Vamvakidis, 2010).

2.3 The International Investment in AI

Global investments in the field of artificial intelligence have achieved numerous promising indicators. According to the International Data Corporation (IDC), global spending on AI alone reached \$19.1 billion by the end of 2018, an increase of 54.2% compared to 2017, and rose to \$52.2 billion in 2021, recording a compound annual growth rate (CAGR) of 46.2%. Currently, the retail sector is the highest spender on AI, followed by the financial sector (Studies and Research Department, 2021).

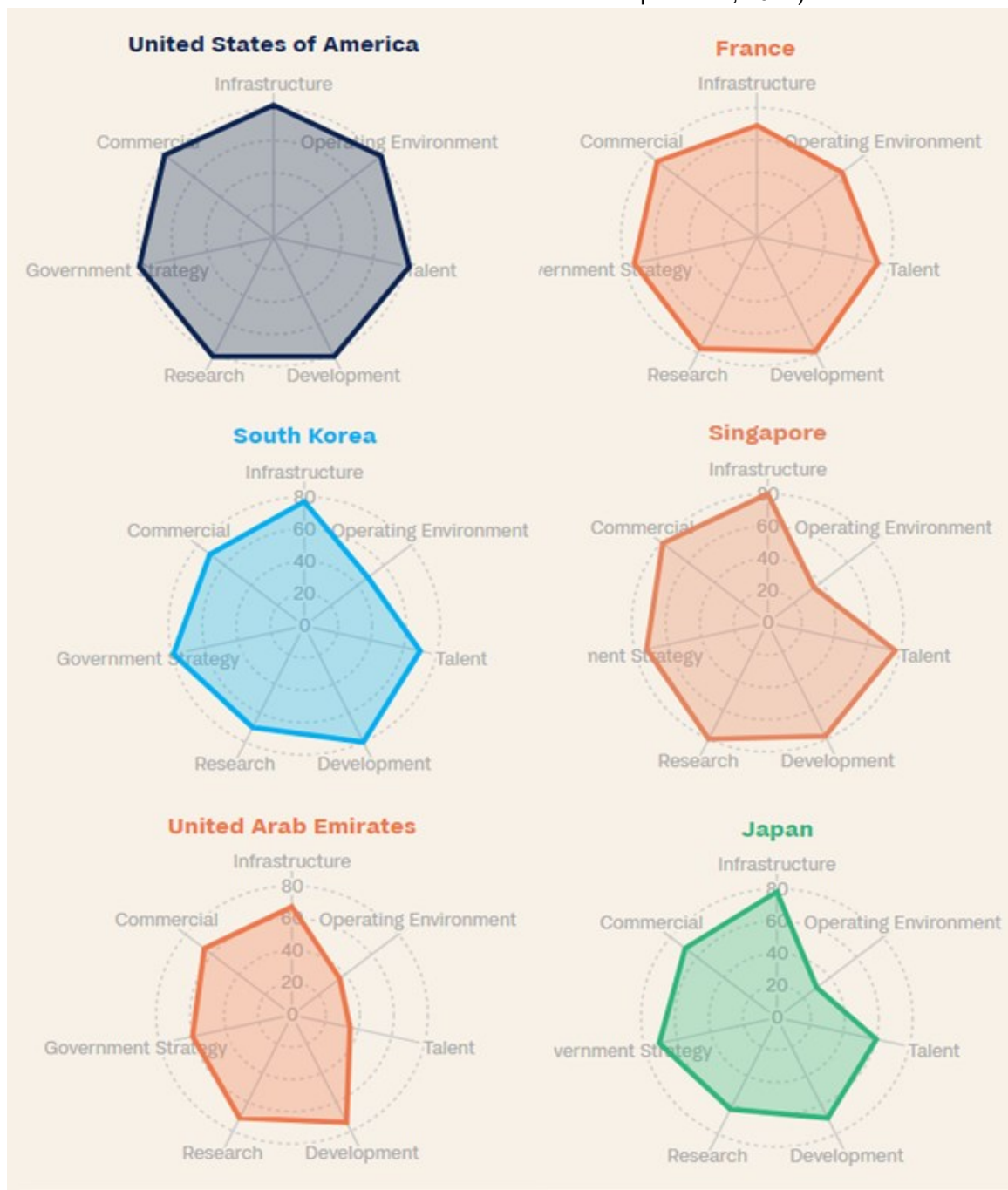


Figure 1a. Global Index on Responsible AI: 2024 scores

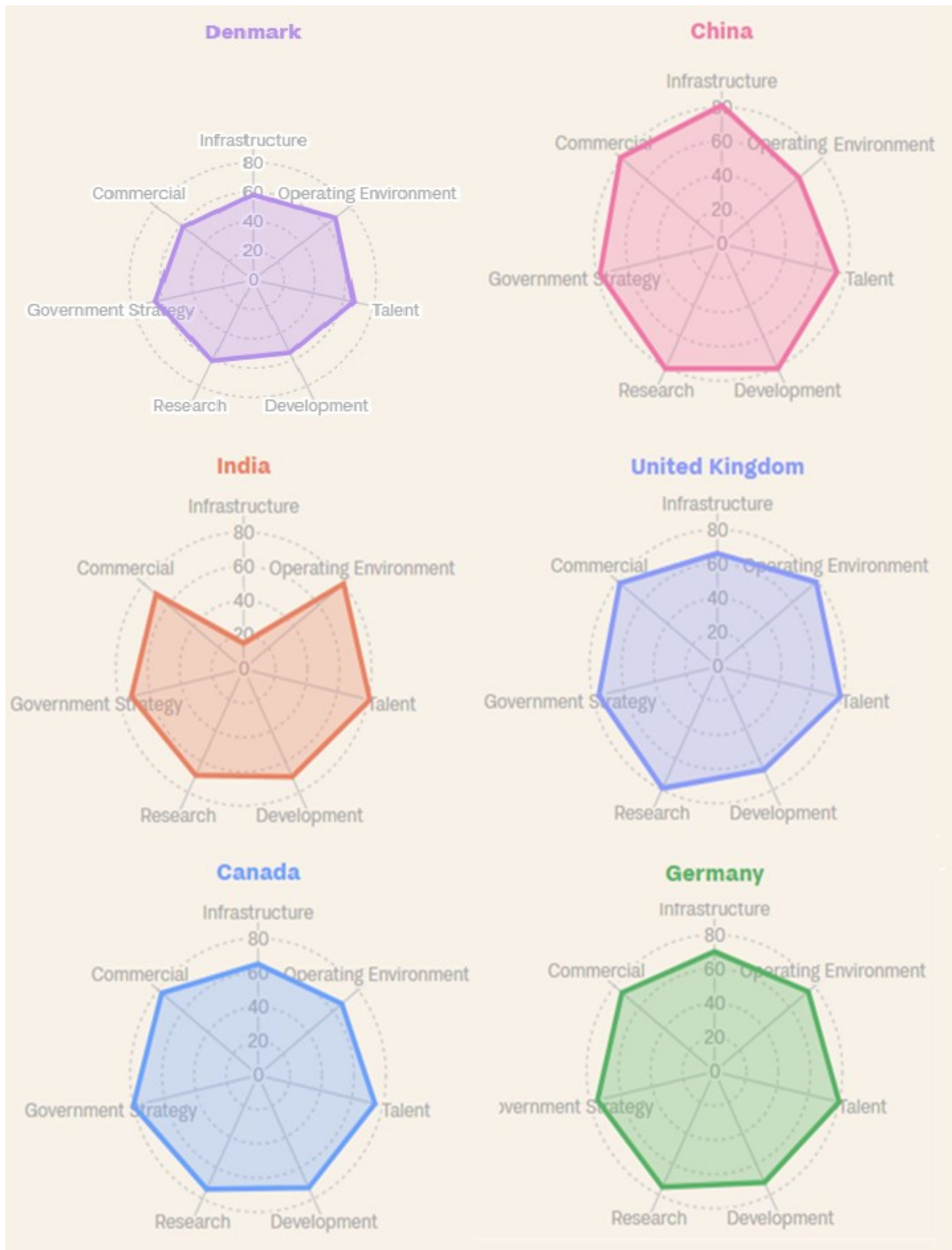


Figure 1b. Global Index on Responsible AI: 2024 scores

Source: (The Global AI Index, n.d.).

In 2024, private investment in AI in the United States rose to \$109.1 billion, nearly 12 times that of China (\$9.3 billion), and 24 times that of the United Kingdom (\$4.5 billion). Notably, generative

AI witnessed particularly strong momentum, attracting \$33.9 billion in private global investments, an 18.7% increase compared to 2023. AI adoption in the business sector is also

accelerating, with 78% of companies using AI in 2024, marking a 55% increase from the previous year. The chart (Figures 1a and 1b) highlights the leading countries focusing on investment in this field (Human-Centered Artificial Intelligence (HAI), 2025).

The Global AI Index for 2024 presents the level of advancement among leading economies that are actively engaged in AI applications, based on the following criteria: infrastructure, trade, government strategy, research, growth, talent, and operating environment. According to the index, the United States, China, Germany, France, Canada, and the United Kingdom ranked highest across these indicators. However, as technological progress, particularly in artificial intelligence (AI) continues to reshape societies, its impact on economic activities, markets, and social structures has begun to create significant challenges for policymakers, especially amid rising international investment in this field (Saba & Pretorius, 2024).

2.4 AI Applications in the Financial Sector

The use of artificial intelligence technologies is generally beneficial for companies. On one hand, AI as a potentially general-purpose technology can stimulate the growth of firms and institutions by fostering process innovation or product innovation, which are two complementary channels. Through cost reduction, innovation, expansion, and product diversification, AI becomes a vital mechanism for the economic, commercial, and financial growth of companies and institutions, Babina et al. (2023).

On the other hand, the specific applications of AI in the financial sector are numerous and include fintech and blockchain technologies, market operations, pricing decisions, and hedging, smart customer interaction and demand forecasting, fraud and scam detection, risk assessment and pricing of insurance contracts through complex algorithms that leverage real-time data and developments, investment management, back testing and simulation of financial instruments before their market release (Studies and Research Department, 2021).

In this regard, an important concern arises around the evaluation of AI methods used by asset

management firms, which require reliable forecasting tools for making investment decisions. Financial authorities and supervisory bodies also share this concern and researchers, who need to understand how markets function by incorporating these emerging methods (Giudici & Raffinetti, 2023).

2.5 FINTECH AND AI

Fintech can enhance the financial services industry in many ways, more broadly, fintech is likely to have a greater systemic impact through key transformational mechanisms, such as the disintermediation of incumbents, disaggregation of financial services and decentralization of networks (*Fintech and Financial Stability*, 2017). As a result, artificial intelligence and financial technology (FinTech) are seen as powerful forces capable of transforming the structure of future financial services, given that FinTech blends innovation with emerging technologies and integrates AI into financial activities (Saad Guermech, 2025). AI enables lower operational costs, improves the performance of financial institutions, and enhances their profitability. This is why many institutions are pursuing this new direction. According to PwC, AI is expected to contribute around \$15.7 trillion to the global economy by 2030, including \$6.6 trillion from increased productivity and \$9.1 trillion from higher consumption driven by improved product quality worldwide an amount equivalent to ten times the value of global oil sales (Majed, 2018).

3 AN ECONOMETRIC STUDY ON: STOXX G. AI. I, ALTFI, AND NASDAQ

The econometric study examines the impact of artificial intelligence usage on both employment-related and investment-related aspects within the financial sector. This is done by analyzing the financial values of the following indices: STOXX Global AI Innovators, AltFi Fintech, and Nasdaq Composite, over the period (03/2019–06/2025), with values assessed in U.S. dollars.

These indices were selected as they serve as indicators for various variables that align with the objectives of the study. the table1 represents the selected financial indicators used in the study.

Table 1. Definition of study indicators

The indicator	The definition
STOXX Global AI Innovators (European)	The index monitors the performance of a group of companies considered major contributors to the development of artificial intelligence. It includes around 200 companies from a wide range of sectors that heavily invest in AI technologies, including Apple, Deutsche Telekom, Bank of America, and Facebook. The new STOXX AI Index selects its components using AI technology, making it the first objective index to do so. STOXX collaborated with Yewno, an award-winning AI company, in its creation. The index's composition is based on the STOXX Global Index and the Developed Markets Index, which together track around 7,000 stocks (Deutsche Boerse Group, 2025).
AltFi Fintech (German)	The index is rule-based and tracks the market performance of a selected group of global companies listed on international stock exchanges. These companies benefit from disruptive innovations in financial products and services and utilize emerging technologies that affect the strategies and structure of traditional financial sector markets. The index components are weighted using a modified free-float market capitalization algorithm (BITA, 2023).
Nasdaq Composite (American)	The Nasdaq Composite Index is a composite index that includes over 3,000 listed companies and is considered one of the most closely followed indices worldwide. It comprises both U.S. and non-U.S. companies, with some of the largest listed firms being Apple, Amazon, Microsoft, and others. Each stock's weight in the index is calculated based on its market capitalization, and the index is commonly used as a benchmark for the performance of technology company stocks (Aoun Allah, 2025).

Source: Prepared by the author.

3.1 Study Tools and Tests

The Autoregressive Distributed Lag (ARDL) model was applied to the financial values of the variables during the study section, to determine the nature of the relationship between them, allowing for achieving the desired results using the 10Eviews program.

3.2 Autoregressive distributed lag model (ARDL)

By relying on the frontier approach to joint integration, which is based on the autoregressive distributed lag (ARDL) model developed by Pesaran et al (2001), and based on the study variables, the logarithmic model can be formulated according to the following relationship:

$$\begin{aligned}
 \ln(S) &= \beta_0 + \beta_1 \ln(N) + \beta_2 \ln(T) + \varepsilon_t \\
 \Delta(\ln S)_t &= \beta_0 + \beta_1 (\ln S)_{t-1} + \beta_2 (\ln N)_{t-1} + \beta_3 (\ln F)_{t-1} + \sum_{t=1}^p \beta_1 \Delta(\ln S)_{t-1} + \sum_{t=1}^p \beta_2 \Delta(\ln N)_{t-1} \\
 &\quad + \sum_{t=1}^p \beta_3 \Delta(\ln F)_{t-1} + \Psi(ECT)_{t-1} + \varepsilon_t
 \end{aligned}$$

Where:

Δ : the first difference,

ε_t : Random error term

s : Monthly returns of the STOXX Global Artificial Intelligence Innovators Index

N : Monthly returns of the Nasdaq Composite Index

F : Monthly returns of the AltFi Fintech Index

$(ECT)_{t-1}$: Error correction term

This formulation is used to verify the existence of cointegration or a long-term relationship between the study variables, Breshi et al. (2020).

3.3 Study of Stability

The financial values are considered during the study period, as shown in the following figures, to test their stability:

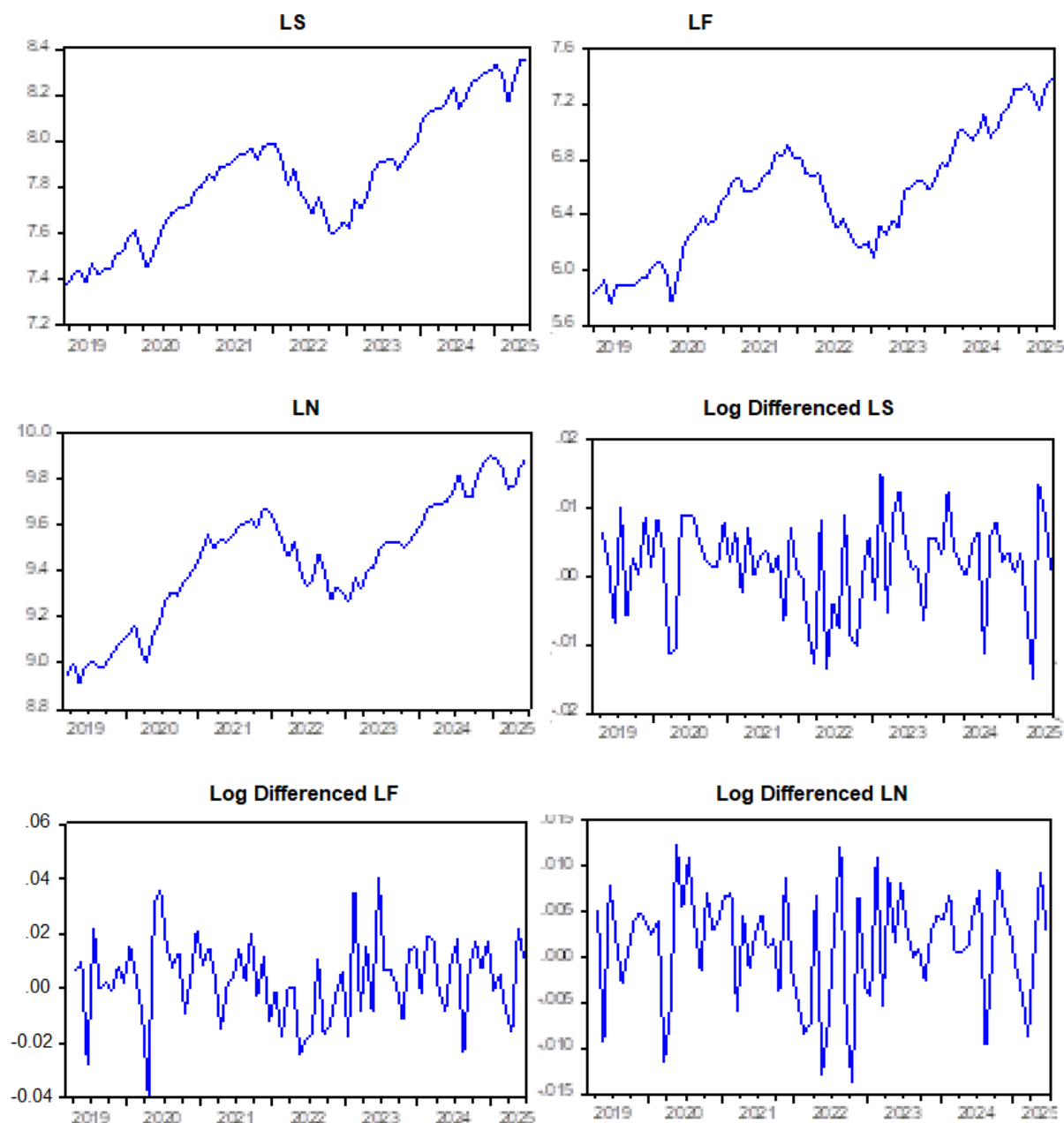


Figure 2. Financial values of the study variables during the period: (03/2019-06/2025)

Source: Prepared by the author based on the outputs of EViews 10.

Figure 2 shows a pattern of significant ups and downs in the financial returns of the indices during the study period. Notably, sharp declines occurred in 2020 across all variables, which can be attributed to the health crisis period marked by strict lockdown measures that affected nearly all sectors, especially industry, and had a notable impact on global stock markets overall. Despite the gains made by major technology companies during that time, investment uncertainty dominated pricing movements in most sectors (except for investments in the healthcare sector).

The Nasdaq Index also recorded significant losses in 2022, driven by concerns over inflation and rising interest rates. Similarly, the years 2024 and 2025 saw sharp declines as well, following disappointing earnings reports from some major tech companies. As shown in Figure 2, the Artificial Intelligence Index (S) and the Fintech Index (F) followed similar waves, though with less intensity, given that these indices are influenced by the financial and investment activity of major technology firms.

3.4 Stability Test

To test the stability of the financial value series, the Augmented Dickey-Fuller (ADF) test will be applied. The ADF formulation involves adding lagged differences s_{t-j+1} to address the problem of autocorrelation among values (Meziene, 2019). Additionally, the Phillips-Perron (PP) test will be

used due to its higher accuracy. Phillips and Perron developed a generalization of the Dickey-Fuller method that accounts for conditional heteroskedasticity in the error terms, which the ADF test does not address (Delmi & Zeghoudi, 2021). After conducting the tests on the study variables, the results were obtained as shown in Table 2.

Table 2. Unit root test results

Variables	Unit root test results at the level and first-order differences (D)					
	A Dickey-Fuller					
	constant only		constant and trend		Without constant and trend	
	t-Statistic	Prob	t-Statistic	Prob	t-Statistic	Prob
LS	-0.698839	0.8402	-1.68674	0.7476	2.06791	0.9904
D- LS	-8.908109	0	-8.85570	0	-8.49794	0
LF	-0.613274	0.8606	-1.57218	0.7947	1.81739	0.9827
D- LF	-8.806685	0	-8.76038	0	-8.47581	0
LN	-1.138966	0.6963	-1.84653	0.672	1.84655	0.9838
D- LN	-8.544264	0	-8.48359	0	-8.24785	0
Variables	Phillips-Perron					
	constant only		constant and trend		Without constant and trend	
	t-Statistic	Prob	t-Statistic	Prob	t-Statistic	Prob
	t-Statistic	Prob	t-Statistic	Prob	t-Statistic	Prob
LS	-0.698839	0.8402	-1.70082	0.7413	2.067913	0.9904
D- LS	-8.908109	0	-8.8557	0	-8.50017	0
LF	-0.594123	0.8649	-1.56977	0.7956	1.849997	0.984
D- LF	-8.806658	0	-8.7604	0	-8.47558	0
LN	-1.106621	0.7094	-1.84653	0.672	1.99092	0.9884
D- LN	-8.559311	0	-8.4947	0	-8.24785	0

Source: Prepared by the author based on the outputs of EViews 10.

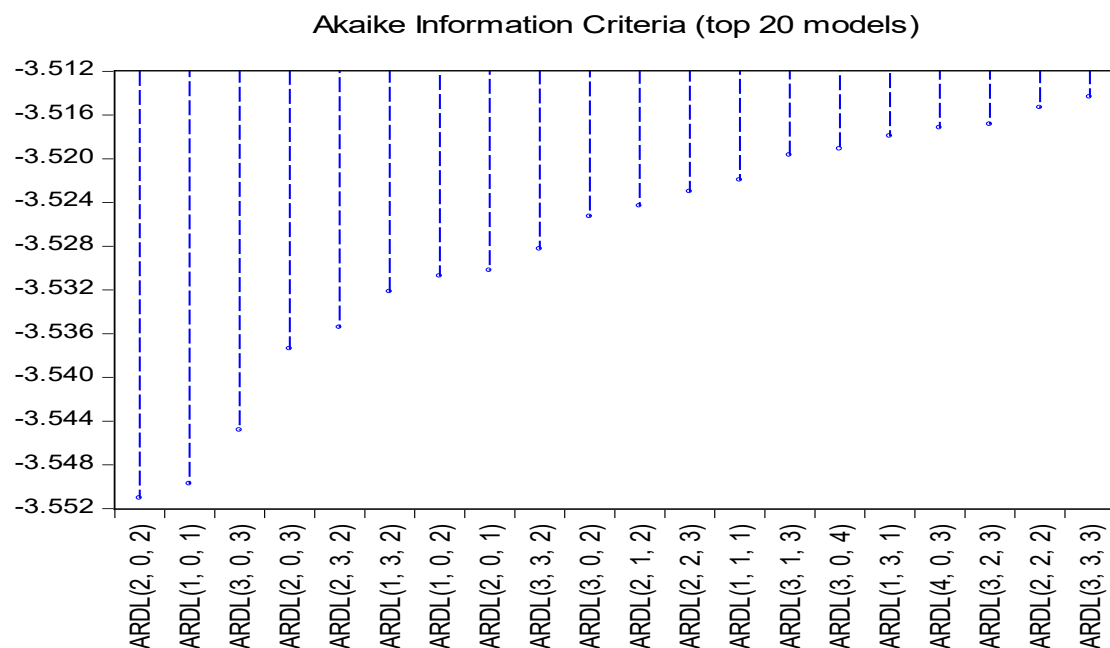


Figure 3. Optimal lag length of the model according to the Akaike Information Criterion (AIC)

Source: Prepared by the author based on the outputs of EViews 10.

Based on the test results (Table 2), it was found that the value series were not stationary at the level. Therefore, first-order differencing was applied in both the ADF and PP tests for the study variables. The results confirmed that all variables became stationary at first difference in the case of a constant, a constant and a trend, and without a constant or trend. The p-values presented in the table show the outcomes of the tests performed.

3.5 The Optimal Lag Length

To determine the optimal lag length for the studied variables, the Akaike Information Criterion (AIC) was used, as illustrated in Figure 3.

The optimal lag lengths for the ARDL model were determined according to the Akaike Information Criterion (AIC) as (2, 0, 2).

3.6 Testing the Goodness of Fit of the ARDL Model

To determine the suitability of the ARDL model, a model compatibility test was conducted with the study sample, and the results were: the R-squared value was 0.979416, and the F-statistic was 531.3304, with a p-value less than 0.00001, indicating a high level of statistical significance. These results confirm that the model is suitable for further analysis, as shown in Table 3.

Table 3: ARDL model

Dependent Variable: LS				
Method: ARDL				
Date: 11/22/25 Time: 12:08				
Sample (adjusted): 2019M05 2025M06				
Included observations: 74 after adjustments				
Maximum dependent lags: 4 (Automatic selection)				
Model selection method: Akaike info criterion (AIC)				
Dynamic regressors (4 lags, automatic): LF LN				
Fixed regressors: C				
Number of models evaluated: 100				
Selected Model: ARDL(2, 0, 2)				
* Note: final equation sample is larger than selection sample				
Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LS(-1)	0.553182	0.126862	4.360500	0.0000
LS(-2)	0.215113	0.125895	1.708661	0.0921
LF	0.095352	0.068697	1.388010	0.1697
LN	0.578458	0.104400	5.540781	0.0000
LN(-1)	-0.272676	0.129968	-2.098020	0.0397
LN(-2)	-0.228875	0.113650	-2.013861	0.0480
C	0.471919	0.554905	0.850449	0.3981
R-squared	0.979416	Mean dependent var		7.857453
Adjusted R-squared	0.977573	S.D. dependent var		0.266353
S.E. of regression	0.039888	Akaike info criterion		-3.515658
Sum squared resid	0.106601	Schwarz criterion		-3.297706
Log likelihood	137.0793	Hannan-Quinn criter.		-3.428714
F-statistic	531.3304	Durbin-Watson stat		2.043098
Prob(F-statistic)	0.000000			

* Note: p-values and any subsequent tests do not account for model selection.

Source: Prepared by the author based on the outputs of EViews 10.

3.7 Diagnostic Tests of the Model

The Breusch–Godfrey Serial Correlation LM test was employed to examine whether the error terms in the regression model are independent or exhibit serial correlation. This diagnostic procedure is essential for assessing the validity of the model's assumptions regarding the independence of residuals. In addition, a heteroskedasticity test was conducted to evaluate whether the variance of the residuals remains constant or varies systematically with the independent variables. The outcomes of these diagnostic tests are presented below.

3.7.1 Breusch-Godfrey Serial Correlation LM Test

Table 4. Test of Multicollinearity in the Model

Breusch-Godfrey Serial Correlation LM Test:	
F-statistic	1.037449
Obs*R-squared	2.289120
Prob. F(2,65)	0.3601
Prob. Chi-Square(2)	0.3184

Source: Prepared by the author based on the outputs of EViews 10.

Based on the results of the Breusch-Godfrey Serial Correlation LM Test, the null hypothesis (H_0), which states that there is no autocorrelation among the residuals, is accepted, since the p-value is greater than 5%.

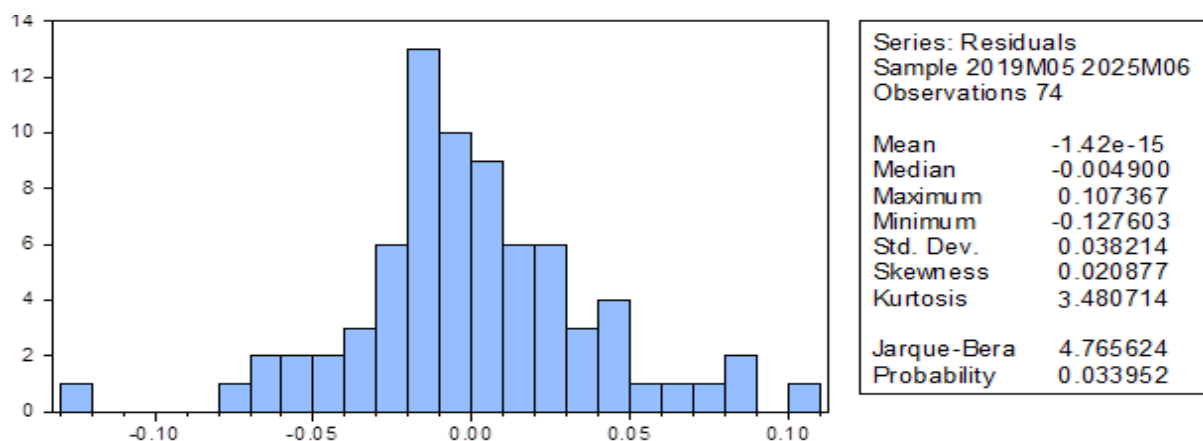


Figure 4. Results of the Normality Test

Source: Prepared by the author based on the outputs of EViews 10.

Based on the test output, it is evident that the residual values follow a normal distribution, which supports the null hypothesis of normality at the 5% significance level. This is further confirmed by the calculated Jarque-Bera statistics of (4.76), which

3.7.2 Heteroskedasticity Test

Table 5. Results of the Heteroskedasticity Test Based on Linear Regression

Heteroskedasticity Test:	
F-statistic	1.597650
Obs*R-squared	1.606505
Prob. F(1,71)	0.2104
Prob. Chi-Square(1)	0.2050

Source: Prepared by the author based on the outputs of EViews 10.

Given that the p-value of the Chi-Square test statistic ($df = 1$) exceeds the 5% significance level, the null hypothesis (H_0) cannot be rejected. Consequently, the alternative hypothesis (H_1), which posits the presence of heteroskedasticity in the residuals, is not supported.

3.8 Estimates of Normality Test

JB is asymptotically chi-squared distributed with two degrees of freedom because JB is just the sum of squares of two asymptotically independent standardized normals (Thadewald & Büning, 2004). In other words, the Jarque-Bera statistics must be statistically insignificant at the 5% level for the null hypothesis of normality to be accepted (Naas, 2023).

Upon applying for the test, the results were as follows (see figure 4):

is less than the critical value of (5.99), in addition to a p-value greater than 5%.

3.9 Bounds Test for Cointegration

According to Pesaran et al. (2001), cointegration in the ARDL model is determined as follows: If the

calculated F-statistic is greater than the upper critical bound, the null hypothesis of no cointegration is rejected; if the F-statistic is less than the lower critical bound, the null hypothesis is accepted, indicating no cointegration. However, if the F-statistic lies between the lower and upper critical bounds, no conclusive decision can be made (Eschouf, 2024).

The F-statistic was calculated as 4.904119, which exceeds the I(1) critical bound values at the 10% and 5% significance levels. This indicates the presence of a long-term cointegrating relationship from the short term to the long term at these levels. Therefore, the null hypothesis of no cointegration between the variables is rejected, and the alternative hypothesis, which suggests the existence of cointegration between the Artificial Intelligence Index (S), the Nasdaq Composite Index (N), and the Fintech AI Index (F), is accepted.

Table 6. Results of the ARDL Bounds Test for Cointegration

ARDL Bounds Test		
Date: 11/22/25 Time: 12:32		
Sample: 2019M05 2025M06		
Included observations: 74		
Null Hypothesis: No long-run relationships exist		
Test Statistic	Value	k
F-statistic	4. 908095	2
Critical Value Bounds		
Significance	I0 Bound	I1 Bound
10 %	3.17	4.14
5 %	3.79	4.85
2.5%	4.41	5.52
1 %	5.15	6.36

Source: Prepared by the author based on the outputs of EViews 10.

Table 7. Results of the Short-Run and Long-Run Relationships in the ARDL Model

ARDL Cointegrating and Long Run Form				
Dependent Variable: LS				
Selected Model: ARDL(2, 0, 2)				
Date: 11/22/25 Time: 12:34				
Sample: 2019M03 2025M06				
Included observations: 74				
Cointegrating Form				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LS(-1))	-0.215113	0.125895	-1.708661	0.0921
D(LF)	0.095352	0.068697	1.388010	0.1697
D(LN)	0.578458	0.104400	5.540781	0.0000
D(LN(-1))	0.228875	0.113650	2.013861	0.0480
CointEq(-1)	-0.231706	0.115756	-2.001674	0.0494
Cointeq = LS - (0.4115*LF + 0.3319*LN + 2.0367)				
Long Run Coefficients				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LF	0.411522	0.235783	1.745345	0.0855
LN	0.331918	0.396117	0.837930	0.4050
C	2.036714	2.253956	0.903617	0.3694

Source: Prepared by the author based on the outputs of EViews 10.

3.10 Estimating the Short- and Long-Run Relationship

Based on the test outputs, it was found that a one-unit change in the price of the Artificial Intelligence Index (S) leads to a change of 0.09 units in the

Fintech Index (F) in the same direction. While the impact is relatively weak, it is still acceptable, as it approaches 10%, and it aligns closely with the findings of the Artificial Intelligence Index Report 2025 published by the Stanford University AI Center (See report: Human-Centered Artificial

Intelligence (HAI), 2025), regarding the adoption of AI in financial technology. This result can be objectively explained, as the Fintech Index (F) captures a wide range of macro-financial variables, including: the performance of major publicly listed companies, innovation in financial services, and emerging technologies affecting the traditional financial sector. These components provide a reasonable interpretation of the estimated coefficient. Furthermore, the use of artificial intelligence in the financial sector is relatively recent, compared to previous financial and technological innovations, and the traditional financial sector remains less flexible in responding to such innovations at this stage, due to the persistence of conventional and trusted products and structures. Also, AI applications in finance are still hard to quantify in many of their forms.

As for the Nasdaq Composite Index, every one-unit increase in the AI Index (S) leads to a 0.57 unit increase in the Nasdaq, which is a very strong effect. This indicates that investment in AI significantly boosts the value of major technology companies listed in the index. It reflects the current investment trend in this sector, which exerts a compound effect on tech companies through both usage and investment in AI technologies.

Regarding the error correction rate from short-run imbalances toward long-run equilibrium, the error correction term (ECT) was estimated at -0.23170 , indicating that about 23% of the short-run disequilibrium is corrected toward the long-run relationship in each period.

Considering the p-value, the null hypothesis (H_0) is rejected in favor of the alternative hypothesis (H_1), which confirms the presence of a long-run equilibrium relationship. The direction of this relationship runs positively from the AI Index (S) toward both the Fintech Index (F) and the Nasdaq Composite Index (N).

3.11 Stability Test of the Estimated ARDL Model

The structural stability test shows that the short-run coefficients are stable and consistent with the long-run coefficients. To assess this, the CUSUM test and the CUSUM of Squares test are used.

Structural stability of the estimated ARDL coefficients is confirmed when both tests remain within the critical bounds at the 5% significance level, thereby leading to the acceptance of the null hypothesis of coefficient stability (Bousba & Sahli, 2020). Figures 5 and 6 illustrate the results of these tests.

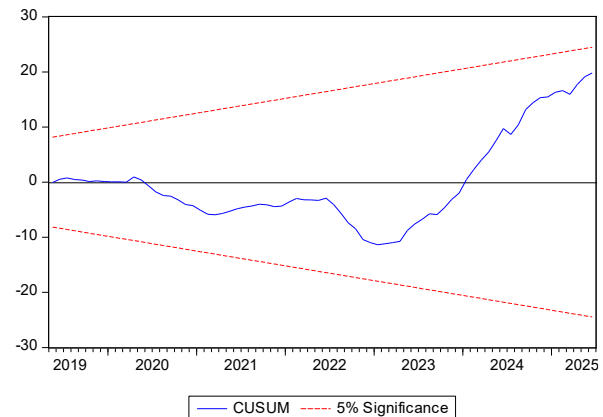


Figure 5. Cumulative Sum of Recursive Residuals.

Source: Prepared by the author based on the outputs of the EViews 10

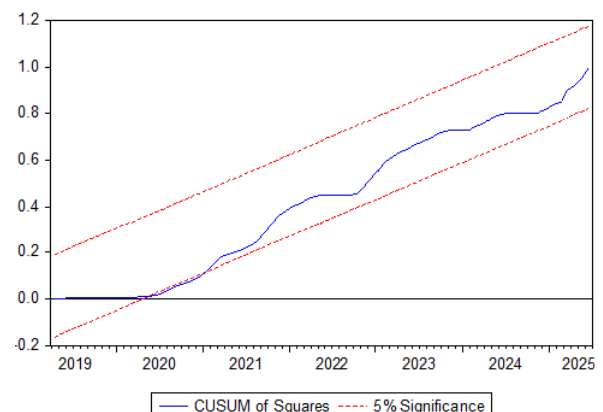


Figure 6. Cumulative Sum of Squares of Recursive Residuals

Source: Prepared by the author based on the outputs of the EViews 10

It is observed from the CUSUM test and the CUSUM of Squares test that both lie within the critical bounds at the 5% significance level. This indicates the stability of the short- and long-run coefficients of the estimated model and reflects consistency between the long-run and short-run results.

4 CONCLUSION

The current phase is marked by pivotal transformations in the field of modern finance, making the rise and expansion of artificial intelligence investments and applications in the

financial sector one of its key outcomes. This development calls for broader and more in-depth research by specialists to fully understand the growing impact of emerging smart technologies in the fields of finance and business, an impact that ultimately reflects on the financial sector in one way or another.

This was clearly demonstrated by the findings of the present study on various levels, including traditional, newly emerging, and innovative dimensions, which are summarized as follows:

- There is a transitional effect of artificial intelligence applications in the financial sector from the short term to the long term, which supports the validity of the first hypothesis. Every action generates reactions as a response to changes within a highly sensitive sector. These reactions may unfold over varying time horizons, whether in the short term, over several years, or even decades.
- The statistical results of this study indicate a weak but acceptable long-term equilibrium relationship (with the potential to grow in later phases) between the use and development of AI and its impact on various components such as: The performance of large companies listed on international stock exchanges, innovations in financial services, and the technologies adopted in the traditional financial sector especially given the vast scope of the financial system. The integration of AI into both modern and traditional financial frameworks is still relatively new, especially when compared to earlier technologies like traditional algorithms or human-based data analysis. This novelty limits AI's current long-term impact on macro-finance and raises several concerns among specialists and experts about the potential risks associated with excessive AI use in financial industries. These concerns may explain the cautious approach adopted by key financial market players, particularly those leading the

markets, regarding the full integration of AI. Some fear that financial investment could drift too far from traditional foundations, possibly reaching a point beyond human control. Additionally, a noticeable mismatch in the pace between the regulatory/legal frameworks and the rapid adoption of AI in financial systems creates uncertainty. This regulatory lag makes the long-term impact of AI less clear and harder to measure than its short-term effects.

- There is a positive impact of investment in AI technologies on the market values of major tech companies, regardless of the investment horizon, confirming the second hypothesis. The results support this claim, as the interactive and complementary relationship between tech companies listed in the AI Index (S) and the Nasdaq Composite Index (N) creates a dynamic synergy in the overall tech investment landscape. This connection is reflected in the prices of tech assets if investment in AI technologies continues. The largest companies investing in AI are already listed in the Nasdaq, which aligns well with the components of the AI Index (S) an index that monitors the development of AI technologies by leading firms such as: Microsoft Corp., NVIDIA Corp., Meta Platforms Class A, Alphabet Inc. Class A, Marvell Technology, etc. (See: Deutsche Borse Group, 2025). These firms are also listed in the Nasdaq Composite Index, and many of them are actively targeting innovation in the financial sector, among others. Therefore, the study's findings are valid and acceptable at this stage. Since these companies aim to fulfill a smart industrial vision, they view continuous innovation in AI as both a way to boost short-term market value and to ensure long-term expansion of their entities.

The study, therefore, recommends periodic evaluations of the effects and integration of AI in micro and macro finance.

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DIGITAL SELF-ASSESSMENT AS A FOUNDATION FOR THE DIGITAL TRANSFORMATION OF THE ENTERPRISE

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ABSTRACT

Changes in the socio-economic environment demand greater awareness of intensifying competition, which in turn stimulates efforts toward business improvement. One result of this drive is continuous improvement in the quality of operations and environmental management, leading to a stronger market position. Even the world's largest and most successful companies must, in the face of unpredictable market changes and rapid technological development, adopt flexible business principles — or risk being outpaced by more adaptive competitors. Business process management should be flexible and simple to adapt to market requirements, yet sufficiently complex and integrated to ensure operational coherence. The company defines its mission as enhancing its core business through the adoption of cutting-edge knowledge and technology in the field of digitization, whose quality derives from a commitment to excellence across all domains. To achieve this, the company aims to embed the principles of quality digital culture and excellence in daily corporate practice. This paper explores digital maturity self-assessment in companies, based on the Lipovec-Rozman-King Business Organizational Model. An example of self-assessment of a modern small enterprise is given.

1 INTRODUCTION

According to Kralj (2013), the concept of organization appears across various fields, primarily in human activity, but also more broadly. It is most used to describe purposeful action aimed at achieving goals in diverse domains of human endeavor. Rozman (1993) notes that organization is a phenomenon we are constantly confronted with citing Pfeffer (1982): “We live in a world of organizations.” He further emphasizes that

phenomena that profoundly affect our lives must be understood so that we can use them to our advantage. Consequently, it is essential to examine the societal impact of organizations, including their role in environmental management.

In the literature, the term “organization” is defined in various ways. Kovač (1999) observes that the number of definitions reflects the diversity of schools, approaches, and perspectives. However, organizational science is not nearly as developed

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as economic science (Lipovec, 1987). Over the past 30–40 years, organizational science has undergone theoretical consolidation, highlighting the need to examine the concept of the group or organization more closely. This perspective enables us to understand how organizations manage and protect their internal and external environments, how they influence broader and narrower contexts, and how these interactions are reflected in performance metrics—such as the alignment between planned and actual sustainability objectives.

The notion of socially responsible behavior in organizations encompasses both a focus on organizational performance and a commitment to maintaining a healthy environment. Lipovec analyzed several dozen sources containing definitions of organizations and concluded that many can be classified into four groups (Kralj, 2013; Kavčič, 1991):

- Definitions that view organization as a formal process or technique for combining activities to increase efficiency.
- Definitions that describe organization as a process ensuring smooth cooperation among the various organs of an enterprise; in this sense, organization is a process between people.
- Definitions that understand organization as a group of people (social unit, association, human group) acting to achieve common goals.
- Definitions that see organization as a composition of parts in a mutual relationship.
- The management of an association or organization is a fundamental responsibility of directors. Their activities extend beyond economic regulation to governance across various operational domains. As Rozman (1993) notes, management is present in all spheres of life—from the family and the army to non-profit organizations and beyond. According to the author, management knowledge becomes more robust when its relevance is recognized during key phases of managerial development. He clarifies that this study complements—rather than replaces—earlier static approaches to organizational implementation, by expanding the understanding of management's role.

Companies demonstrate their digital credentials through several mechanisms, including mandatory compliance with legal requirements and voluntary digital self-declaration. In doing so, they affirm to the public and business partners their capacity to manage digital transformation and related services. Following established guidelines, they manage products and engage with the digital environment in a manner consistent with industry standards. The implementation of digital requirements and elements reflects the ability to introduce organizational and digital innovations yet does not fully represent the scope of digital impacts or the effectiveness of digital management (Kralj, 2013).

Given the ambitious goals of digital transformation across business organizations, as well as the current state of operations and the strategic challenges they face, it is necessary to take a more active role in advancing digitalization and integrating into the modern digital business ecosystem.

2 DEFINITION AND CHARACTERISTICS OF THE ORGANIZATION

A company is responsible for its activities that affect people, communities, and their natural environment, so it needs to research, identify, and measure its negative and positive impacts. This is largely shaped by the organization's internal structure and its management approach.

The concept of organization appears across various disciplines. It is most applied to human activity to achieve diverse objectives, though it also extends more broadly. Rozman (1993) notes that organization is a phenomenon we are constantly confronted with. He states: "We live in a world of organizations" (Pfeffer, 1982) and further argues that the very phenomena profoundly shaping our lives must be understood to harness their potential. It is therefore essential to examine the societal impact of organizations, particularly from the standpoint of environmental management.

The notion of an association or an organization is not unambiguous. The concept has been defined in markedly diverse ways by various authors across different periods and disciplinary perspectives. Considering the growing emphasis on socially responsible behavior toward nature, it

is increasingly necessary to broaden the definition of associations and organizations to include environmental management considerations. Although sustainability-related pollution is generated across various business functions, such as purchasing, human resources, production, sales, and finance, the key decisions that influence ecological performance are made within the organizational structure of the association. This is precisely why the following chapter focuses on the concept of the group and its organizational framework.

Common to the definitions is the understanding of an organization as a group of people working together to achieve goals. Rozman (1993) notes that all of these and several other similar definitions define organizations as "social units, aggregations of people formed to achieve a unit goal"; they consist of several people doing different jobs and fulfilling distinct roles, holding offices and positions, whose activities are coordinated in such a way that their efforts are united. Associations must reconcile the strategic objectives of the organization with the individual goals of its members. Achieving this balance is critical for fostering unity, operational efficiency, and long-term success.

Associations are examined through various scientific disciplines and perspectives. Rozman (1993) emphasizes that studying organizations and associations requires a multidisciplinary approach. Examining organizations through the lens of digital management and its associated objectives and indicators demands cross-disciplinary insight. In the resulting association, each person is linked by relationships with many other people, thus forming a simultaneous network or set of relationships, called an organizational structure.

Lipovec (1987) analyzed several dozen different sources containing definitions of organizations and concluded that many of the definitions can be classified into four groups:

- Definitions that understand an organization as a formal process or a technique of combining processes for the sake of greater efficiency.
- Definitions that understand organization as a process for ensuring the smooth cooperation of the various organs of the enterprise

organism. Organization, in this sense, is a process between people.

- Definitions that understand an organization as an association of people (a social unit, a federation of people, a human group) acting in pursuit of common goals; and
- Definitions that understand an organization as a composition of parts that are in a mutual relationship.

Effective performance is ensured through the processes of planning (business and organization), implementation (organization), which consists of staffing and management in the broad sense (motivation, communication, management in the narrow sense), and control (business and organization). The essence of organizational processes is coordinated action (Lipovec, 1987). Lipovec has thus successfully brought together the relationship and processes, or structural and process aspects (Rozman, 1993).

3 DIGITAL TRANSFORMATION SELF-ASSESSMENT

The Digitalisation Self-Assessment enables the definition of maturity as a measure for evaluating an organization's capabilities across various domains. These models help identify the current level of maturity, guide improvement strategies, and monitor progress. They offer a comprehensive view of maturity stages, outlining the defining characteristics of each stage and the relationships between them.

Assessing transformation readiness plays a pivotal role in shaping a coherent digital strategy. Without a thorough situational analysis, strategic planning lacks a solid foundation. Effective planning depends on a multidimensional readiness assessment, which includes vision development, strategic objective formulation, alignment with broader development strategies, and the establishment of priorities and implementation frameworks.

Through periodic assessments along the digital transformation journey, organizations can track progress, reflected in their evolving levels of competence. Digital capability is evaluated across selected categories, each comprising foundational elements that support the measurement of digital

maturity. Various approaches exist for assessing the digital maturity of organizations.

Evaluating the current state of digitization allows maturity to serve as a benchmark for analyzing organizational capabilities across critical dimensions. The concept of process maturity gained prominence in the 1990s with the

introduction of the Capability Maturity Model (CMM) by the Software Engineering Institute (SEI), which established a five-level framework for assessing the institutionalization and improvement of software development processes (Mislej, 2016). These five maturity levels are presented in Table 1.

Table 1. Example of the 5 CMM maturity levels

Maturity level	Description
Level 5	Organizations that provide training to employees involved in their development to implement processes.
Level 4	Organizations that implement process management use performance factors to achieve their objectives, which are monitored, and objectives are broken down from core processes into sub-processes.
Level 3	Organizations in which most core processes are defined and partially controlled, but where data is not systematically collected and performance indicators are not used for monitoring.
Level 2	Organizations where some top-level processes are identified and implemented with a degree of consistency, yet many processes remain uncontrolled.
Level 1	Immature organizations with ad-hoc processes and no project planning.

Source: (Mislej, 2016)

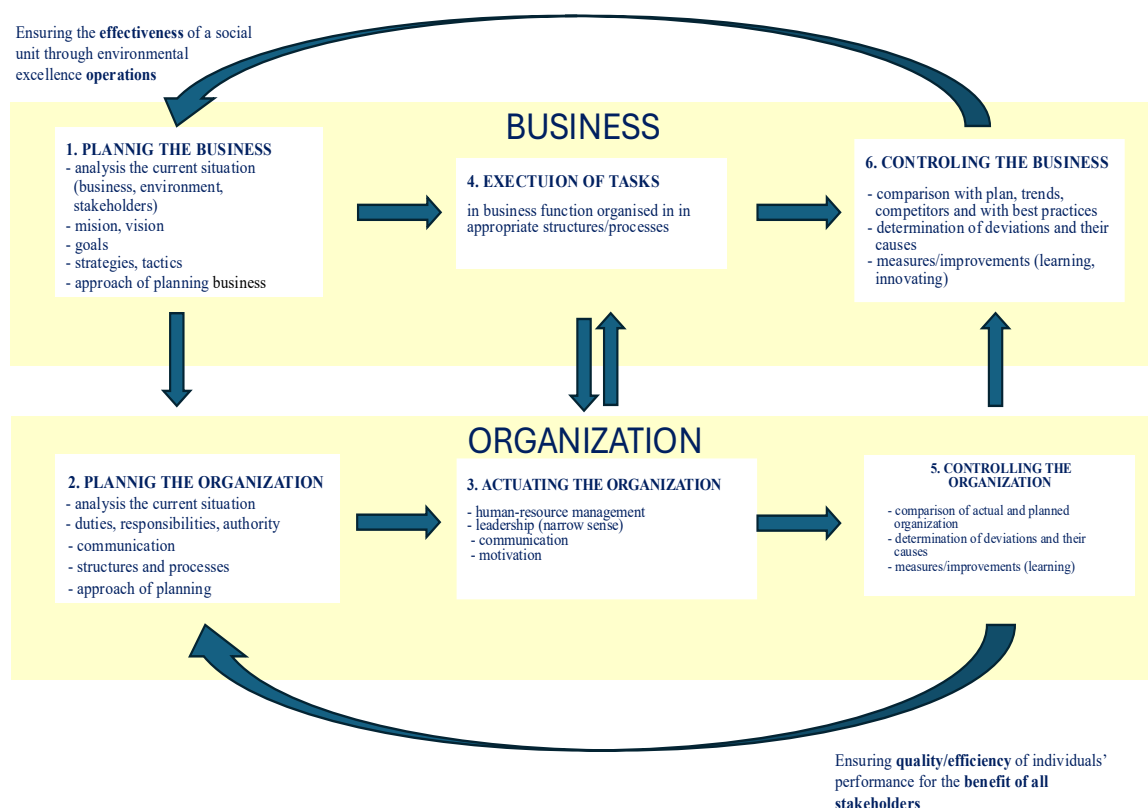


Figure 1 Business and Organization

Source: (Kralj, 2013)

Transformation readiness assessment is essential for developing a digital strategy. Strategic

planning requires both detailed analysis and critical evaluation. It is based on scoping

readiness through multiple perspectives, developing a vision, setting strategic objectives, aligning them with organizational development strategies, and defining priorities and concrete implementation programs.

Consulting firms employ various methodologies to evaluate digital maturity. For example, MIT Sloan Management and Capgemini Consulting (Mislej, 2016) define digital maturity as a combination of two interrelated dimensions:

- Digital intensity, which refers to investments in technology-driven initiatives that transform

how a company operates — including integration, internal operations, and business models.

- Transformation management intensity, which involves developing the management capabilities needed to lead digital transformation. Its components include: a vision to shape the future, engagement and leadership to maintain strategic direction, and close integration between IT and business to drive technological change.

These dimensions are illustrated in Figure 2.

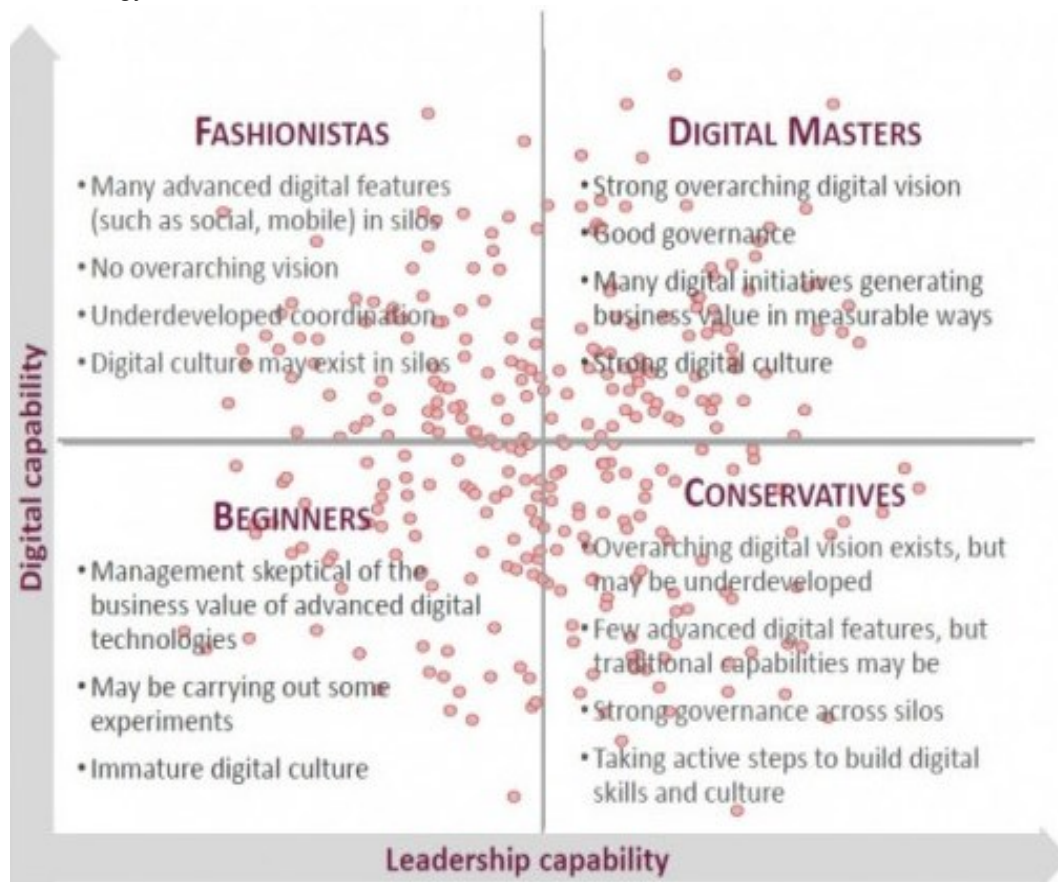


Figure 2 Four levels of Digital Mastery

Source: (Croucher, 2013)

4 KRALJ'S MODEL OF SELF-ASSESSMENT

A digital maturity assessment evaluates how technology can support business improvement. Often, companies continue with familiar practices until rising expectations from customers or employees prompt change. Manual processes, outdated systems, and entrenched habits can hinder growth—especially in today's digital landscape, where innovation drives success.

With the vast array of business technology solutions available, organizations can address numerous challenges through digital tools, including process automation and advanced software functionalities. A digital maturity assessment helps pinpoint areas where technology can resolve organizational issues and foster growth (Wiseman, 2025).

These self-assessments are widely used to gauge an organization's current digital capabilities and

readiness. However, they come with notable limitations:

- *Subjectivity*: Results may be skewed by personal biases. Employees might rate digital capabilities based on individual experiences, leading to inconsistent outcomes.
- *Limited Scope*: Many assessments focus narrowly on specific aspects, overlooking dimensions like cultural readiness or customer experience.
- *Lack of Benchmarking*: Without comparison to industry standards or competitors, organizations may struggle to understand their relative position.
- *Static Evaluation*: Digital maturity evolves rapidly. Assessments can quickly become outdated, missing ongoing developments.
- *Overemphasis on Technology*: Some tools prioritize infrastructure while neglecting culture, talent, and processes—resulting in a skewed view.
- *Limited Actionability*: Without clear guidance, translating results into strategies can be difficult.
- *Resource Intensity*: Comprehensive assessments demand time and resources, which may be challenging for smaller organizations.
- *Inadequate Follow-up*: Without structured re-evaluation, organizations risk stagnation and missed opportunities.

While self-assessments offer valuable insights, organizations should be mindful of these limitations and consider supplementing them with external evaluations, benchmarking, or expert consultations for a more holistic understanding.

DIH Slovenia (DIH, 2025) recommends using both international and Slovenian tools and methodologies to assess digital maturity. The digital strategy should incorporate key findings and recommendations from this assessment, including:

- A SWOT analysis of the company's overall business and the eight strategic areas: Customer experience, Processes and digital solutions, Data strategy, Digital business models/products/services, Digital workforce and jobs strategy, Digital culture strategy, Cybersecurity, and Industry 4.0.
- A digital stocktaking analysis of the company's competitive position, focusing on the same

strategic areas, based on available data. These guidelines do not strictly follow business-organizational theory.

In our case, we apply a hybrid approach that integrates business and Slovenian organizational theory and practice. The digital maturity assessment combines Kralj's indicator model, the Lipovec-Rozman organizational framework, and the Business Excellence Evaluation Model. This integrated approach covers all key components of the digital strategy.

Below is a brief overview of the Business Excellence Model (EFQM, 2012) criteria:

- *Leadership*: How leaders shape mission and vision, foster values for long-term success, and demonstrate personal commitment to governance.
- *Employees*: How the organization develops and utilizes employee potential at all levels to support strategy and process effectiveness.
- *Strategy*: How mission and vision are achieved through stakeholder-focused strategies, supported by policies, plans, and objectives.
- *Partnerships and Resources*: How external partnerships and internal resources are managed to support strategy and process execution.
- *Processes, Products, and Services*: How processes are designed, managed, and improved to deliver value to customers and stakeholders.
- *Results – Employees*: Outcomes delivered to employees, including perception measures from surveys, interviews, and evaluations.
- *Outcomes – Customers*: Results delivered to external customers.
- *Societal Outcomes*: How the organization is perceived by society, based on public feedback and institutional reports.
- *Performance Results*: Key outcomes—financial and non-financial—aligned with strategic goals.

High-performing organizations continually push boundaries. REMEA d.o.o. exemplifies a commitment to performance, well-being, and sustainability. A tailored self-assessment was conducted to evaluate its digital maturity, aligned with organizational performance principles. Table 2 summarizes the results.

Table 2. Level of Digital Maturity of the Organization

Scope \ Maturity level	1	2	3	4	5
	Early		Developing		Mature
Management	Lack of awareness and knowledge		They are aware of digital potential		Digitally sophisticated
Policy, strategy, organization, and organizational (digital) culture	Focus on cost reduction No accepting risk		Focus on customer experience and decision support Tolerate risk, innovate, and collaborate		Focus on fundamental process transformation They take risks and encourage innovation and collaboration
Managing employee knowledge and capabilities	Insufficient investment		Moderate investments		Suitable investments
Partnerships and resources	None		Is gaining in importance		At the heart of digital transformation
Processes (Technical capability, digital operations...)	None		Is gaining in importance		At the heart of digital transformation
Data strategy - results	None		Is gaining in importance		At the heart of digital transformation

Source: Author

5 AIM OF THE STUDY

This study explores the intersection of digital transformation and sustainable eco-management within contemporary business operations. It begins by clarifying key concepts such as digitalisation, digital transformation, and sustainable environmental management, emphasizing how digital technologies enable innovative sustainability solutions.

Technologies like Artificial Intelligence (AI) and machine learning support data-driven strategies for environmental improvement, while Internet of Things (IoT) tools optimize energy consumption. Blockchain enhances transparency in eco-friendly supply chains, and emerging technologies contribute to carbon capture and climate mitigation. These innovations empower businesses to meet Environmental, Social, and Governance (ESG) targets, develop sustainable products and services, and align with global environmental objectives (Homopolitikus, 2022).

The research centers on the preliminary development of a questionnaire designed to assess digital maturity in small and medium-sized enterprises (SMEs), with potential applicability to larger organizations. The startup REMEA was used as a case study, focusing on the creation of

a research instrument for objective analysis and evaluation of digital maturity. Such assessment enables companies to formulate digital strategies that gradually lead to organizational transformation and support environmentally responsible business excellence.

To successfully scale digital business models, companies must enhance their capabilities in stages. A lack of necessary competencies may hinder strategic progress. Before leaders launch their initiatives, they should take three essential steps to determine whether their organization has the capabilities it needs (Westerman et al., 2014):

1. Evaluate the maturity of the organization's digital business.
2. Define what digital business acceleration means for the enterprise.
3. Identify the new capabilities required for transformation.

While various authors approach digital strategy from different angles, many overlook the foundational principles of business and organizational theory. Regardless of the tools employed—be it AI, automation, or digital platforms—the core processes of planning, execution, and control remain essential. This study aims to reaffirm the importance of

integrating digital tools within a structured business-organizational framework.

6 METHODOLOGY

The empirical research presented in this chapter underscores the importance of developing an objective instrument for analyzing and evaluating digital maturity within the framework of environmental business excellence and digital transformation, particularly in the context of small enterprises.

The methodology includes the design of a preliminary questionnaire, its initial evaluation through a case study of a small start-up (REMEA), and the interpretation of participant responses. The research tool is original and seeks to integrate the Lipovec–Rozman–Kralj business-organizational model into practical entrepreneurial application. The central aim is to explore how digital maturity can be assessed objectively, and how such assessment contributes to the development of environmentally responsible business practices.

The questionnaire was designed for self-evaluation of digital maturity in SMEs, grounded in the Lipovec–Rozman–Kralj model of business environmental excellence. It was further enriched with items related to digital business and organizational structure, reflecting an interdisciplinary approach to understanding and managing the digital transformation process in SMEs.

Assuming compliance with environmental legislation, the study examined which indicators and measures—pertaining to both environmental performance and digital transformation—support continuous improvement in the context of sustainable development. The goal was to create a preliminary instrument suitable for SME self-assessment and future refinement through broader research.

The research adopted a null hypothesis (H_0), positing no significant differences between the observed variables. Data collection was conducted through a collaborative brainstorming session within a small company of four employees. The final assessment was reached through group consensus, following detailed discussion, analysis, and reasoned deliberation.

The results of the survey are valid exclusively for the start-up REMEA and serve as a pilot example for future studies involving a larger sample of SMEs. The survey was conducted on March 2nd, 2025.

7 SMALL ENTERPRISE DIGITAL SELF-ASSESSMENT RESEARCH RESULTS

The small enterprise and its partners operate as a comprehensive provider of e-mobility services, offering consulting, implementation of charging infrastructure, and management of corporate charging stations.

According to EUROSTAT (2025), 59% of EU enterprises reached at least a basic level of digital intensity in 2023. Among small and medium-sized enterprises (SMEs), the share was 58%, while 91% of large enterprises achieved this level. The Digital Intensity Index (DII) defines “at least basic level of digital intensity” as the use of at least 4 out of 12 selected digital technologies, including AI, social media, cloud computing, Customer Relationship Management (CRM), or having e-commerce sales accounting for at least 1% of total turnover.

The assessment includes partial results from the survey questionnaire and interviews conducted with participants at the national level. The insights derived from these findings are used to shape a digital strategy and are presented through a SWOT analysis. The evaluation summarizes the results of the digital maturity test, alongside other company assessments, particularly a review of the firm's competitive position.

The focus of this paper is on management, which plays a central role in defining the mission and vision and ensuring their implementation. Management integrates digital transformation components across key strategic domains. To assess the current state of a company's digital transformation strategy, a structured set of 50 questions was developed—comprising 30 core and 20 supplementary items. These questions address critical dimensions such as management and leadership, policy, strategy, organizational structure, and organizational (digital) culture (see Tables 3 and 4).

Activities reflecting the characteristics of management and leadership were evaluated using a five-point scale:

- 1 not at all (no awareness),
- 2 very little (lack of awareness and knowledge),
- 3 medium (gaining importance),
- 4 good (awareness of digital capabilities),
- 5 very good (focus on fundamental process transformation).

Table 3 presents the survey findings related to the domain of Management, while Table 4 covers Policy, Strategy, Organizational Structure, and Organizational (Digital) Culture. These domains are essential for evaluating a company's digital transformation strategy, as they represent its foundational components.

The design and implementation of a new organization with digital transformation elements depend heavily on management's role in developing the mission, vision, policy, strategy,

and digital culture. Organizations fulfill their mission and vision by cultivating a strategy and organizational culture—particularly digital culture, which encompasses the values, assumptions, and beliefs shared by employees and is primarily expressed through management actions.

Digital culture, as a subset of corporate culture in the digital economy, is crucial for delivering positive employee experience and customer experience. It is a key factor influencing every strategic initiative, especially those related to digital transformation.

Rating descriptions emphasize:

- 5 very good (focus on fundamental process transformation)
- 4 good (aware of the importance of digital capabilities).

Table 3 *Survey Results on Management*

Questions	Rating description
1. The organization's management has a clearly defined mission, vision, strategy, and goals, as well as values and ethics, and they set an example of a culture of excellence.	5
2. The organization's management has a clearly outlined vision, strategy, and goals regarding the digital transformation of the business and organization.	4
3. Management is personally involved in the development, implementation, and continuous improvement of the organization's management system.	5
4. Management constantly informs employees in the organization about the organization's strategy and goals (including the company's digital transformation) and encourages employees to engage in digital transformation.	5
5. Management collaborates with clients, partners, and company representatives in the digital transformation of the company	4
6. Management strengthens the culture of excellence and digital culture among employees in the organization.	4
7. Directors recognize the need for changes related to the digital transformation of business and organization and are the first to advocate for them.	4
8. Digital transformation affects changes in the structure of an organization.	4
9. If a management representative is appointed to implement the digital transformation of a business and organization, is he/she a member of executive management?	4
10. Management is an example of creative problem-solving in the digital transformation of business and organizations and in achieving set goals.	4
11. Management effectively informs employees about the digital transformation of the business and organization, as well as problems for which new solutions need to be sought.	4
12. The goals of digital business and organizational transformation are an integral part of the business plan.	5
13. Indicators of digital transformation of business and organization have become an integral part of the business report.	4
14. The topic of digital transformation of business and organization is often discussed at top management meetings.	4

Questions	Rating description
15. Management encourages taking initiatives, finding new opportunities, and finding new solutions to solve problems of digital transformation of business and organization.	4
16. Management encourages and enables the acquisition of new knowledge and experience in the digital transformation of business and organization.	4
17. Management encourages and enables employees to participate in decision-making during digital transformation.	4
18. Management values creative work, new ideas, risk-taking, and responsibility in the digital transformation of business and organization.	4
19. Management encourages and enables independence in the digital transformation of business and organization.	4
20. Management encourages and enables independence in work and allows for mistakes in the implementation of digital transformation.	4
21. Management rewards creative and innovative work (praises, awards).	4
22. Management determines the efficiency and success of the digital transformation of the business.	5
23. Measures for the digital transformation of business and organization are planned, implemented, monitored, and continuously improved.	5
24. It is known what the target state is that the company wants to reach in each area/element of the digital strategy.	4
25. The initial state of each area in the field of digitalization is known.	5
26. The strategic goals in the field of digitalization are known.	5
27. The strategic directions for achieving the strategic goals of digitalization are known.	5
28. The metrics for monitoring the implementation of the digital strategy (KPIs) are known.	5
29. The company's digital capabilities development plan is known.	5
30. The list of initiatives and projects for implementing the digital strategy is known.	5

Source: Author

Table 4. Policy, Strategy, Organization, and Organizational (Digital) Culture)

Questions	Rating description
1. Policy and strategy (including digitalization strategy) are based on the current and future needs and expectations of all stakeholders.	4
2. The digital transformation policy and strategy are well understood and supported by top management.	4
3. The digital transformation strategy is aligned with the organization's strategy.	4
4. The organization develops, reviews, and updates its digital business transformation policy and strategy (including digitalization strategies).	4
5. In business and organizations, customers represent a key element of orientation (customer focus).	4
6. We are convinced that an organization's competitive advantage is based on digital transformation.	4
7. There is a framework for a plan to promote customer orientation.	4
8. The organization has defined the necessary elements of a digital culture.	4
9. There is a business agility development plan framework.	4

Questions	Rating description
10. Management is focused on business excellence, including components of digital transformation.	4
11. I trust the organization's mission, the set digital transformation policy, the strategy (including the digitalization strategy, and the goals (including digital transformation) of the organization, business units, or departments.	4
12. Employees have the opportunity to use IT (computers, internet), which enables effective communication and rapid exchange of ideas and information in the digital transformation of business and organization.	4
13. Mutual relationships in the organization are characterized by trust, respect for diversity, and openness to new ideas.	4
14. Any errors or mistakes in the digital transformation of business and organization are addressed, and corrective and preventive measures are then implemented with the aim of continuous improvement.	4
15. Suggestions from individuals for improving the digital transformation of business and organizations are evaluated.	4
16. There is a framework for a plan to promote innovation and experimentation concepts (a plan to introduce Design Thinking).	4
17. There is a plan to support co-creation and collaborative work.	4
18. In general, we in the organization are willing to take risks when introducing digital innovations and changes.	4
19. In an organization, the organizational structure places the overall customer experience ahead of the efficiency of individual organizational units.	5
20. There is a digital leadership development plan.	4

Source: Author

The average score of responses is 4.20, indicating that the company is at an advanced stage of digital transformation in terms of business operations and organizational development. This result reflects the company's long-term evolution in commercial activities, as well as the strategic integration of key management components such as mission, vision, policy, strategy, and digital culture.

The highest-rated indicators of leadership quality in the context of environmental and digital management include:

- Clear vision, strategy, and goals
- Careful planning, implementation, and continuous improvement
- Assessment of efficiency and effectiveness
- Encouraging initiative and seeking innovative solutions to environmental and digital challenges
- Communicating business excellence and addressing environmental and digital issue (Kralj, 2013).

The general Leadership Quality dimension was further defined by:

- Promoting autonomy in the workplace
- Encouraging employee participation in decision-making and identifying organizational change needs.

The indicator Leaders encourage and enable employees to participate in decision-making showed a lower factor loading, suggesting a weaker contribution to this dimension.

Based on reliability coefficients, the selected items were used to calculate the average value of each indicator within its respective dimension, as presented in Table 5.

The following indicators were defined and tested using the same methodology as the first two dimensions:

- Managing employee knowledge and capabilities
- Partnerships and resources
- Processes (technical capability, digital operations, etc.)
- Data strategy
- Management and policy, strategy, organization, and organizational (digital) culture.

Table 5. Overall assessment of the company's digitalization performance

Maturity level Scope	1	2	3	4	5	Score
	Early		Developing		Mature	
Management	A lack of awareness and knowledge		Aware of digital capabilities		Digitally sophisticated	4.36
Policy, strategy, organization, and organizational (digital) culture	Focus on cost reduction Risk-averse		Focus on customer experience and decision support Tolerate risk, innovate, and collaborate		Focus on fundamental process transformation Risk-taking, fostering innovation and collaboration	4.05
Managing employee knowledge and capabilities	Too small investments		Moderate investments		Adequate investments	4.20
Partnerships and resources	Does not exist		Is gaining in importance		At the heart of digital transformation	4.00
Processes (Technical capability, digital operations...)	Does not exist		Is gaining in importance		At the heart of digital transformation	4.00
Data strategy - results	Does not exist		Is gaining in importance		At the heart of digital transformation	4.20
Overall Score						4.14

Source: Author

The average score across all responses for the Business Excellence Model is 4.14, placing the company at an evolving level of maturity in its digital transformation of business operations and organizational structure. This score reflects substantial potential for enhancing digital capabilities in alignment with strategic objectives and the overall direction of digital transformation.

The RADAR logic, applied at the Attribute level in conjunction with the EFQM Model (Al Balushi, 2025), can be used:

- To identify current organizational strengths and areas for improvement
- To define future goals by outlining desired outcomes and the actions required to achieve them (EFQM, 2012).
- Figure 3 provides a comprehensive visual assessment of the company's digitalization performance, illustrating its current position within the evolving stage of transformation. Organizations that rate general leadership positively tend to also rate digital leadership favorably. This suggests a strong correlation between traditional leadership qualities and digital management effectiveness.

Companies plan, implement, and monitor processes to meet stakeholder expectations, thereby creating greater value. The management of digital systems is integrated into broader business processes, particularly in organizations committed to sustainable development (Kralj, 2013),

Based on the digital maturity assessment results, it is crucial to develop targeted digital strategies for individual business components. The success of these strategies depends on the presence of a robust and adaptive digital culture. Such a culture fosters innovation by encouraging employees to experiment, take risks, and embrace new ideas. Leaders play a key role in cultivating an environment that values creativity, collaboration, and continuous learning (Devensis_team, 2024).

Applying this model to additional companies would enhance the analytical robustness of the developed tool. It is suitable for large enterprises as well as other private and public organizations. Future research is essential to improve both the practical relevance and theoretical depth of business and organizational analysis.

Developing a standardized model for assessing digital maturity is vital for enabling consistent and comparable research across organizations. The results from the small startup case should be interpreted primarily as reflections of employee

perceptions rather than objective organizational conditions. Therefore, expanding the sample to include more companies and employees is necessary for refining future models.



Figure 3 Overall assessment of the company's digitalisation performance

Source: Author

8 CONCLUSIONS

The science of principalship can be understood as the study of leadership roles and the provision of guidance on how to regulate organizational groupings to achieve overall effectiveness—or at least the effectiveness of individual components. This foundation is essential for understanding environmental management, which requires applied scientific approaches to achieving goals efficiently and effectively.

In this context, the development of human capabilities and the behavior of individuals and groups within organizations must be considered. This involves studying people and the relationships between them. The author advocates for a systemic and situational approach to management, recognizing that management science is inherently multidisciplinary. It integrates and adapts knowledge from various fields. This perspective is equally valid for digital management and the management of digital transformation.

Drawing from management theory, the study aimed to identify and structure the most influential indicators of success in digital transformation.

Focus was placed on components such as digital governance, policy and strategic orientation, and the continuous education and awareness-raising of stakeholders, including owners, employees, customers, suppliers, and the broader community.

The development of these indicators is an ongoing process, continuously refined through consultation with relevant literature and established sources. The proposed model contributes to a more holistic understanding of environmental management indicators and is structured around key phases of the management and governance process:

- Business planning
- Organizational planning
- Organizational implementation
- Business control
- Organizational control

These phases represent core organizational processes designed to ensure operational effectiveness. Achieving excellence requires that these processes be executed systematically, with a focus on delivering planned outcomes and measurable performance.

The model also incorporates criteria of business excellence widely recognized in corporate practice. For further development, mechanisms for more objective assessment should include the involvement of experts from diverse fields.

However, the foundation remains rooted in business-organizational theory and behavior, as established both in academic literature and everyday practice.

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IMPACT OF DEMOGRAPHIC INDICATORS ON HOUSEHOLD CONSUMPTION IN ALGERIA USING PCA

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ABSTRACT

This study examines the influence of demographic indicators on household consumption in Algeria from 1985 to 2022, utilizing Principal Component Analysis (PCA) as the primary methodological tool. Using annual data on population structure, life expectancy, urban and rural distribution, and household disposable income, the analysis identifies the demographic variables most strongly associated with consumption dynamics. The results reveal a robust positive relationship between household consumption and factors such as disposable income, total population, life expectancy, and age-specific cohorts (0–14, 15–64, and 65+), while the rural population exhibits a negative association. The PCA highlights four distinct phases in Algeria's demographic-consumption trajectory, reflecting shifts in rural development, economic recovery, improvements in health and income, and recent increases in household consumption linked to demographic transitions at both ends of the age spectrum. These findings underscore the importance of integrating demographic considerations into economic policy design. By recognizing the interplay between demographic change and consumption behavior, policymakers can better anticipate demand patterns, strengthen social infrastructure, and promote sustainable growth. The study also points to methodological and contextual limitations, suggesting future research directions such as nonlinear modeling, cross-country comparisons, and micro-level household analyses to deepen the understanding of demographic influences on consumption.

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1 INTRODUCTION

Since its inception, the Algerian economy has undergone economic, social, and demographic transformations that have influenced the concepts and strategies of household consumption. Household consumption is considered one of the most important macroeconomic variables and a key driver of economic growth, as it constitutes the largest share of GDP. It is affected by several demographic factors, such as population size and structure, as well as other variables, including consumption expectations and credit conditions. Therefore, it is essential to analyze these factors using econometric tools to understand consumption behavior, forecast its trends, and design more effective economic policies. Household consumption reflects the state of the economy, with higher levels indicating stronger consumer confidence and lower levels pointing to economic uncertainty. However, in developing economies such as Algeria, this indicator does not always reflect the true economic state due to various considerations, including the structure of output and weak economic growth rates.

Demographic indicators are among the most influential factors shaping household consumption patterns. Studying demographic transitions alongside consumption patterns and their forecasts is therefore vital. During the 1980s and 1990s, Algeria experienced sustained population growth accompanied by a gradual rise in consumption levels, which boosted domestic demand and supported economic activity. However, the acceleration of demographic transition and declining fertility rates since the 1990s generated new household consumption dynamics. A decline in births led to higher per capita income, which in turn increased demand for goods and services, raising aggregate consumption and positively impacting employment and growth rates.

Since the early 2000s, with improved security and political stability, Algeria has launched a series of development programs that helped restore demographic balance and stimulate the economy. The population grew from about 36 million in 2010 to over 45 million in 2021, alongside a rise in household consumption to nearly 9.8 trillion Algerian dinars in 2021. These dynamics highlight

the uniqueness of the Algerian case, where household consumption serves as a key channel for stimulating domestic economic growth, making it necessary to conduct an in-depth analysis of the reciprocal relationship between demographic transformations and household consumption, as well as to identify mechanisms for directing it toward supporting sustainable development.

2 LITERATURE REVIEW

Demographic transitions remain crucial to understanding household consumption dynamics. In developing countries, increases in disposable income have improved consumption environments, particularly in rural areas Guo and Feng (2024). In China, demographic variables such as age structure and dependency ratios have been shown to influence household consumption and energy use Wang et al (2022). These studies highlight that smaller and aging households tend to consume differently, often prioritizing health-related and service expenditures.

Evidence from advanced economies mirrors these patterns. In the United States, household composition was found to significantly affect food expenditures Benus et al (1976), while lifestyle indicators were equally important as income in shaping household-level emissions Baiocchi et al (2022). In Canada, Ricciuto et al. (2006) demonstrated that family size, income, and education significantly determine food purchases.

2.1 Demographic indicators

Methodological advancements have allowed deeper insights into demographic influences on consumption. For example, Ali et al. (2022) proposed a validated model in Australia linking demographic factors such as household size and occupancy rates to energy use. Similarly, Hristov et al. (2022) applied a survey-based analysis across 13 European countries during COVID-19, highlighting the explanatory power of socio-demographic variables on shifts in food purchasing behavior.

In South Asia, Aslam et al (2018) identified education, employment status, and household size as significant predictors of household energy expenditures in Pakistan. Likewise, Mohanty et al. (2016) emphasized the role of age structure in driving health-related consumption in India, where

the elderly population increased healthcare spending disproportionately. Studies from Latin America also underlined the importance of household size, location, and appliance ownership in explaining more than half of household energy expenditures Jimenez Mori and Yépez-García (2017).

Closer to the Algerian context, research demonstrates the salience of demographic determinants. Adel et al. (2016) found that household size, income, and occupation significantly affect food consumption frequencies in Algeria. Akli et al. (2024) further revealed that demographic factors such as age, income level, and household structure influence preferences for agro-ecological foods. At the macroeconomic level, Traich and Amal (2023) showed that energy subsidies had a greater impact on household consumption in Algeria than demographic growth alone.

Comparable studies from the MENA region reinforce these findings. Souissi et al. (2022) identified household size and socio-economic status as critical determinants of water consumption footprints. Nyatefe and Okey (2020), using Togo's survey data, found that education and urban residence affect cultural spending positively, while large household size exerted a negative impact. In Ethiopia, Kalwij et al. (1998) reported that household size and spousal employment significantly alter household expenditure patterns.

Overall, the reviewed literature highlights the multidimensional nature of demographic determinants on household consumption. Household size, age composition, education, and

income consistently emerge as key factors, though their effects vary across contexts. In North Africa, including Algeria, demographic shifts interact with structural policy factors such as subsidies and food security measures, shaping consumption behaviors in unique ways. Thus, a regionally grounded, methodologically rigorous analysis remains crucial for understanding Algeria's household consumption dynamics.

2.2 The Research Gap

Based on the discussion presented in this section, it is evident that the topic of household consumption has received considerable attention in economic literature, where it has been addressed through various methodological approaches. Our contribution in this study lies in the attempt to identify the demographic indicators that determine household consumption by employing the Principal Component Analysis (PCA) method. This is particularly relevant given that most previous studies on household consumption have been theoretical and analytical in nature, relying primarily on conventional econometric techniques.

3 DATA AND METHODOLOGY

We identify and highlight the most relevant demographic indicators related to household consumption using Principal Component Analysis (PCA) in R Studio. We present the demographic variables in a table consisting of five demographic indicators, along with one economic variable, household disposable income, which is considered a key determinant of household consumption.

Table 1. Data source

Variables	Measurement	Descriptions	Sources
Total Population	In millions	Pop	https://www.ons.dz
Life Expectancy	In years Agrarian investment lands	Life expectancy (LE)	https://fr.statista.com
Population Aged 65 and over	In thousands	pop[65+]	https://data.worldbank.org
Population Aged 15–64	In millions	pop[15,65]	
Population Aged 0–14	In millions	pop[0,14]	
Urban Population	In millions	pop_urb	
Rural Population	In millions	pop_rur	
Household Disposable Income	In millions	Yd_M	https://www.ons.dz

Source: Author's calculations

Table 1 presents the demographic indicators under study. We aim to examine the impact of these variables on household consumption (denoted as Cons_M), based on data covering 38 observations representing the years from 1985 to 2022.

4 EMPIRICAL ANALYSIS

Means and standard deviations are fundamental tools for analyzing and understanding demographic indicators. Table 2 presents the means and standard deviations for the demographic indicators.

Table 2. Averages and Standard Deviations for Demographic Indicators

Variables	Means	Standard Deviation	Minimum value	Maximum value
Cons_M	33304	14897	13477	58947
Pop	32.57	6.65	21.86	45.38
pop [65+]	1468512	590973	667925	2731082
pop [15,65]	20290276	5206712	11508322	27878915
pop [0,14]	10853241	1059210	9572368	13567972
pop_urb	20678427	6501668	10616712	32807002
pop_rur	11933601	393318	11370967	12531184
Yd_M	44615	23420	15553	80455
Life expectancy (LE)	72.58	4.47	63.59	77.80

Note: Number of Observation=38

Table 2 presents a detailed statistical summary of the variables included in the study. The variables pop (total population) and Life expectancy (LE) appear to play a significant role in the demographic concentration of the population, as indicated by their relatively low standard deviations (6.65 and 4.47, respectively), which suggest a high degree of stability and consistency in the data. Conversely, the variable p.rub (urban population) contributes to greater dispersion within the studied population due to its higher standard deviation. Given the heterogeneity in the means and standard deviations across the variables, we employ normalized Principal Component Analysis (PCA Normé). This method involves standardizing each variable by subtracting its mean and dividing by its standard deviation, allowing for the generation of homogeneous, dimensionless values suitable for multivariate analysis.

5 RESULTS

The results section first presents the presentation of the correlation matrix. The second section applies Bartlett's Sphericity Test to verify whether the matrix represents an identity matrix. Subsequently, the eigenvalues and the

proportions of variance explained by the axes associated with the demographic variables are presented. The final section focuses on examining the axes and analyzing the correlations between the demographic variables and these axes.

5.1 Correlation Matrix

After calculating the mean and standard deviation for each variable, we proceed to compute the correlation matrix, as illustrated in Table 3.

Table 3. Correlation Matrix for Demographic Variables

	Cons_M	pop	pop[+65]	pop[15,65]	pop[0,14]	pop_urb	pop_rur	Yd_M	Life expectancy (LE)
Cons_M	1.00	0.98	0.97	0.95	0.54	0.98	-0.76	0.99	0.89
pop	0.98	1.00	0.99	0.98	0.50	1.00	-0.68	0.96	0.94
pop[+65]	0.97	0.99	1.00	0.97	0.51	0.99	-0.72	0.94	0.92
pop[15,65]	0.95	0.98	0.97	1.00	0.33	0.98	-0.67	0.94	0.98
pop[0,14]	0.54	0.50	0.51	0.33	1.00	0.49	-0.23	0.46	0.20
pop_urb	0.98	1.00	0.99	0.98	0.49	1.00	-0.70	0.96	0.94
pop_rur	-0.76	-0.68	-0.72	-0.67	-0.23	-0.70	1.00	-0.78	-0.62
Yd_M	0.99	0.96	0.94	0.94	0.46	0.96	-0.78	1.00	0.90
Life expectancy (LE)	0.89	0.94	0.92	0.98	0.20	0.94	-0.62	0.90	1.00

Source: Author's calculations using R Studio.

The presented matrix illustrates the degree of correlation between the variables. In the first column, we observe the correlations of the household consumption variable (Cons_M) with the other variables. This variable shows a strong positive correlation of 98% with the total population, which clearly reflects a significant relationship between these two variables. In addition, Cons_M also exhibits strong positive correlations with urban population, population aged 65 and over, population aged 15–64, life expectancy, and population aged 0–14, respectively. The economic variable household disposable income shows an even stronger positive correlation of 99%, indicating its crucial role in determining household consumption. Conversely, a negative correlation is observed with rural population, suggesting an inverse relationship between rural residency and household consumption.

5.2 KMO and Bartlett's Sphericity Test

Table 4 presents the results of KMO. This test assesses the suitability of data for factor analysis or Principal Component Analysis (PCA). And Bartlett's Test of Sphericity, which is used to verify whether the correlation matrix is an identity matrix. Bartlett's Test of Sphericity allows us to test the null hypothesis that the correlation matrix is an identity matrix. If the p-value is less than 0.05, the null hypothesis is rejected, indicating that the correlation matrix is not an identity matrix.

Table 4. KMO and Bartlett's Sphericity Test

Test	Value
Kaiser-Meyer-Olkin (KMO)	0.627
Bartlett's Sphericity	
Khi² (Critical value)	41.34
Khi² (Observed value)	1850.187
DDL	28
p-value (bilateral)	< 0.0001
Alpha	0.05

Source: Author's calculations using R Studio.

According to the test results, the null hypothesis is rejected since the calculated Chi-square value (1850) is greater than the critical value (41.34), and the p-value (0.0001) is significantly lower than the conventional significance threshold (0.05). Therefore, the correlation matrix is not an identity matrix. The Kaiser-Meyer-Olkin (KMO) value of 0.627 (Table 4) indicates a minimally acceptable level of data adequacy, suggesting that the correlations among the variables are statistically significant and strong enough to justify the use of standardized Principal Component Analysis (PCA Normé).

5.3 Calculating Eigenvalues

After computing the correlation matrix, the next step is to calculate the eigenvalues, which are derived from it.

Table 5. Eigenvalues and the Proportion of Variance Explained by the axes for the Demographic Variables

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5	Dim.6	Dim.7	Dim.8	Dim.9
Eigenvalues	7.519	0.908	0.493	0.064	0.013	0.002	0.001	0.000	0.000
Percentage (Variance Explained %)	83.544	10.087	5.481	0.716	0.139	0.024	0.008	0.001	0.000
Cumulative %	83.544	93.631	99.112	99.828	99.968	99.991	99.999	100.0	100.00

Source: Author's calculations using R Studio

5.4 Axes Test

We may retain only those eigenvalues whose contribution to the total variance exceeds the average. In general, in Principal Component Analysis (PCA), we focus on the axes (components) that carry more information than

1/9, which in our case equals approximately 0.11 or 11.11%. Based on Table 5, we select the first principal component, and the second component may also be added as a supplementary axis to achieve greater precision. Together, these two components account for 93.63% of the total

information contained in the dataset. Therefore, we conclude that these two components provide the best representation in the first factorial plane. As a result, it is sufficient to represent the variables

on a two-dimensional, orthogonal, and standardized coordinate system defined by axes F1 and F2.

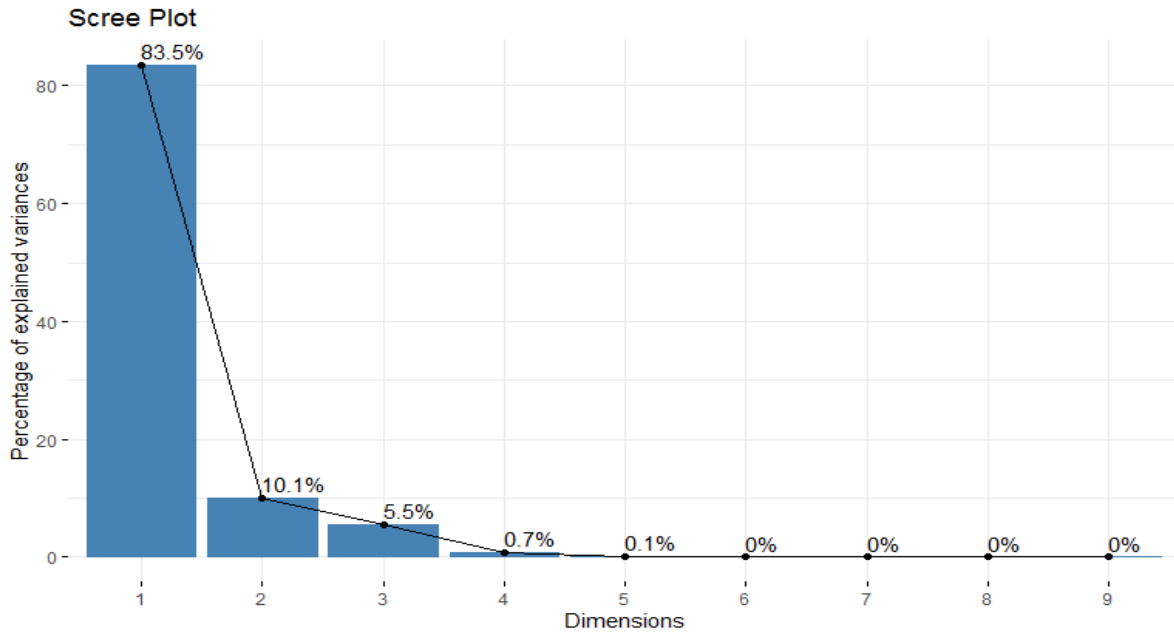


Figure1 Graphical Representation of Eigenvalues

Source: Author's calculations using R Studio.

5.5 Correlations Between Demographic Variables and Components

Table 6 and Figure 2 display the coordinates of the variables on the two principal components, F1 and F2.

Table 6. Coordinates of Demographic Variables

Variables	F1	F2
Cons_M	0.991	0.067
Pop	0.992	0.032
pop [+65]	0.989	0.031
pop [15-65]	0.975	-0.150
pop [0-14]	0.483	0.874
pop_urb	0.999	0.014
Pop rur	-0.757	0.188
Yd_M	0.981	-0.015
Life expectancy (LE)	0.929	-0.282

Source: Author's calculations using R Studio.

By using the variable coordinates presented in the table above on the factorial plane (F1; F2), we obtain the graphical representation known as the

correlation circle. This circle allows us to interpret the various correlations that exist among the variables.

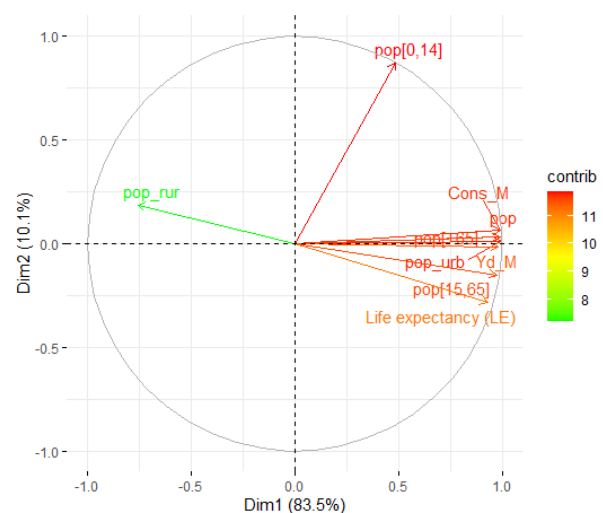


Figure 2 Graphical Representation of Demographic Variables

Source: Author's calculations using R Studio.

The endpoints of the vectors representing all the variables appear to lie very close to the circumference of the correlation circle. This indicates that the quality of representation for the

variables is satisfactory, meaning that the graphical output can be reliably used to interpret and analyze the relationships among the variables over the study period. This conclusion is supported both visually and by the high percentage of explained inertia, which reaches 93.63%. In other words, this value confirms that the first factorial representation provides a robust and meaningful analysis of the interrelationships between the variables, enhancing the validity of the conclusions drawn from this graphical representation. The first principal component (F1) explains 83.54% of the total variance. It is strongly and positively associated with the variables: household consumption, total population, life expectancy, population aged 65 and over, population aged 15–64, urban population, and the economic variable household disposable income, all plotted with positive coordinates. To a lesser extent, the variable population aged 0–14 also shows a positive association. In contrast, the variable rural population is strongly and negatively correlated with this axis the explanation of 83.54% of the variance indicates that there are strong linear relationships among the variables, meaning that most of them move in the same direction and follow a similar pattern. This phenomenon is known in statistical analysis as multicollinearity

Thus, the first axis effectively represents most of the variables, serving as the dominant dimension. This is clearly reflected in the variable factor map,

where most variables cluster to the far right of the F1 axis, indicating a high level of contribution and similarity in their influence. Only one variable, rural population, shows a negative influence on this axis. The second principal component (F2) explains 10.09% of the total variance, which is notably less than the first component. The variable population aged 0–14 is strongly and positively associated with this axis. In contrast, variables such as total population, population aged 65 and over, urban population, and rural population show weak positive correlations with F2. Meanwhile, life expectancy, population aged 15–64, and household disposable income exhibit weak negative correlations with this component. As such, F2 can be considered a supplementary axis, offering a more nuanced classification of the variables. From the biplot (F1, F2), we can draw the following conclusion: There are two distinct groups of variables. The first group includes: household consumption, total population, life expectancy, population aged 65 and over, population aged 15–64, urban population, population aged 0–14, and household disposable income. These variables are strongly and positively correlated with each other and are well represented on the factorial plane, reflecting similarity in their characteristics and mutual influence. The second group consists solely of the variable rural population, which is negatively represented due to its negative coordinates, highlighting its opposing relationship to the first group..

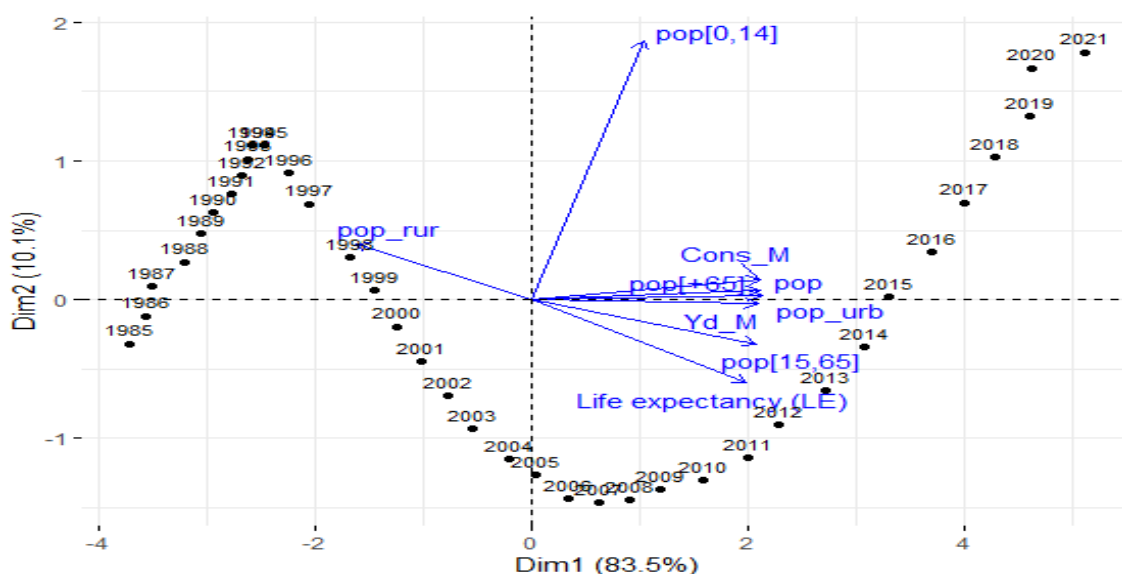


Figure 3 Graphical Representation of Individuals and Demographic Variables

Source: Author's calculations using R Studio

5.6 Demographic Visualization and Analysis

Based on the data and using R Studio, we obtained the following results.

The graph in Figure 3 illustrates the relationship between demographic variables and the years under study. From this representation, we can distinguish four groups reflecting the distribution of these variables:

- Group One (Rural Population), covering the period from 1985 to 1999.
- Group Two, covering the period from 2000 to 2004.
- Group Three (Life Expectancy, Population Aged 15–64, and Disposable Household Income), covering the period 2005–2014.

Group Four (Household Consumption, Population Aged 65 and Above, Population Aged 0–14), covering the period 2015–2021.

6 DISCUSSION

6.1 Group One: Rural (1985–1999)

During this period, many countries, including several in North Africa, focused on agriculture as a key sector of their economies. Algeria emphasized rural development and agricultural policies, which led to a higher proportion of the population living in rural areas. This phase was marked by the enactment of the Agricultural Investment Law in 1987, introduced as part of the reorganization of the agricultural sector following the abolition of agrarian socialism. This measure represented a significant milestone for Algerian agriculture: it defined the rights and obligations of producers and established conditions for land use. The new organizational framework promoted agricultural investments in the following forms:

- Model Farms: These include 188 agricultural farms specialized in plant production and farmer training.
- Collective Agricultural Holdings: These include 28,909 holdings, each consisting of 3 to 6 farmers and covering an area of about 80 hectares of land.
- Individual Agricultural Holdings: These include 16,436 individual farming units.

The 1987 reforms laid the groundwork for the transition to a market economy. The government reduced its intervention in the marketing of fruits and vegetables, enabled farmers to obtain loans from the Agricultural and Rural Development Bank, and allowed young people and graduates of agricultural schools to benefit from land designated for agricultural investment. These measures contributed to improving rural incomes and reducing rural-to-urban migration. This period represented the beginning of a strategic shift in the structure of the Algerian economy, as the centralized approach was replaced by a move toward empowering local producers and promoting private investment in agriculture. Table 7 shows land use by sector during the period 1987–1990.

Table 7. Land Use by Legal Sector during the Period 1987–1990 Unit: (million/hectare)

	1987	1988	1989	1990
Arable agricultural land area	7.62	7.63	7.67	7.66
Agricultural land used for cultivation	3.970	3.976	3.972	3.959

Source: Ministry of Agriculture: S/D land organization: Report on operations related to agricultural land. (June 1994)

Table 8. Evolution of Production for the Periods (1985–1989, 1990, 1991) in millions

Sectors	1985–1989	1990	1991 Provisional
Agriculture	- - +8.9	-17	+35
Hydrocarbon	- - +3.6	+6.3	+1.6
Non-hydrocarbon Industry	- +0.4	+1.1	-2.9
Construction and Public Works	- -0.7	- 1	- 7
Services	- - -0.6	-3.7	+2.6
Gross Domestic Product (GDP)		+1 -2.5	+3.3

Source: Ministry of Agriculture: S/D Land Organization: Report on Operations Related to Agricultural Land (June 1994)

In addition to the points, industrial activity experienced a decline due to the scarcity of foreign currency resources. This led to an increase in the rural population, as job opportunities were limited in urban areas. Referring to Table 8, which shows the evolution of production for the periods 1985–1989, 1990, and 1991, fluctuations in industrial production performance can be observed. These fluctuations reveal the fragility of the rent based economic structure, highlighting the need to diversify the economy and develop agro-industrial manufacturing during that period.

Another reason that contributed to migration to rural areas was the political instability (the “Black Decade”) that Algeria experienced in 1991, which lasted until 1999. This period led to harsher economic and social conditions and had a direct impact on industry and economic development. The effects of these disturbances intensified in the cities, forcing millions of families to leave urban areas for the countryside in search of safety and stability. This demographic shift contributed to the redistribution of the workforce toward the agricultural sector; however, it simultaneously weakened the productive structure in urban areas.

6.2 Group Two (2000–2004)

This group covers the period from 2000 to 2004, which contrasts with the fourth group, which includes indicators such as the number of people aged 0–14, the number of people aged 65 and above, and household consumption. This group experienced the lowest growth compared to 2015–2021, during which household consumption increased at a faster pace than population growth. This reflects both real and overall improvements in purchasing power. This stage corresponds to Algeria’s recovery period, during which the government launched a series of economic programs and reconstruction initiatives. The relative increase in household consumption compared to later periods can be seen as a phase in which the economy remained constrained, mainly due to its heavy dependence on hydrocarbons, limited diversification, and weak job creation outside the hydrocarbon sector. Encouraging the development of the private sector and investment, expanding financing opportunities for small and medium-sized enterprises (economic diversification), and adopting inclusive

employment policies are essential to ensure the sustainability of consumption growth in the long term.

6.3 Group Three: Life Expectancy, Working-Age Population, and Income (2005–2014)

This stage was characterized by a strong representation of life expectancy, the population aged 15–64, and disposable household income indicators. Algeria experienced positive economic growth during this period due to factors such as rising oil prices, and government policies played a crucial role in shaping the economic and social landscape.

Algeria implemented a series of development plans to meet citizens’ needs in employment, healthcare, housing, education, and social protection, which had a positive impact on disposable household income, as well as on birth and death rates, contributing to an increase in life expectancy and population growth. During these five years, the health sector benefited from 244 billion DZD in public investment, directed towards the construction of around 800 facilities, including (National Economic and Social Council, 2008, p. 77):

- 20 hospitals with 200 beds each
- 70 hospitals with fewer than 200 beds
- 260 specialized hospitals and centers
- 133 multi-service clinics

Since 2013, life expectancy has reached 77 years, and in 2021, it stood at 77.7 years, reflecting stability in this regard. ONS (Based on the household survey and not published online) (2019). In parallel, household consumption volume increased, which indicates a further improvement in the standard of living.

This can be interpreted as both the population aged 15–64 and household consumption being equally influenced by household income. According to Modigliani’s Life-Cycle Hypothesis of Consumption, individuals follow their lifetime income when making consumption decisions. Families make lifetime consumption decisions based on their income expectations and population size, which are particularly sensitive to income changes in developing countries. An increase in household income leads to lower

mortality rates, encourages childbirth, and consequently increases both population size and household consumption. Furthermore, political stability, a key driver of economic development, characterized Algeria during this period, attracting foreign investment, boosting economic activities, and contributing to an overall improvement in living standards.

6.4 Group Four: Household Consumption, Population Aged 0–14 and 65+ (2015–2021)

Economic progress and the expansion of infrastructure, including healthcare, social services, and education, compared to previous years, had a profound impact on household consumption and population growth. This, in turn, improved living standards, increased age-specific fertility rates ONS (2019), and reduced mortality rates. (These figures are considered close to reality, as they are based on the 2019 household survey and are not published online, however some differences exist when compared with World Bank data.) Consequently, the population increased in both the 0–14 age group and the 65+ age group.

These increases reflect the government's role in revitalizing economic activity by supporting both consumer and investment demand. This period was marked by two promising five-year programs aimed at giving a strong boost to the Algerian economy during that time. This period can be considered a pivotal stage in Algeria's development trajectory, as it represented a gradual transition toward a more stable economy driven by domestic demand. However, it remained vulnerable to external shocks due to the continued dependence on the hydrocarbon sector. To ensure the sustainability of household consumption growth, it is essential to strengthen economic diversification by supporting non-oil productive sectors, particularly agriculture, manufacturing, and domestically oriented services.

7 CONCLUSIONS

This study identified key demographic indicators influencing household consumption in Algeria using PCA. Results show that household income,

population size, and life expectancy are positively associated with consumption, while rural population exerts a negative effect. Four distinct phases of demographic-consumption dynamics were observed between 1985 and 2022. These findings highlight the importance of integrating demographic factors into economic policy design. Future strategies should focus on leveraging demographic transitions to support sustainable consumption growth, while addressing rural–urban disparities and enhancing social infrastructure.

8 STUDY LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This study constitutes a contribution to the ongoing efforts aimed at deepening the understanding of household consumption dynamics. Nevertheless, certain methodological and practical limitations should be acknowledged, which may serve as avenues for future research. In this regard, several directions are suggested:

- While PCA methodology is useful in capturing linear relationships, dimensionality reduction, and correlations among variables, it does not account for nonlinear dynamics. Future studies could therefore employ more advanced nonlinear models to explore the complex relationships between variables.
- Broadening the scope of analysis by conducting comparative studies between Algeria and a sample of North African countries or other emerging economies that share similar demographic and household consumption patterns.
- Developing household consumption functions within the Algerian economy by incorporating qualitative variables in addition to quantitative ones.
- Extending the analysis to the microeconomic level by modeling household consumption at the household or individual unit level.
 - Enriching the analysis by integrating additional indicators such as consumer expectations, credit market conditions, and living standards to provide a more comprehensive and multidimensional assessment.

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ENTREPRENEURIAL SUPPORT AND SME SUSTAINABILITY: A CASE STUDY IN TWO ALGERIAN PROVINCES

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ABSTRACT

This research examines the role of entrepreneurial support in sustaining small and medium enterprises (SMEs). The case study focuses on the National Unemployment Insurance Fund (CNAC) in Annaba and El Tarf, Algeria, administratively known as wilayas. SMEs are vital for job creation, economic growth, and local innovation, yet they face persistent challenges in financial management and long-term survival. The study employs a descriptive-analytical methodology supported by empirical data and questionnaires targeting entrepreneurs engaged in CNAC's programs. It emphasizes key forms of assistance, including financial and administrative support, training and capacity building, and follow-up processes. Findings indicate that entrepreneurial support has helped reduce unemployment by encouraging business creation. However, such support alone is insufficient to ensure long-term economic sustainability unless complemented by policies such as tax reductions, improved facilities, and a more favorable entrepreneurial climate. The study therefore recommends reconsidering current support mechanisms to help SMEs transition from aid dependency to competitiveness and sustainability, which is essential for local development and a resilient national economy.

1 INTRODUCTION

Today, small and medium-sized enterprises, or SMEs, play a crucial role in the social and economic advancement of numerous countries. In addition to being a vital source of employment, they also stimulate innovation and territorial

dynamism. SMEs seem to be a strategic response to the difficulties of economic diversification and professional integration in an era of significant economic diversification and growing unemployment rates. But the significance of their function presents the crucial question: how can

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their sustainability and viability be guaranteed in frequently unstable and limited environments?

Entrepreneurial systems of assistance hold a central place in that perspective. Their goals are to support project promoters, encourage individual initiative, and establish an environment that is conducive to business growth (Ratinho et al., 2020). The Algerian government has put in place several measures to encourage self-employment and reduce dependence on the salaried labor market. The National Unemployment Insurance Fund (CNAC) is particularly noteworthy for the extent of its institutional development. Originally created to oversee unemployment benefits, it has progressively evolved into a significant force in assisting entrepreneurs, especially by offering funding and mentoring to young entrepreneurs.

One of the essential issues of this policy lies in the transition between support for business creation and ensuring the sustainability of SMEs. In other words, encouraging the creation of new projects is not enough; it is also essential to make sure that these projects endure, expand, and make a sustainable contribution to the socioeconomic fabric (Barron et al., 2023). Because it affects the actual efficacy of support systems and their capacity to achieve goals for social and economic development, the sustainability of SMEs thus becomes a crucial issue.

The National Unemployment Insurance Fund, CNAC-Annaba and El Tarf, as the case study, are explained by their geographical position and their economic specificities. These areas, which are on the country's eastern border, have many resources but still face structural challenges. As such, it provides a useful framework for observing how local entrepreneurial dynamics are affected by support mechanisms, especially CNAC. In addition to determining the possible constraints of these mechanisms, the examination of the CNAC (Annaba and El Tarf) case will enable an assessment of the degree to which the assistance offered aids in the establishment and, more crucially, the sustainability of SMEs.

1.1 Research Problem

The present research examines the role that entrepreneurial support plays in the expansion

and sustainability of SMEs. The efficacy of support programs varies depending on the region, industry, and organizational context. Therefore, an analytical framework is required to connect public policies and support mechanisms to social, economic, and environmental outcomes. Given the above context, this research seeks to examine the following question: to what extent do entrepreneurial support mechanisms provided by CNAC foster the sustainability of SMEs in Annaba and El Tarf provinces?

1.2 Research Objectives

The objectives are:

- Assess the role of support: Determine whether the CNAC's support (financial and technical) not only facilitates immediate job creation but also ensures the long-term viability of businesses (growth, innovation, and resilience to risks such as economic fluctuations).
- Analyze the transition to sustainability: Investigate the factors that enable (or hinder) the shift from "initial support" (to combat unemployment) to "autonomy" (profitable and export-oriented businesses). For example, how to overcome barriers perceived by entrepreneurs (financial risks, bureaucracy, lack of skills).
- Draw local lessons for national policy: Based on the contrasting cases of El Tarf (a rural area characterized by agriculture and cross-border trade) and Annaba (an industrial city), the study offers recommendations to strengthen public support mechanisms in Algeria, particularly in a country where, the National Office of Statistics (ONS), more than 70% of the population is under the age of 35 (ONS, 2025).

2 LITERATURE REVIEW AND HYPOTHESES

The significance of entrepreneurial support in fostering the development and sustainability of SMEs has been the subject of extensive academic and policy discussions globally. As we undergo significant changes in our economies and societies, SMEs are essential to economic development. They generate most employment, reinforce local industries, influence communities, and play key roles in domestic and global value

chains. They additionally help reduce inequality and broaden the advantages of technological and international developments when the conditions are correct (OECD, 2019). However, SMEs' survival and growth frequently face more obstacles due to limited access to capital, inadequate managerial skills, and insufficient institutional support mechanisms, and limited access to finance is one of these (Beck & Demircug-Kunt, 2006).

2.1 SMEs and Entrepreneurial Support

There is no one definition of SMEs that everyone agrees on. Different nations and even within countries have different ideas about what SMEs are (Tonge, 2001). The number of workers determines the definition of SMEs to group enterprises (Mbaye, 2023). The Organisation for Economic Co-operation and Development (OECD, 2000) defines SMEs as independent firms, non-subsidiary businesses (Van Wyk, 2022) with fewer than 250 employees. The European Union (EU) has the same definition, and SMEs must have either an annual turnover of less than €50 million or a balance sheet total of less than €43 million (European Commission, 2005). Complementing this, the World Bank also says that SMEs are formal and informal businesses with less than 250 workers that are very important for creating jobs and making money in developing countries. In the EU, a micro enterprise has no more than 9 employees. The Small Business Funding Scheme is an example of a government program that uses a tiered categorization system. Businesses with 0–9 workers are considered micro-businesses, those with 0–19 employees are considered small enterprises, and those with 0 – 249 employees are considered medium-sized firms. In addition to size, categorization systems may also consider things like yearly turnover. These many criteria constitute the basis for the classification of SMEs and guide further assessments. In general, these definitions stress that SMEs are essential to the dynamics of the economy, external financing and operational efficiency are significant for their growth and sustainability (Utara Malaysia, 2020). In this context, entrepreneurial support can be understood as the set of financial, administrative,

technical, and advisory services provided to new and existing businesses to enhance their chances of success. Studies highlight that access to credit, capacity-building, and mentorship programs significantly improve SMEs' performance (Storey, 2004). It is essential to specify the nature of entrepreneurial support; it includes both the ways that firms may be started and grown and the circumstances that ensure they will last for a long time. Entrepreneurial support encompasses mechanisms that facilitate business creation, financing, and growth. It includes both financial measures (loans, grants, tax relief) and non-financial measures (training, follow-up, strategic support) (Ferreira & Ferreira, 2025).

International experiences show that effective support mechanisms are those that include both financial and non-financial support. Sole financing, without adequate follow-up, does not guarantee business sustainability (Poojari, 2023).

2.2 SMEs and Sustainability

A key dimension of this discussion lies in examining the organizational structures of SMEs and their capacity to support sustainability. SMEs exhibit considerable heterogeneity in their business models and organisational structures. So far, the literature has not provided a clear characterization of SMEs, particularly in reference to their internal structures and models of operation (Caputo et al., 2024). Despite growing interest in understanding the role of SMEs in the sustainability transition, academic literature is still not very clear. Current research frequently yields conflicting insights and is devoid of a cohesive theoretical framework that addresses the distinctive attributes of this sort of organization (Miethy et al., 2025). Indeed, according to Dyllick and Hockerts (2002), sustainability within SMEs goes beyond mere financial survival. It includes their ability to continually adapt to market dynamics, sustain competitive advantages, and actively contribute to socio-economic progress.

2.3 The Algerian Context and CNAC's Role

In Algeria, the government has introduced several programs to address unemployment and stimulate entrepreneurship. The National Unemployment

Insurance Fund (CNAC) is one of the most prominent initiatives (Mouhous et al., 2023). (National Unemployment Insurance Fund) supports individuals with no jobs to create and sustain SMEs through an entrepreneurship program. This mechanism operates by connecting the promoter, a partner bank, and the CNAC itself through a triangle financing model. The maximum investment is 10 million Algerian dinars. It combines a mix of tax and customs incentives (Ministère des Finances, 2023), interest-subsidized bank credit, and a public guarantee that covers up to 70% of the project's value (Ministère Des Finances, 2025). It also offers complete coaching and support from the idea stage to the launch of the business and the first few months of operation.

It should be noted that the National Entrepreneurship Support and Development Agency (NESDA) has overseen running the creation and growth program since 2022. CNAC, on the other hand, is still in charge of collecting unpaid debts and carrying out its main unemployment insurance duties (CNAC, n.d.).

The CNAC mechanism is mainly for jobless people who are registered with the National Employment Agency (ANEM) or CNAC. Historically, this included people between the ages of 30 and 50, but Presidential Decree No. 19-58 (2019) raised the maximum age restriction to 55 (Gouvernement, 2019). Eligible beneficiaries must submit proposals for starting or growing a business that meet the CNAC eligibility requirements and stay under the program's 10 million DZD investment limit.

Lastly, it is crucial to know the difference between financial tools like loans, guarantees, and tax breaks, and non-financial tools like advice, training, and technical help for project development inside the CNAC's support system.

2.4 CNAC Mechanisms in Support of SMEs

CNAC implements several mechanisms:

- In terms of financial support, it provides a non-remunerated loan, subsidized bank credit, and fiscal and customs incentives to reduce investment costs (CNAC, n.d.).

- The financing structure is triangular (promoter + bank + CNAC) with an investment ceiling of 10 million Algerian dinars (DZD) (CNAC, n.d.).
- The non-financial support includes technical assistance, entrepreneurial training, validation of professional experience, and management support through local offices (CNAC, n.d.).
- Finally, other forms of support involve social incentives, institutional synergy with the National Agency for Microcredit Management (ANGEM) and National Entrepreneurship Support and Development Agency (NESDA) (Fethallah & Rais, 2024), and post-creation monitoring to ensure business sustainability.

Consequently, our research formulates the following hypotheses to investigate the correlation between entrepreneurial support and SME sustainability, utilizing the National Unemployment Insurance Fund (CNAC) program as a case study in Annaba and El-Tarf provinces:

- H₁: CNAC's financial support has a significant and positive effect on entrepreneurial support.
- H₂: The CNAC's Post-Creation Follow-up has a significant and positive effect on entrepreneurial support.
- H₃: CNAC's Entrepreneurial Support has a significant and positive effect on the long-term sustainability of SME.
- H₄: Internal and external business factors have a significant and positive effect on SME Sustainability.
- H₅: Entrepreneurial Support has a significant indirect effect on SME Sustainability through Internal and External Business Factors.

3 METHODOLOGY

In this research paper, "sustainability" denotes explicitly the economic sustainability of SMEs, encompassing their long-term survival, stability, and financial performance, rather than environmental or ecological sustainability.

To explore the role of entrepreneurial support on the sustainability of SMEs, a questionnaire was administered to 216 projects supported by the CNAC in two Algerian provinces (Annaba and El Tarf). The choice of this population is justified due to the diversity of the sectors represented (steel

industry, tourism, services, agri-food, construction materials, chemicals/rubber/plastics...) and the economic significance of the CNAC's programs in fostering youth entrepreneurship and mitigating unemployment. This fieldwork aims to determine how financial and Post-Creation Follow-up impact the long-term success and competitiveness of these businesses.

3.1 Questionnaire Survey

The questionnaire was created in several steps: To find the main variables and how to measure them, we first did a thorough review of the literature on entrepreneurial support and SME sustainability. Drawing from prior empirical research and theoretical frameworks, three principal constructs were delineated: Entrepreneurial Support (*Independent Variable*), Internal and External Business Factors (*Mediating Variables*), and SME Sustainability (*Dependent Variable*).

The questionnaire items were formulated and categorized based on these constructs:

- Entrepreneurial support includes financial support (like loans, reductions in taxes, and guarantees), and Post-Creation Follow-up (like visits, calls, reviews).
- Internal and External Business Factors: the entrepreneur's skills, motivation, and experience, as well as the resources and organization of the business (financial management, innovation, and managerial practices).
- SME Sustainability: long-term survival, stability, and financial success.

A five-point Likert scale was used to rate everything, with number (1) being "Strongly Disagree" and (5) being "Strongly Agree" (Vagias, 2006).

To ensure the measurement instrument's reliability and validity, we used Cronbach's alpha, which measures the degree of internal consistency and the homogeneity of the items.

3.2 Data Collection

The researchers collected the data for this study between February and September 2025 by distributing a bilingual (French–Arabic) questionnaire to entrepreneurs who benefited

from CNAC's support in Annaba and El-Tarf provinces.

The questionnaire was administered online via Google Forms and complemented by field visits to local CNAC agencies, ensuring adequate representation of supported SMEs.

In total, the researcher received 216 valid responses from SME managers whose businesses were established with CNAC's assistance.

In this study, Partial Least Squares Structural Equation Modeling (PLS-SEM) was utilized, as it is recommended over Covariance-Based SEM (CB-SEM) due to its effectiveness with relatively small sample sizes (Nguyen et al., 2024, p. 70).

The collected data were then coded and analyzed using SmartPLS 4, applying the PLS-SEM technique.

This method made it possible to empirically assess the role of entrepreneurial support (financial and post-creation) on SME sustainability, while testing the mediating role of internal and external business factors.

4 RESEARCH RESULTS

4.1 Descriptive Statistics

In total, 216 valid responses were obtained, all beneficiaries of the National Unemployment Insurance Fund (CNAC) in Annaba and El-Tarf provinces (Algeria). Most of the SMEs surveyed are small and very small businesses with an average of about two jobs created per project. 38% of them have been in business for 1 to 3 years, and 67.6% employ fewer than 10 people. The population studied is mainly characterised by services (37%), agriculture (30.6%), and tourism (18.5%), which reflect the local economy of Annaba and El-Tarf. Most entrepreneurs have a high school education (47.2%) or a university degree (44%), and a significant proportion have already acquired work experience (69.4%). The sample is primarily composed of educated and relatively experienced small business owners working in key local economic sectors, which coincides with the CNAC's mission objective of promoting sustainable entrepreneurship in the

region. The sample mainly consists of educated and relatively experienced small company owners engaged in essential local economic sectors, which coincides with the CNAC's aim to promote sustainable entrepreneurship in the regions.

4.2 Testing the Measurement Model

The process of PLS-SEM generally involves a two-step approach that includes evaluating both the measurement and the structural model (Nyankom Takyi, 2021). The initial phase involves

assessing the measurement model to confirm the reliability and validity of the constructs. The examination of internal consistency reliability is examined by applying Cronbach's Alpha (CA) and Composite Reliability (CR) (Wui San et al., 2024), where threshold values above 0.70 signify satisfactory reliability (Nurhafizah et al., 2024; Gordon et al., 2023). Following this, the assessment of convergent and discriminant validity of the constructs is conducted to verify the adequacy of the measurement model, as shown in Figure 1.

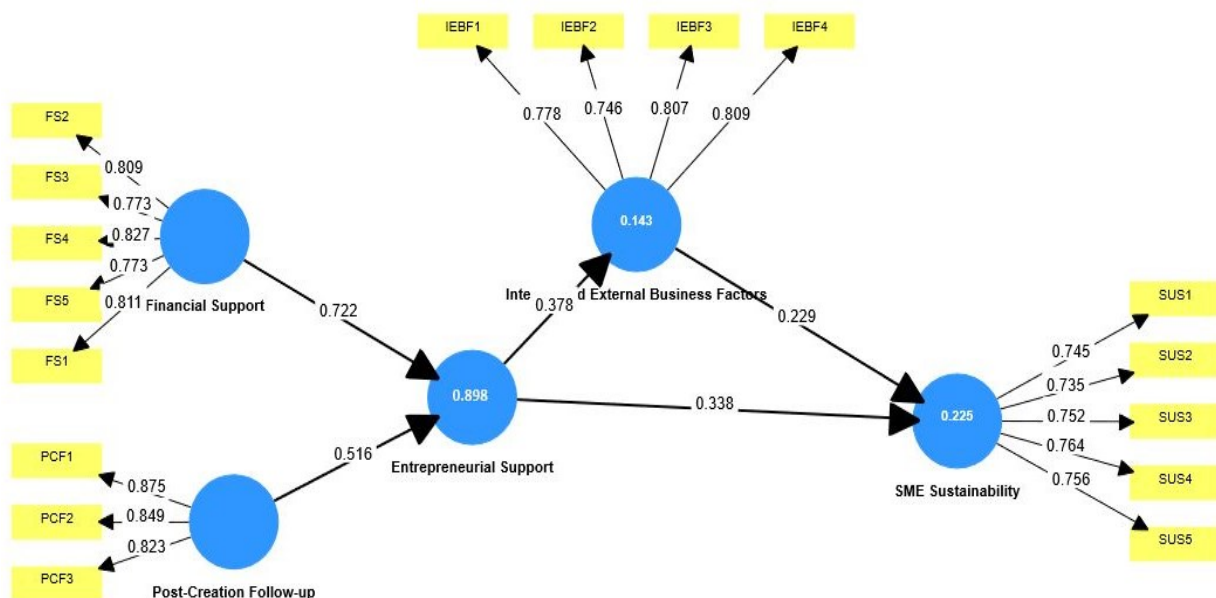


Fig. 1 Measurement Model. (Source: the outputs from Smart-PLS 4)

- Cronbach's Alpha (CA) coefficient assesses the internal consistency among items measuring the same construct. The obtained values range from 0.793 to 0.858, which exceed the minimum values of 0.60 to 0.70 (Hair et al., 2017). This indicates that all measurement scales demonstrate satisfactory internal consistency, meaning that the items are homogeneous and measure the same fundamental concept.
- In the internal reliability analysis, Cronbach's Alpha, the fourth PCF item (PCF4) was excluded due to its low item-total correlation, which compromised the overall reliability. The removal of this item significantly improved the internal consistency of the construct, thereby justifying its exclusion.
- The composite reliability (ρ_a) values range from 0.801 to 0.860, and the CR values from 0.865 to 0.898. All these values are above the recommended 0.70 threshold (Hulland, 1999), indicating high reliability and measurement stability. The slightly higher CR compared to CA suggests that the shared variance among the indicators is greater than the error variance.
- The Average Variance Extracted (AVE) evaluates the proportion to which the indicators of each construct account for the variance. The AVE values span from 0.563 to 0.722, exceeding the suggested threshold of 0.50 (Ab Hamid et al., 2017).
- The outer loadings obtained fall within the following ranges: Financial Support (FS): from 0.773 to 0.827, Internal and External Business Factors (IEBF): from 0.746 to 0.809, Post-Creation Follow-up (PCF): from 0.702 to 0.875, SME Sustainability (SUS): from 0.735 to 0.764. All these values exceed the threshold of 0.70,

indicating that the indicators associated with each construct exhibit a strong correlation with their respective latent variables.

These coefficients suggest that each item contributes significantly to measuring the concept it is intended to represent.

This demonstrates an acceptable level of convergent validity, meaning that the indicators are well correlated with their respective latent construct. The Cronbach's Alpha (CA) coefficient, CR, AVE, and outer loadings scores are shown in Table 1.

Table 1. Reliability and Convergence Assessment

	Cronbach's alpha (CA)	Composite reliability (rho_a) (CR)	Composite reliability (rho_c) (CR)	Average variance extracted (AVE)	Outer loadings
Financial Support (FS)	0.858	0.860	0.898	0.638	0.773-0.827
Internal and External Business Factors (IEBF)	0.793	0.801	0.865	0.617	0.746-0.809
Post-Creation Follow-up (PCF)	0.807	0.810	0.886	0.722	0.702-0.875
SME Sustainability (SUS)	0.806	0.807	0.866	0.563	0.735-0.764

Establishing convergent validity is the initial requirement for demonstrating discriminant validity. Discriminant validity, alongside convergent validity, necessitates that each indicator loads uniquely on only one construct. Utilizing the same indicator for two constructs complicates the assertion of their distinctiveness. Unidimensionality necessitates the absence of cross-loaded indicators, which is essential for attributing meaning to a latent construct. This criterion was suggested in Fornell and Larcker's model, which posited the absence of cross-loaded indicators. This criterion was explicitly outlined in (Henseler et al., 2015), who proposed the Heterotrait Monotrait (HTMT) approach for assessing discriminant validity.

- Each indicator's loading on its own construct (the bolded diagonal values conceptually) is higher than its loadings on the other constructs. The results of the cross-loading analysis validate that all measurement items are distinctly distinguished and that each latent variable represents a unique theoretical construct (Table 2).
- The Fornell–Larcker criterion is utilized to evaluate discriminant validity, ensuring that each latent construct is empirically distinct from the others. Fornell and Larcker (1981) (Gordon et al., 2023) indicate that discriminant validity is confirmed when the square root of the AVE for

each construct (the diagonal values) exceeds the correlations between that construct and all other constructs (the off-diagonal values). The results indicate that each construct in the model exhibits greater variance with its respective indicators than with any other construct within the model (Table 3). This suggests that the constructs of Financial Support, Internal and External Business Factors, Post-Creation Follow-up, and SME Sustainability are both conceptually and empirically distinct.

- The HTMT ratio is a stricter way to check for discriminant validity in PLS-SEM. It calculates the average correlation across indicators across constructs in comparison to the average correlation within the same construct (Henseler et al., 2015). Table 4 demonstrates that all the HTMT values are much lower than 0.85 and 0.90. This means that the constructs are distinct from each other in a real way and that there is no substantial multicollinearity or conceptual overlap between them.

The evaluation of discriminant validity for the constructs was conducted through three established methods: cross-loadings, the Fornell–Larcker criterion, and HTMT. The results of these tests, shown in Tables 2, 3, and 4, demonstrate that all constructs are empirically distinct, thus validating the measurement model's adequacy.

Table 2. Cross-loadings Discriminant Validity

Construct	Item	ES	FS	IEBF	PCF	SUS
Financial Support (FS)	FS1	0.698	0.811	0.191	0.253	0.314
	FS1	0.698	0.811	0.191	0.253	0.314
	FS2	0.713	0.809	0.252	0.241	0.325
	FS2	0.713	0.809	0.252	0.241	0.325
	FS3	0.664	0.773	0.218	0.212	0.298
	FS3	0.664	0.773	0.218	0.212	0.298
	FS4	0.737	0.827	0.264	0.262	0.332
	FS4	0.737	0.827	0.264	0.262	0.332
	FS5	0.648	0.773	0.246	0.148	0.302
	FS5	0.648	0.773	0.246	0.148	0.302
Internal and External Business Factors (IEBF)	IEBF1	0.318	0.238	0.778	0.270	0.169
	IEBF2	0.272	0.227	0.746	0.191	0.263
	IEBF3	0.303	0.219	0.807	0.277	0.311
	IEBF4	0.297	0.240	0.809	0.230	0.351
Post-Creation Follow-up (PCF)	PCF1	0.644	0.246	0.296	0.875	0.257
	PCF1	0.644	0.246	0.296	0.875	0.257
	PCF2	0.605	0.222	0.304	0.849	0.202
	PCF2	0.605	0.222	0.304	0.849	0.202
	PCF3	0.582	0.250	0.178	0.823	0.226
	PCF3	0.582	0.250	0.178	0.823	0.226
SME Sustainability (SUS)	SUS1	0.304	0.293	0.243	0.179	0.745
	SUS2	0.331	0.313	0.289	0.197	0.735
	SUS3	0.297	0.293	0.278	0.170	0.752
	SUS4	0.304	0.250	0.271	0.235	0.764
	SUS5	0.351	0.324	0.255	0.227	0.756

Table 3. Fornell-Larcker Discriminant validity

	FS	IEBF	PCF	SUS
FS	0.799			
IEBF	0.293	0.785		
PCF	0.282	0.307	0.849	
SUS	0.394	0.357	0.270	0.750

Table 4. Heterotrait-Monotrait Ratio (HTMT)

	FS	IEBF	PCF	SUS
FS				
IEBF	0.356			
PCF	0.336	0.382		
SUS	0.472	0.435	0.333	

After confirming the reliability, convergent validity, and discriminant validity of the measurement model, the subsequent step is to evaluate the structural model. This phase seeks to assess the interrelations among the latent constructs, their

explanatory power, and the predictive relevance of the model.

4.3 Testing the Structural Model

The structural model was evaluated based on the collinearity between constructs, the significance and relevance of the hypothesized paths (indirect effects and interaction effects), the adjusted R^2 coefficient, the effect size (f^2), and the predictive relevance (Q^2) (Cheah et al., 2020).

- Variance Inflation Factor (VIF): Checks for multicollinearity by determining the degree to which the variance of an estimated regression coefficient increases when there are correlations among the explanatory variables. (Akinwande et al., 2015). The recommended threshold for this criterion is that VIF values below 5 signify the absence of considerable multicollinearity, hence ensuring the results of the structural model and the

study's conclusions are more reliable. The outcomes are presented in Table 5.

Table 5. Collinearity statistics (VIF)- Inner model

	VIF
Entrepreneurial Support → Internal and External Business Factors	1.000
Entrepreneurial Support → SME Sustainability	1.183
Financial Support → Entrepreneurial Support	1.087
Internal and External Business Factors → SME Sustainability	1.290
Post-Creation Follow-up → Entrepreneurial Support	1.087

- The VIF values indicate no collinearity issues in the model. All predictors show VIF values between 1.000 and 1.290, well below the recommended threshold of 5 (Hair et al., 2021). These results confirm that the predictor constructs are sufficiently distinct and that multicollinearity does not threaten the reliability of the structural model estimates.
- Coefficient of Determination R^2 : Most researchers interpret the coefficient of determination (R^2) as a measure of the model's in-sample fit, obtained by using the model estimates to predict the observations of the full dataset. Nevertheless, R^2 captures only the explanatory power of the model (Shmueli et al., 2019).

Table 6. Coefficient of Determination (R^2)

	R-square	R-square adjusted
Entrepreneurial Support	0.899	0.897
Internal and External Business Factors	0.143	0.139
SME Sustainability	0.225	0.218

Following the results shown in Table 6, the coefficient (R^2) provides an overview of how well the predictor constructs explain the variance of the endogenous variables:

- Entrepreneurial Support is almost fully explained by its predictors ($R^2 = 0.899$).

- IEBF shows low explanatory power ($R^2 = 0.143$).
- while SME Sustainability has moderate explanatory power ($R^2 = 0.225$).

Overall, the model demonstrates substantial prediction for ES and weaker prediction for IEBF and SME Sustainability.

- The effect size (f^2): In PLS-SEM, Cohen's f^2 is used to assess the effect size of each predictor on an endogenous construct. It measures how much the R^2 value decreases when a specific predictor is removed from the model. According to Cohen (1988), f^2 values of 0.126, 0.167, and 0.922 indicate small, medium, and large effects, respectively.

Table 7. (f^2) Effect Size Results

	f-square
Entrepreneurial Support → Internal and External Business Factors	0.167
Entrepreneurial Support → SME Sustainability	0.126
Financial Support → Entrepreneurial Support	0.922
Internal and External Business Factors → SME Sustainability	0.058
Post-Creation Follow-up → Entrepreneurial Support	0.894

The effect size (f^2) results indicate that:

- Entrepreneurial Support has a moderate effect on IEBF ($f^2 = 0.167$) and a small effect on SME Sustainability ($f^2 = 0.126$).
- IEBF shows a small effect on SME Sustainability ($f^2 = 0.058$).
- In contrast, Financial Support ($f^2 = 0.922$) and PCF ($f^2 = 0.894$) exhibit very strong effects on Entrepreneurial Support. These values indicate that both predictors substantially contribute to the variance of Entrepreneurial Support within the model.
- Q^2 predict: Since 2018, recommend PLSpredict as the preferred approach for assessing predictive power; the present study relies on the PLSpredict results. The LV summary table reporting Q^2 -predict, RMSE, and MAE are commonly used metrics for evaluating models (Hodson, 2022).

Table 8. *PLSpredict LV*

	Q ² predict	RMSE	MAE
Entrepreneurial Support	0.997	0.057	0.045
Internal and External Business Factors	0.119	0.947	0.764
SME Sustainability	0.157	0.927	0.751

Predictive relevance (Q²), namely, testing to obtain information about how good the observation value is because of the model, and considering the parameters. If Q² values greater than zero for a particular reflective endogenous latent variable signify the predictive validity of the path model. (Hair et al., 2017), and vice versa, if the Q² value < 0, then the model used shows that it lacks predictive relevance.

- Entrepreneurial Support (Q²-predict = 0.997), this value is extremely high, indicating excellent out-of-sample predictive performance.
- Internal and External Business Factors (Q²-predict = 0.119), this positive but low value suggests weak predictive relevance, although the model still performs better than a naïve benchmark.
- SME Sustainability (Q²-predict = 0.157), this value indicates moderate predictive accuracy, showing that the model has a meaningful predictive capability for the sustainability of SMEs.

All Q²-predict values are positive, confirming that the model possesses predictive relevance for all endogenous variables.

- The Root Mean Square Error (RMSE) measures the average error of a model's prediction (Wensheng et al., 2024). It penalizes large errors more strongly because the differences are squared. RMSE is particularly useful when evaluating how well the model performs across observations and when large errors are especially undesirable.
- RMSE can be applied to a variety of features because it aids in determining whether a feature enhances model prediction or not (Aryan et al., 2022).

- Entrepreneurial Support (RMSE = 0.057). The very low RMSE indicates minimal prediction error and excellent accuracy.
- Internal and External Business Factors (RMSE = 0.947). The higher RMSE shows that predictions for this construct are less accurate, consistent with its weaker Q²-predict.
- SME Sustainability (RMSE = 0.927). Its RMSE value indicates a moderate level of prediction error.

Entrepreneurial Support is predicted with the highest precision, while IEBF and SME Sustainability show acceptable but less accurate predictions.

- Mean Absolute Error (MAE): Regularly employed in model evaluation studies (Chai & Draxler, 2014). MAE is the average absolute difference between predicted and actual values, easy to interpret because it uses absolute values, making it less sensitive to extreme errors compared to RMSE.
- Entrepreneurial Support (MAE = 0.045), a very small MAE, confirms highly accurate and consistent predictions.
- Internal and External Business Factors (MAE = 0.764), the large MAE indicates substantial prediction deviation, reflecting weaker predictive power.
- SME Sustainability (MAE = 0.751), this value shows a moderate average prediction error.

MAE values support the previous findings: Entrepreneurial Support is predicted very accurately, while the other two constructs show moderate to low accuracy.

Overall, the structural model demonstrates satisfactory quality. The VIF values indicate that multicollinearity among predictors is absent. The R² results indicate significant explanatory power for Entrepreneurial Support, while indicating acceptable levels for IEBF and SME Sustainability. The effect size analysis (f²) indicates that Financial Support and Post-Creation Follow-up have a significant impact on Entrepreneurial Support, whereas the other relationships demonstrate small to moderate effects. If Q² values exceed zero, the model can be considered to have meaningful predictive relevance. These results collectively support the robustness and reliability of the structural model.

4.4 Hypotheses Testing

To evaluate the stated hypotheses, we used standardized path coefficients (β), t-values, and p-values to analyze the structural model. Table 9 shows the results for the four hypothesized correlations. All hypotheses are validated, indicating that the components within the model exert strong and positive impacts on one another.

The examination of the factors influencing Entrepreneurial Support reveals that Financial Support has a robust and statistically significant effect ($\beta = 0.722$, $t = 6.949$, $p < 0.001$), hence offering considerable validation for H₁, showing how important financial support is for helping entrepreneurs by making it easier for them to get the resources they need; relieving financial constraints and enhancing managerial competencies. Post-Creation Follow-up is a strong predictor of Entrepreneurial Support ($\beta = 0.516$, $t = 4.088$, $p < 0.001$), which supports

H₂. This research underscores the need for continuous mentorship, advisory services, and oversight following firm creation in fostering entrepreneurial development.

The findings demonstrate that Entrepreneurial Support significantly influences SME Sustainability ($\beta = 0.338$, $t = 4.587$, $p < 0.001$), providing support for H₃ and underscoring the importance of training, mentoring, and access to resources in strengthening the long-term viability of SMEs. Moreover, both Internal and External Business Factors exhibited a positive and substantial effect on SME Sustainability ($\beta = 0.229$, $t = 3.202$, $p = 0.001$), hence validating H₄, indicating that beneficial internal competencies and external circumstances, such as operational efficiency, market accessibility, and competitive positioning, play a crucial role in the sustainability of SMEs.

Table 9. Structural Model Path Coefficients and Hypothesis Testing Results

Hypotheses	Path	Coeffi-cient (β)	t-value	p- value	Supported
H ₁	Financial Support → Entrepreneurial Support	0.722	6.949	0.000	Yes
H ₂	Post-Creation Follow-up → Entrepreneurial Support	0.516	4.088	0.000	Yes
H ₃	Entrepreneurial Support → SME Sustainability	0.338	4.587	0.000	Yes
H ₄	Internal and External Business Factors → SME Sustainability	0.229	3.202	0.001	Yes

The specific indirect effects analysis indicates that Entrepreneurial Support has a positive and significant indirect effect on SME Sustainability via Internal and External Business Factors ($\beta = 0.087$, $t = 2.934$, $p = 0.002$). Table 10 shows the result for the fifth hypothesized correlation. This result corroborates the mediating function of Internal and External Business Factors in the correlation

between Entrepreneurial Support and SME Sustainability. The direct relationship between Entrepreneurial Support and SME Sustainability is still positive and significant ($\beta = 0.338$, $p < 0.001$); hence, validating H₅ means that Entrepreneurial Support contributes to SME Sustainability in two ways: directly and by improving business conditions better inside and outside the company.

Table 10. Specific indirect effects and Path coefficient

Hypothesis	Path	β (Coefficient)	t-value	p- value	Supported
H ₅	Entrepreneurial Support → Internal and External Business Factors → SME Sustainability	0.087	2.934	0.002	Yes

5 DISCUSSIONS

The results of this study offer robust empirical evidence corroborating the theoretical proposition that entrepreneurial support systems are essential for enhancing operational conditions and supporting the sustainability of SMEs. These findings enhance the current research by illustrating that financial support and post-creation follow-up are critical determinants of SME success and long-term sustainability, especially in emerging nations.

First, the study shows that Financial Support has a considerable and significant positive influence on Entrepreneurial Support ($\beta = 0.722$; $p < 0.001$). This shows how important financial resources are for entrepreneurs to get the things they need, get around obstacles, and plan. This conclusion is consistent with (Beck & Demircuc-Kunt, 2006), who underscore that access to credit is crucial for SME growth, particularly in emerging nations.

Second, Post-Creation Follow-up is a strong and positive predictor of Entrepreneurial Support ($\beta = 0.516$; $p < 0.001$). This backs up the research of Chandler and Hanks (1998), who show that mentorship and advising services after starting a business improve management skills and strategic decision-making. The importance of this connection shows that SMEs get much help from institutions in the early stages, which helps them better manage risks and create skills that will help them survive in the long run.

Third, the results demonstrate that Entrepreneurial Support has significant effects on the sustainability of SMEs ($\beta = 0.338$, $p < 0.001$). This backs up what Urbano and Alvarez (2014) found in earlier research, that ecosystems that assist entrepreneurs make businesses more innovative, competitive, and able to persist over time. This indicates that cultivating entrepreneurial abilities and providing specialized support programs can directly improve SMEs' ability to adapt, expand, and sustain operational stability.

Fourth, internal and external business factors have significant effects on SME sustainability ($\beta = 0.229$, $p = 0.001$). This conclusion shows that good business circumstances, such as easy access to markets, efficient operations, and available resources, are still very important for the long-term success of SMEs. These findings are in

line with Fatoki's (2014) work, which shows that both external influences and internal business factors affect the survival and competitiveness of SMEs.

Lastly, there is a significant indirect impact from Entrepreneurial Support to SME Sustainability through Internal and External Business Factors ($\beta = 0.087$; $p = 0.002$), which means that there is some mediation. This means that helping entrepreneurs helps SMEs stay in business by making their internal and external conditions better.

6 CONCLUSIONS

This study examined the importance of entrepreneurial support, including financial support, post-creation follow-up, and both internal and external business factors, in enhancing the sustainability of SMEs supported by CNAC in Annaba and El Tarf regions. The study utilized PLS-SEM to evaluate the direct and indirect impacts of different support mechanisms on the development of SMEs.

The results reveal that financial support and post-creation follow-up after starting a business are important factors that affect entrepreneurial capacity. Financial support helps entrepreneurs start and grow their businesses. Support once the business has been established, such as advice, training, supervision, and technical help, helps them develop their abilities, lower their risks, and improve their performance. Entrepreneurial support significantly assists SMEs in staying in business, and both internal and external business elements are equally important, with some of them acting as intermediaries in this interaction.

Methodologically, model indicators (VIF, R^2 , f^2 , Q^2 , and direct and indirect effects) validate the robustness of the proposed framework and illustrate the applicability of PLS-SEM for examining intricate entrepreneurial support in emerging nations. In practice, the results show that CNAC and other comparable organizations should make their financial programs stronger, improve their post-creation follow-up services, and offer more opportunities for ongoing training. Digitalization, better governance, and easier access to markets are all things that policymakers should do to make the SME environment better.

Future studies may integrate additional variables, like innovation, digital transformation, or institutional quality, and employ longitudinal or comparative methodologies to enhance the understanding of how entrepreneurial assistance affects SME sustainability over time.

7 LIMITATIONS

This study has certain limitations, even if it made some important contributions. First, it was only done in the Annaba and El Tarf regions, which might make it hard to apply the results to other

regions of Algeria where the economic, institutional, and entrepreneurial situations are different. Second, the study relies on cross-sectional data collected at one specific moment. A longitudinal methodology would enable academics to examine the evolution of entrepreneurial support over time and accurately represent the dynamics of SME sustainability. Consequently, subsequent research could extend the scope to include new locations and incorporate a time-based approach to enhance external validity and analytical depth.

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THE LABOR MARKET IN TERMS OF THE SHADOW DIGITAL ECONOMY

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ABSTRACT

This article examines the shadow digital economy (SDE), a growing phenomenon amid digital transformation and rising information costs. We review technical and economic definitions and propose an integrated definition of the SDE. The study offers the first systematic analysis of labor markets and the qualitative traits of participants in this criminal ecosystem. We identify a structured set of labor-market roles within the SDE model. We analyze institutional traps that sustain shadow employment and show how the SDE perpetuates informal and illicit labor arrangements. The paper proposes a clear classification of criminally oriented products and services. We introduce a concise conceptual model of a “shadow” project for designing SDE products or services organized by criminal groups, detailing participant roles and project composition. Specialized services that require further study are grouped and highlighted. Our findings indicate that SDE activity extends beyond direct financial loss, eroding consumer trust, damaging brand reputation through data breaches, fraud, and counterfeiting, and posing risks to national security. The study ends with policy implications and recommendations for periodic evaluation and integration of AI-related risks into financial governance.

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1 INTRODUCTION

In the mid-20th century, interest in the shadow economy began to grow in various countries. Various studies conducted during this period led to the emergence of a new field in economics and the development of government initiatives aimed at combating the shadow economy and its integration into the legal sphere.

This paper examines the phenomenon of the shadow digital economy (SDE) as a form of latent but escalating digital warfare operating at the intersection of informal economic activity and cybercrime.

The authors analyze key practices within the digital economy, encompassing cyberattacks,

labor-market distortions, transnational data trading, cyberextortion and monetized attacks, platform-based informal labor exploitation, money laundering, and tax evasion, enabled by anonymity and digital payment systems. These processes not only operate "outside the law" but also actively transform the institutional environment, exploiting its vulnerabilities and creating a parallel system of value chains where legal and illegal practices are intertwined.

Based on comprehensive studies of the digital economy, the authors propose an analytical framework that allows us to consider the digital economy as a systemic challenge requiring comprehensive strategies for digital sovereignty, institutional sustainability, and international regulation.

Table 1. Definitions of Technological Risks

Adverse outcomes of AI technologies	Intended or unintended negative consequences of advances in AI and related technological capabilities (including Generative AI) on individuals, businesses, ecosystems and/or economies
Adverse outcomes of frontier technologies (quantum, biotech, geoengineering)	Intended or unintended negative consequences of advances in frontier technologies on individuals, businesses, ecosystems and/or economies. Includes, but is not limited to brain-computer interfaces, biotechnology, geoengineering and quantum computing.
Censorship and surveillance	Broad and pervasive observation of a place or person and/or suppression of communication, information and ideas, physically or digitally, to the extent that it significantly infringes on human and civil rights (e. g. privacy, freedom of speech and freedom of expression).
Cyber espionage and warfare	Use of cyber weapons and tools by state and non-state actors to gain control over a digital presence, cause operational disruption, and/or compromise or damage an entity's technological and information networks and infrastructure. Includes: defensive and offensive cyber operations that occur during or trigger armed conflict, and cyberattacks that steal classified, sensitive data or intellectual property to gain an advantage.
Misinformation and disinformation	Persistent false information (deliberate or otherwise) widely spread through media networks, shifting public opinion in a significant way towards distrust in facts and authority. Includes, but is not limited to: false, imposter, manipulated and fabricated content.
Online harms	Erosion of protection from and/or prevalence of harmful behaviour that poses a digital threat to the emotional or mental health and well-being of individuals. Includes, but is not limited to: online child sexual abuse, online harassment and cyber bullying.

Source: (World Economic Forum, 2025, p. 76)

The Global Risks Report 2025 (World Economic Forum, 2025) confirms the seriousness of the problems and challenges. It outlines the current

global risk landscape in five key dimensions: economic, environmental, geopolitical, social, and technological. The latter group includes Adverse

Outcomes of AI Technologies and Cyber Espionage and Warfare. Global risks ranked by short- and long-term severity include Misinformation and Disinformation, Cyber Espionage and Warfare, Online Harms, Censorship and Surveillance, and Adverse Outcomes of Frontier Technologies (ranked 1st, 5th, 14th, 16th, 31st, and 33rd in the short term) and Misinformation and Disinformation, and Adverse Outcomes of AI Technologies (ranked 5th, 6th, and 5th in the long term, respectively). A detailed description of the technological risks is provided in Table 1.

These categories expand our understanding of the SDE, but they don't answer the question of how technological risks influence the situation.

We also review key literature to deepen understanding of the SDE. These include the works of renowned Austrian economist Friedrich Schneider (Medina & Schneider, 2019; Medina & Schneider, 2021), and his co-authors, scholars Ligita Gasparenienė and Rita Remeikiene (Gasparenienė et al., 2016), and Dinara Orlova (Ohrimenco et al., 2025), whose publications focus on the shadow economy and the digital economy, as well as its various variants, the SDE. Of the recent works, it is worth mentioning (Berdiev et al., 2024), in which the authors highlight “new” features of the SDE, such as the connection between corruption and digital currencies.

Austrian scholar Friedrich Schneider made a significant contribution to the development of the scientific field of measuring the shadow economy. His works examine in detail various aspects of the shadow economy in both developed and developing countries. Schneider (2017) argues that the shadow economy represents the informal sector of a national economy that is not recorded in official statistics.

In addition to “shadow economy,” the literature commonly employs terms such as alternative economy, hidden, concealed, twilight, invisible, autonomous, black, cash, secret, illegal, parallel, and unofficial.

2 RESEARCH METHODOLOGY

This article is based on an analysis of available literature and a structural synthesis of data aimed

at identifying and addressing problems associated with SDE.

The methodological approach includes:

- *a research framework*. This framework derives from the problem being studied and a set of key questions, including characteristics and definitions of SDE, assessments of the labor market and institutional traps, criminally oriented products and services, and specialized services.
- *literature review*. This study employs a systematic review of scholarly and practitioner literature and reports from research firms specializing in information security and its economic aspects. We use these sources to synthesize existing knowledge and identify emerging trends related to the shadow digital economy. The study included a review of scientific databases, including Google Scholar, IEEE Xplore, and Scopus (for the period 2019-2024), except for a few publications. Keywords for identifying sources included terms such as Labor Market, Shadow Digital Economy, Product and Services, Dark Market, Computer Crime, and Cybersecurity.
- *categorization of problems and solutions*. Several security-related issues were identified, including the finding that SDE activities extend far beyond financial losses by undermining consumer trust, damaging brand reputation (notably via data breaches, fraud, and counterfeiting), and threatening regional and national security.
- *data analysis and synthesis*. All collected data was systematized by thematic areas: technological risks, the digital economy and its definitions, labor markets, as well as categories such as the shadow, non-observed, and criminal economies.

A significant obstacle hinders the development of a unified methodology for defining the SDE, its structural components and sectors, and for assessing their economic impact. This primarily relates to the lack of statistical data on SDE. The available data characterizing individual aspects of SDE manifestations are based on surveys conducted by individual researchers and research firms. Evidence indicates that government and commercial organizations are reluctant to report computer incidents and the damage they cause.

This, according to the authors, is precisely what hinders the development of a methodology for studying SDE.

3 DEFINITION OF THE DIGITAL ECONOMY

Let's begin by defining the digital economy:

"The digital economy represents the pervasive use of IT (hardware, software, applications and telecommunications) in all aspects of the economy, including internal operations of organizations (business, government and non-profit); transactions between organizations; and transactions between individuals, acting both as consumers and citizens, and organizations. The technologies underlying the digital economy also go far beyond the Internet and personal computers. IT is embedded in a vast array of products, and not just technology products like cell phones, GPS units, PDAs, MP3 players, and digital cameras" (Malecki & Moriset, 2007).

We will attempt to analyze categories such as the shadow, non-observed, and criminal economies. The methodology proposed by the Organization for Economic Co-operation and Development (OECD) (2017) should be adopted as a starting point. Specifically, the following categories are identified:

- *Underground production* - activities that are productive and legal but intentionally concealed by government authorities to avoid paying taxes or complying with laws (regulations).
- *Illegal production* - production activities that result in the creation of goods and services prohibited by law or that are illegal, through the implementation of unauthorized procedures.
- *Informal sector production* - production activities carried out by unincorporated enterprises in the household sector or other units that are not registered and/or smaller than a specified size in terms of employment and have a market production.
- *Production of households for own-final use* - production activities that result in goods or services being consumed or capitalized by the households that produced them.
- *Statistical underground* - defined as all productive activities that should be recorded in core data collection programs but are omitted due to deficiencies in the statistical system.

Based on the research conducted, the authors propose the following definitions of the shadow digital economy (Ohrimenco et al., 2024; Ohrimenco et al., 2019; Ohrimenco et al., 2021B):

- The shadow digital economy is a specific sphere of economic activity with its own structure and system of economic relations. This specificity is determined by the illegality, informality, and criminal nature of economic activity and the concealment of income.
- From an economic perspective, it is a sphere of economic relations encompassing all types of production and business activities that, in their direction, content, nature, and form, contradict the requirements of current legislation and are carried out contrary to state regulation of the economy and bypassing oversight.
- From a technological perspective, it is an individual and/or collective activity that is illegal, related to the design, development, distribution, support, and use of information and communication technology components hidden from society and of a criminal nature.

Thus, the shadow digital economy (SDE) is understood as a sector of economic relations where production and economic activity, regardless of its direction, content, nature and form, do not comply with the norms of current legislation and is carried out through digital technologies outside the framework of state regulation and control.

Shadow entrepreneurship lies at the core of the SDE and is characterized by the following common features: first, it is a hidden, latent activity that is not recorded by government agencies and is not reflected in official reporting; second, it encompasses all stages of social reproduction: production, distribution, exchange, and consumption; third, all processes, from the analysis of software source code to the monetization of botnet rentals, are criminal and parasitic in nature.

4 LABOR MARKETS

Academic debate surrounds the qualitative characteristics of participants engaged in the shadow digital economy. The model of the shadow digital economy identifies a unique system of labor market participants (Clayton, 2019).

The first group consists of researchers whose work focuses on identifying and studying weaknesses in information systems. Based on the data obtained, new exploitation techniques are developed. The next group consists of developers who create software, including malware designed for extortion or data theft. These developers also create tools for infiltrating systems to gain unauthorized access to information.

After software development comes the distribution stage, where vendors-the final link in the software development process-play a particularly important role. They not only sell malware and stolen data but also provide feedback between developers and end users, allowing for improvements in the quality and functionality of the software being developed. Ensuring the functioning of the entire system infrastructure also requires IT technicians who build and maintain networks, servers, and databases. These specialists create conditions for all other groups to operate. Hackers are also a key element, searching for vulnerabilities in various information systems, applications, and networks that allow criminals to access protected data.

Fraudsters play a key role in the functioning of the SDE system, analyzing vulnerabilities and developing new schemes to deceive and manipulate potential victims. Additionally, there is a category of hosting service specialists who provide hosting services to criminals, supporting fraudulent content and associated websites.

Finally, managers oversee the organization, recruit and onboard participants, assemble teams for specific functions, and coordinate day operations.

It's worth noting that the SDE blurs the lines between employment and individual entrepreneurship. A successful specialist can be employed by a large IT company and simultaneously hire their own contractors, typically working online, who can therefore be located anywhere in the world with internet access.

The IT labor market model demonstrates a new approach, where specialists are both employees and employers. They work for several companies, delegating some of their responsibilities to a team of assistants hired through platforms like Upwork. This allows them to significantly increase their income without formal employment, creating a

multi-tasking system in which they coordinate the team's work while their assistants perform their duties. This model gives flexibility and financial stability but is also fraught with risks due to the difficulty of monitoring by employers and the potential for breaches of employment agreements.

One of the key characteristics of the shadow IT labor market is its secrecy. Programmers working on large projects are often unaware that their labor is being used to create illegal products or implement criminal schemes. This creates conditions for the functional isolation of individual workers from the overall functioning of the underground economy. In some cases, such workers believe their activities are limited exclusively to legal operations, making it difficult for law enforcement to track criminal projects.

Shadow labor markets in the information sphere are characterized by a high level of organizational complexity. Unlike traditional forms of criminal activity, such as drug trafficking or smuggling, which employ more overt and transparent schemes, the use of hired labor in the digital sphere requires much more sophisticated methods of disguise. This allows criminal groups to operate effectively within the framework of legitimate enterprises, concealing the true nature of their activities.

A key feature of such projects is not only the lack of direct worker awareness of the illegality of their work, but also the control structure that minimizes the risk of detection. Organizational mechanisms in shadow-economy projects commonly restrict workers' access to information about the true purpose of their work, thereby lowering the probability that they will perceive their involvement as criminal.

The system of criminal labor organization described above can be examined through the lens of institutional traps, allowing for a deeper understanding of its operating dynamics and parallels with formal systems.

In the context of the SDE criminal organization, developers, traders, hackers, fraudsters, and other participants operate within a specific institutional environment, where their activities are not only subject to criminal "norms" and "rules" but also create conditions for the emergence of institutional traps. Such traps include:

The Legalization Trap. In a traditional labor system, market participants may face a situation where the uncontrolled growth of informal or semi-legal professions leads to the formation of a shadow market where rules are not properly regulated. In a criminal organization, this is analogous to a situation where criminals begin to operate according to established criminal patterns, and such actions become the norm. This leads to the stabilization of criminal practices, making them more difficult to suppress. Participants in the system adapt to these conditions and, in a sense, become dependent on them.

The Trust Trap. Within a criminal network, interactions between developers, traders, and hackers can lead to the formation of a specific trust between participants, which in turn gives rise to institutions that support criminal activity. This creates a vicious circle in which the criminal organization becomes resilient to external interference, and its participants, using existing channels, develop and maintain their activities. In the official economy, a similar situation can arise in shadow labor markets when workers begin to collaborate with informal structures, thereby strengthening illegal schemes. Another example of a “trust trap” is the establishment of arbitration tribunals to resolve disputes between individual and group interests among participants in the energy market.

Corruption trap. Participation in criminal schemes—by fraudsters and managers alike—creates a system in which each participant becomes, to some extent, dependent on corrupt relationships to achieve their objectives. Internal networks of loyalty and dependency hinder potential change, as any violation of established rules can lead to a breakdown of the entire structure. Similarly, in legitimate markets, when institutional problems (such as ineffective legislation or corruption) lead to ineffective functioning, this creates a vicious cycle in which the system becomes incapable of reform.

Automatism trap. In criminal organizations, as in ordinary institutions, situations can arise where participants begin to act out of habit, automatically following established patterns and routine processes. This can lead to the stabilization of existing practices, even if they become less

effective or dangerous. This automatism in actions can be compared to institutional traps in the economy, when the labor market experiences difficulties due to outdated practices or a lack of receptivity to innovation.

These institutional traps in the context of the SDE criminal organization are not only a consequence of certain norms and processes but also a factor that sustains its existence. Participants in the SDE system frequently find themselves trapped: adherence to current rules and norms consolidates the criminal structure. This mirrors formal labour markets, where legacy institutions can restrict development and maintain unstable or ineffective practices.

Shadow employment negatively impacts the labour market in the following ways: informal employment represents a serious distortion of labour relations. The lack of proper employment registration leads to employers' disregard for labour laws and for workers a lack of rights, social guarantees, and legal protection. This opens the door to predatory exploitation of the labor force, particularly through underpaying, noncompliance with labor safety requirements and standards, and the use of labor (high-intensity and excessive working hours, lack of days off, paid vacations, etc.). Underpaying informal workers, in turn, reduces incentives to improve production and implement new technologies. All this leads to poor health among workers, a deskilled workforce, a decline in the quality of labor and the products produced, and ultimately, a decline in the country's and region's labor quality potential. Finally, paying wages in unaccounted cash leads to the concealment of income and the loss of social and tax payments. The latter, in turn, limits the potential for wage increases in the public sector. The lack of control over employment processes, coupled with various law violations, leads to the criminalization of the labor market.

The education system, which also plays a significant role in participation in the informal sector, deserves close attention. Authors Görksány and Cichocki (Gërkhani & Cichocki, 2023) show that highly educated individuals are less likely to engage in the informal sector, not only because they have a more stable income but also because they are more susceptible to social norms of tax compliance. However, in conditions

of economic instability, even highly educated individuals may resort to informal employment methods if the formal labor market does not provide sufficient jobs.

5 PRODUCTS AND SERVICES

It should be noted that the rapid development of new technologies for processing, transmitting, and storing information, as well as mobile devices and applications, ensures a relatively rapid turnover of hardware and software platforms and ecosystems, making products and services constantly fluid. As soon as manufacturers introduce a product or service to the market, they immediately become the subject of intense scrutiny by cybercriminals and the criminal underworld for potential use in crimes (Ohrimenco et al., 2021B), (PMBOK, 2000).

Due to its specific nature, tangible goods in the digital economy are extremely rare and typically involve hardware, while most products are intangible software.

It's important to note one crucial fact: as in the real economy, all goods and services in the digital economy are produced rationally and using a project-based approach (Heldman, 2018). Most "shadow" projects stem from the strategic need to overcome external environmental complexities and the challenges of managing the project as a dynamic system. Using the fundamental principles of a systems approach, project activity can be characterized as managing the relationships between project elements to achieve the project's defined goals.

Let us consider a conceptual model (basic structure) of a "shadow" project for designing a product or service in the sphere of fuel and energy efficiency, organized by a criminal group.

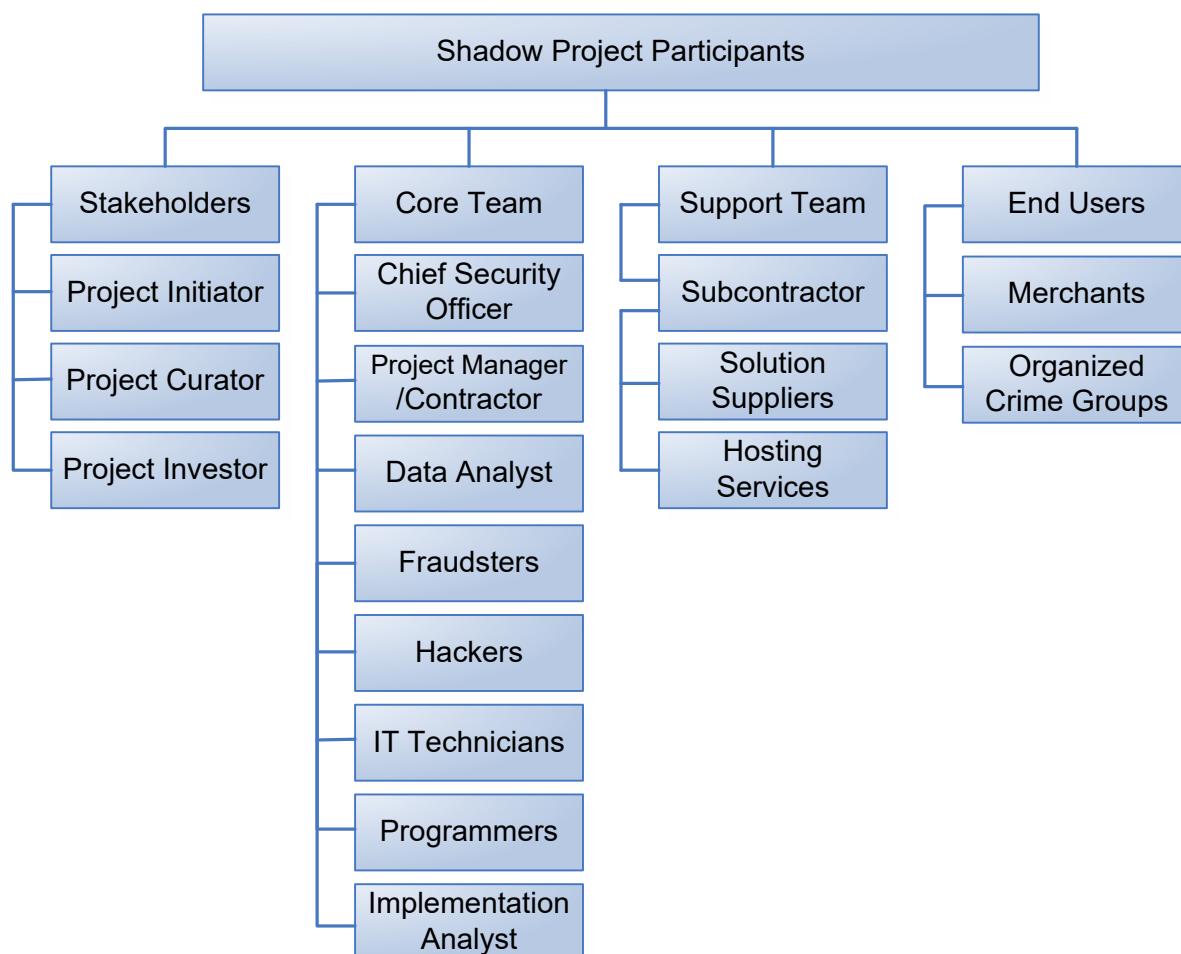


Figure 1: Conceptual model of a project to create a product or service in the SDE

Source: Original work by authors

Based on their level of involvement in a "shadow" project, four groups of participants can be distinguished:

1. *Stakeholders*. These are groups pursuing their own interests and exerting some influence on the members of the core and support teams, as well as on the progress of the project. It is important to note that stakeholder groups do not directly interact with the teams.
2. *Core Team*. A group of specialists working directly on the project in close collaboration.
3. *Support Team*. Larger in size and quality than other project teams. It brings together diverse specialists and relevant structures that provide indirect assistance and influence to members of the core team. It should be noted that support team members are not directly involved in achieving project goals.
4. *End Users*. These are primarily individuals, as well as informal organizations, interested in using the created product or service for their own purposes (individually or collectively) in accordance with its purpose and technical parameters.

Let's consider the project's key participants, which include representatives of the stakeholders:

- *Project initiator*. This is the party with an interest in the successful implementation of the project and the achievement of its primary objectives and is the future owner of the project's outcome. The initiator formulates the key requirements for the project's outcomes, secures project financing from its own or borrowed funds, searches for potential investors, and enters contracts with the project's primary contractors.
- *Project Curator*. This is a senior representative of the organizational structure implementing the project. This person oversees the project's implementation on behalf of the initiator, providing overall control and operational support for the project, including sourcing financial, logistical, human, and other resources. The curator is directly responsible to the initiator for ensuring the project achieves its final goals.
- *Investor*. The party is investing in the project, for example, through loans or borrowed funds. In most cases, the initiator and investor in the project may be criminal organizations.

The following members should be identified within the core team of a "shadow" project:

- *Project Security Manager* – the individual responsible for overseeing the entire range of security and safety functions within the project. Their responsibilities include: preventing the unauthorized collection, processing, and transfer of confidential information about the project and its participants to competing organizations and law enforcement agencies; identifying informants (insiders); exposing agents of influence and undercover law enforcement officers; preventing and countering attempts at infiltration and recruitment of agents from project employees; monitoring the loyalty of project employees, combined with measures to protect them from law enforcement.
- *Project Manager/Contractor* – the specific individual responsible for project management within the project office. They are accountable to the project manager for achieving project objectives within the budget, on time, and to the specified quality level, and ensure operational management of the core project team within the context of key management functions (deadlines, costs, risks, etc.). The project manager is responsible for the overall implementation of the project, as well as for the execution of all work and services under the contract.
- *Data Analyst*, a versatile specialist with knowledge in various fields like mathematics and economic-mathematical methods, programming languages, statistics, information and communications technology, economics, and business. Their responsibilities include collecting and processing analytical data and interpreting it for project management.
- *Expert Analysts*. This is a diverse group of fraud experts with extensive experience in developing new fraud schemes and manipulating victims.
- *Hackers*. A large group of cybersecurity experts with the knowledge and skills to overcome information security systems, software protection tools, organize attacks on information systems, and search for and exploit vulnerabilities in networks, products, and applications.

- **IT Specialists.** A group of specialists who create, maintain, and expand the project's technological infrastructure – networks, systems, servers, databases, etc.
- **Programmers.** Specialists involved in developing algorithms and source code for programs designed to implement various types of software exploits for project implementation.
- **Implementation Analyst.** A specialist who provides assistance and consultations to end users through implementation services. They may also prepare source documentation, coordinate final customer requirements, and fine-tune the product or service being implemented.

Support team members may act as auxiliary participants in a "shadow" project:

- **Subcontractor.** An individual or small organization that provides liaison with the contractor and is responsible for the implementation of specific work and services in accordance with the contract.
- **Supplier.** This is a subcontractor that supplies various goods and services within the project on a contractual basis-equipment, consumables, intangible assets, etc. An example would be a "shadow" service providing hosting services as part of a criminal infrastructure.

The final, but not the least, links in the structure of a "shadow" project, organized and managed by a criminal enterprise, are:

- **Traders.** Individuals or commercial entities that sell and resell the developed product or service in the SDE sector to representatives of organized crime groups and hackers. At the same time, through the feedback function, they provide project office developers with information about user issues to improve the quality of product or service development, as well as support services.
- **Organized criminal group.** This is a stable group of individuals who have united in advance to commit one or more crimes, using a product or service in the shadow digital economy to improve the "quality and effectiveness" of their crime.

It should be noted that the project-based nature of all "shadow" processes for creating products and

services in the digital economy allows them to be implemented "effectively and reliably" and controlled throughout the entire project lifecycle. It should be noted that such a project does not have a highly rigid structure, as such structures are highly unstable.

Criminal services include the deployment of malware, unauthorized system intrusion (hacking), attacks conducted via social networks, acquisition of insider information and abuse of privileges, physical theft or loss of valuable assets, and the exploitation of system vulnerabilities and malicious environments.

The information incidents generated by shadow services are shown in Figure 2 and include the following categories: malware infection, malware distribution, disruption or slowdown of an information resource, unauthorized access, information gathering using ICT, security breach, dissemination of information with inappropriate content, and vulnerabilities.

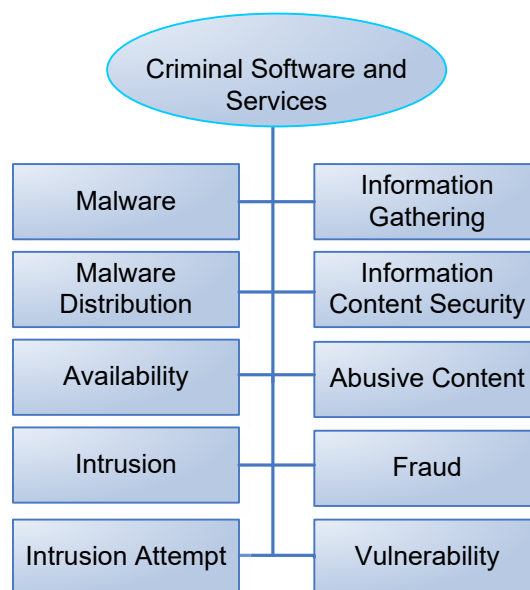


Figure 2: Composition of SDE services
Source: Original work by authors

6 SPECIALIZED SERVICES

The main services in the SDE are the following:

- **Cybercrime-as-a-Service (CaaS)** – is the provision of services to others to facilitate their commission of cybercrime. This service is also called by names such as Attacks-as-a-Service, Malware-as-a-Service, and Fraud-as-a-Service. This is a set of models for developing criminal functions that cybercriminals supply to

their clients (customers) in exchange for payment for their services and products. A logical extension of this is the following services:

- *Ransomware as a Service (RaaS)* – Cybercriminals offer ransomware packages that other individuals or groups can use to infect and encrypt their targets' data. The attackers then demand a ransom from the victim to decrypt the data. Ransomware is constantly evolving through the development of additional features and is becoming a sophisticated mechanism for targeted and successful attacks.
- *Phishing-as-a-Service (PhaaS)*. PhaaS vendors sell phishing kits for a fee. These packages include the tools and documentation required to carry out phishing attacks. Buyers obtain ready-made phishing pages and message templates, lists of potential victims, and other resources. User-friendly interfaces enable nontechnical actors to create and manage campaigns, and the services typically provide prebuilt templates, hosting for fraudulent sites, and data-collection mechanisms designed to harvest victims' credentials and personal information.
- *Distributed Denial of Service-as-a-Service (DDoSaaS)*. In this service, cybercriminals provide tools and infrastructure for launching distributed denial of service (DDoS) attacks on websites or online services, causing them to become unavailable to legitimate users.
- *Botnets-for-hire (BfH)*. Cybercriminals may rent out their botnets, which are networks of compromised computers or devices controlled by a central entity (the botmaster). Cybercriminals can use these botnets to send spam, conduct DDoS attacks, or spread malware.
- *Credential-theft-services (CTS)*. Some cybercriminals offer services to steal login credentials (e.g., usernames and passwords) from individuals, companies, and other cybercriminals.
- *Research-as-a-Service (RaaS)*, delivered via application programming interfaces (APIs), enables digital-era companies to integrate timely research into customer interactions. Information instability also compels cybercriminals to analyze complex events in real time to adapt their activities

7 CONCLUSION

The shadow digital economy, which fuels and scales cybercrime activities, is a crucial element of modern cyberthreats (Olejnik & Kurasiński, 2023). The study confirmed that such processes as the formation of parallel illegal markets (forums, darknet marketplaces), the creation of 'service' models (Crime-as-a-Service, Ransomware-as-a-Service), and the spread of illegal financial flows through cryptocurrencies and mixers are forming a stable and increasingly professional cybercrime ecosystem. A special place here is occupied by the affiliate programme model, where malware and infrastructure developers profit from each ransomware or successfully executed attack. Thus, the threshold of entry for new attackers is significantly lowered, leading to an increase in the total number of attacks worldwide.

A comprehensive assessment shows that, along with the emergence of criminal 'digital corporations, there is a trend toward diversifying forms of illegal online activity, from DDoS attacks to cyber espionage and compromised business communications. The latest technological advances (artificial intelligence, quantum computing, 5G networks) will inevitably become targets of further attacks, as it is in the area of advanced developments that vulnerabilities appear that have not yet been adequately protected. Consequently, cyber threats are becoming truly global in nature and pose serious risks to government institutions, businesses and individuals.

The situation requires a systemic approach to cybersecurity organization, which should include legal and regulatory aspects for current and potential threats, cooperation between different states in prosecuting cybercriminals (given the cross-border nature of cyberattacks), and the development of multi-layered defence systems covering the personal level, the corporate environment and critical infrastructures. As attackers evolve their means and methods of attack, traditional forms of anti-virus and firewall defences need to be supported by more flexible and intelligent technologies, including machine learning and real-time anomaly detection.

Thus, this study not only underscores the historical significance of computer security but also identifies new avenues for countering threats that

arise from the evolving shadow digital economy (Priyadarshini & Cotton, 2022). The scale and complexity of contemporary cyberattacks call for strengthened international cooperation, the development of integrated methods to anticipate future attack scenarios, and the cultivation of a shared cybersecurity culture (Abd El-Latif et al.,

2023). Only coordinated efforts by government, the private sector, research and development organizations, and civil society can curb the exponential growth of cybercriminal activity and ensure the long-term security of the digital environment.

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ISSUES IN ENSURING WORKFORCE AVAILABILITY IN TOURISM

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ABSTRACT

This paper examines workforce security in the tourism industry. It focuses on seasonality, labor shortages, employee motivation, and the impact of the COVID-19 pandemic. Tourism is highly vulnerable to seasonal fluctuations, which create an unstable labor market dominated by temporary, part-time, and migrant work. These conditions lead to high turnover and difficulties in retaining skilled employees. Low wages and poor working environments further reduce job satisfaction and morale. The study analyzes how these challenges affect both workers and employers, emphasizing the growing reliance on migrant labor in many regions. It also explores strategies to mitigate problems, such as improving motivation, offering better conditions, and adopting flexible employment models. In addition, the paper considers the long-term effects of COVID-19 on tourism employment, including shifts in demand, migration patterns, and new health and safety standards. The findings provide actionable insights for policymakers and industry leaders. They propose practical measures to build a more stable and sustainable workforce. By addressing the root causes of labor insecurity, the study contributes to developing effective workforce strategies and a more resilient labor market.

1 INTRODUCTION

Tourism is one of the fastest-growing economic activities on a global scale. According to the World Tourism Organization (UNWTO, 2022), the sector accounts for over 10% of global GDP and provides millions of jobs. However, securing a qualified and stable workforce has become an increasing

challenge, especially after the COVID-19 pandemic. Issues such as seasonality, low wages, labor shortages, migration flows, and generational differences reduce the attractiveness of tourism professions and threaten the long-term sustainability of the industry.

Main problems in securing the workforce are:

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1. The seasonal dynamics of tourism
2. Motivating employees
3. The shortage of skilled labor in the tourism industry
4. Migrant labor force
5. Impact of the COVID-19 pandemic and emerging trends.

This research also carries clear policy relevance. It offers evidence-based insights to guide governments and institutions in stabilizing employment and strengthening workforce sustainability in tourism.

2 SEASONAL DYNAMICS IN TOURISM

Tourism is widely acknowledged as one of the economic sectors most significantly affected by seasonal fluctuations. Seasonality in tourism, a globally pervasive phenomenon, leads to substantial variations in the demand for tourism services, resulting in an uneven distribution of resource utilization throughout the calendar year (Weidner, 2009). The principal determinants of tourism seasonality include climatic conditions, national holiday schedules, and dominant cultural practices, all of which significantly shape travel behavior.

Among natural factors, climatic conditions exert the strongest influence, while socio-cultural determinants primarily include school vacations and periods of annual leave (Fernández-Morales et al., 2016). Despite continuous efforts to promote year-round tourism activities, the concentration of tourists flows during specific peak periods remains a prevailing pattern.

The consequences of such seasonality are multifaceted. During peak seasons, the tourism industry often experiences the overexploitation of human and material resources, whereas off-season periods are characterized by underutilization, resulting in reduced labor engagement, lower revenue generation, and inefficient consumption of operational resources such as food supplies, heating, and electricity (Fernández-Morales et al., 2016).

Strategies to mitigate the negative impacts of seasonality have focused on the development of alternative forms of tourism—such as cultural, wellness, and business tourism—and the stimulation of off-season travel through targeted

discounts and the organization of special events (Kotler et al., 2016). Within this framework, sustainable tourism management, supported by appropriate public policy measures, emerges as a critical strategy for reducing the sector's dependency on seasonal demand cycles.

3 MOTIVATING EMPLOYEES

While the aesthetic and experiential appeal of the tourism sector plays a vital role in attracting workers, it is equally important for tourism employers to align their offerings with the expectations and needs of the labor force they aim to engage. Employment in tourism must be viewed not as a unilateral offer but as a bilateral relationship—one in which both the client and the employee hold significant stakes. In this context, the employer must establish a system built on the principle that “a satisfied customer is the result of a satisfied employee.”

The concept of “good service” in the tourism industry transcends mere functionality; it is not sufficient to assume that satisfactory service alone will prompt customers to recommend a business to others (Collier et al., 2018, p. 150). Instead, clients increasingly demand high levels of perceived effort, observable empathy, and unexpected positive experiences from service employees. This shift places a renewed focus not on *why* quality service matters, but rather on *how* organizations can support their employees in delivering flexible and customer-oriented service experiences.

Contemporary clients exhibit more sophisticated expectations than in previous decades, and their direct interactions with employees often represent the decisive factor in whether a service or establishment gains a favorable reputation. Therefore, ensuring the motivation of employees becomes crucial for service excellence.

To cultivate a workforce capable of delivering these elevated service standards, employers must first identify both motivational drivers and potential inhibitors within the workplace. One such motivational factor is job autonomy. Research indicates that even highly experienced and competent employees may refrain from displaying adaptive service behaviors if they perceive a lack of autonomy in their roles (Leischnig & Kasper-Brauer, 2015). Similarly, fostering employee

creativity contributes significantly to service quality, especially in a work environment where the definition of “personalized” service continues to evolve.

In response to these dynamics, effective leadership becomes instrumental. Leadership practices that emphasize empowerment—specifically through decentralization of authority and the delegation of responsibilities—can activate intrinsic motivation among employees and enhance the predictability of service-oriented behaviors (Lin et al., 2020). Such leadership approaches equip employees to navigate the complexities and broaden scopes of their roles more effectively.

Also, higher salary, permanent employment, training and professional development, better work environment, and work-life balance.

Ultimately, only by addressing these motivational dimensions can organizations secure a workforce that is both capable and enthusiastic in meeting the expectations of increasingly demanding clientele in the tourism sector.

4 SKILLED LABOR IN TOURISM: SHORTAGES AND CHALLENGES

The global tourism sector, a vital component of numerous national economies, has persistently grappled with a shortage of skilled labor. This challenge has become increasingly pronounced due to rising international tourist flows, heightened consumer expectations, and the rapid digitalization of tourism services. The lack of adequately trained personnel presents a significant obstacle for both developed and developing countries, undermining service quality, reducing competitiveness, and threatening the long-term sustainability of tourism enterprises.

A principal driver of this labor shortfall is the persistent misalignment between formal education systems and the practical needs of the tourism labor market. Many vocational and higher education institutions have failed to adapt curricula to reflect the evolving operational realities of the industry, thereby producing graduates whose competencies often fall short of industry requirements (Baum, 2012). This disjunction contributes to skills gaps that are not easily remedied through on-the-job training alone.

Compounding this issue is the widespread perception of tourism-related occupations as low-status, poorly remunerated, and lacking in long-term career prospects—a view particularly prevalent among younger generations (Richardson, 2010).

The seasonal and unpredictable nature of tourism employment further exacerbates labor instability. A significant proportion of jobs within the sector are characterized by temporary contracts, part-time hours, or dependence on fluctuating demand, all of which deter long-term commitment and investment in skill development (Joppe, 2012). Geographical imbalances also contribute to the challenge, with tourist destinations experiencing acute labor shortages during off-peak periods, despite surpluses during high-demand seasons (Zampoukos & Ioannides, 2011).

Technological transformation has redefined the skillsets required within the sector, introducing a growing demand for digital competencies, adaptability, and multilingual communication. Despite these shifts, education and training frameworks have been slow to respond, leaving many workers unprepared for roles involving online marketing, digital booking platforms, and smart tourism technologies. As a result, the demand for hybrid professional profiles, those combining traditional hospitality expertise with digital literacy—has increased sharply.

Migration trends have also significantly influenced labor supply dynamics. In many regions, skilled tourism workers have transitioned to higher-paying industries or migrated abroad, deepening domestic workforce deficits. Concurrently, the sector’s reliance on migrant and seasonal labor has grown, raising critical concerns regarding labor rights, working conditions, and the socio-cultural integration of foreign workers (Baum et al., 2016).

In response, a variety of remedial measures have been implemented, including the establishment of public-private training partnerships, employer branding strategies, and the promotion of more inclusive employment policies. Nevertheless, in the absence of strategic and sustained investment in human capital—and without structural reform in how tourism careers are framed, supported, and valued, these efforts have produced limited long-term results.

In conclusion, the skilled labor shortage in tourism during the 2010–2020 period reflects a complex interplay of factors, including educational inadequacies, precarious employment structures, technological change, and migration dynamics. Addressing this challenge in a post-pandemic context necessitates systemic reorientation toward workforce development and the repositioning of tourism as a viable, stable, and desirable career path.

5 THE ROLE OF MIGRANTS AS A WORKFORCE IN TOURISM

Migrant workers constitute an essential component of the labor force within the global tourism industry, particularly in economies experiencing persistent shortages of domestic labor for low-wage, low-skill, and seasonal positions. The tourism sector, characterized by its labor-intensive structure and pronounced fluctuations in demand, increasingly depends on migrant labor to maintain service continuity and operational flexibility during peak periods.

Migrants are commonly employed in a broad spectrum of occupational roles—including housekeeping, food and beverage service, kitchen support, logistics, and maintenance—many of which are regarded as unattractive by the local population (Joppe, 2012). These roles, though critical to the sector's functionality, often remain invisible in public discourse. As Joppe (2012) aptly describes, migrant workers serve as the “invisible heroes” of tourism, sustaining daily operations under often strenuous and undervalued conditions. Despite their contributions, migrant employees frequently encounter systemic challenges such as low remuneration, precarious employment, restricted access to social protection, and limited upward mobility.

In the European context, countries such as Spain and the United Kingdom exhibit particularly high reliance on migrant labor within their tourism economies. According to Baum et al. (2016), migrant workers play a pivotal role in bridging the gap between labor supply and seasonal demand, especially during peak tourist periods when domestic labor availability is insufficient. Nonetheless, migrant integration into the labor market is hindered by several barriers, including linguistic obstacles, discriminatory practices, and

exclusion from vocational training and skill development opportunities.

Beyond their functional role in service delivery, migrants contribute significantly to the cultural diversification of tourism services. Their presence facilitates the provision of authentic, multicultural guest experiences, supports multilingual communication, and enriches culinary diversity. However, without targeted institutional support and inclusive human resource policies, the sector often fails to capitalize on these advantages. As Ruhs and Anderson (2010) argue, the sustainable incorporation of migrant labor in tourism depends on the existence of supportive institutional frameworks and the consistent enforcement of fair labor standards.

In summary, migrant workers are indispensable to the structural and operational resilience of the tourism industry. However, realizing the full potential of their contribution requires more than functional engagement; it necessitates policy-driven efforts to ensure social inclusion, equitable labor conditions, and institutional recognition. A sustainable and mutually beneficial tourism workforce can only be achieved through the systematic protection and empowerment of migrant employees.

6 TOURISM, MOBILITY, AND LABOR PRECARIETY IN THE AFTERMATH OF COVID-19

The COVID-19 pandemic, unprecedented in its global scale and velocity, disrupted virtually every aspect of human mobility and economic life. Among the hardest-hit sectors was tourism, which—due to its intrinsic reliance on unrestricted movement and interpersonal interaction, was swiftly paralyzed by the international health crisis. Large-scale cruise operations and international air travel were identified as significant vectors in the early global spread of the virus (Chinazzi et al., 2020), triggering a cascade of restrictive public health interventions aimed at containment.

Governments worldwide implemented an array of emergency measures, including mandatory vaccination policies, national lockdowns, border closures, restrictions on public gatherings, and stringent limitations on tourism and hospitality services. In this context, the notion of “social distancing” became a normative social practice,

fundamentally altering the nature of interpersonal communication and public life (Long, 2020). The pandemic not only reconfigured the operational environment of the tourism sector but also challenged societal perceptions of the right to travel, a freedom long viewed in many industrialized societies as a normalized entitlement.

Although not formally codified as a legal right, tourism has been conceptualized as a form of social participation that ought to be accessible across socioeconomic strata. As McCabe and Diekmann (2015) argue, while "tourism may not be considered a human right and there is no legal basis to support such a right" (p. 202), it constitutes a vital component of social inclusion and well-being. The interruption of tourism, therefore, extended beyond economic loss—it also curtailed individual freedoms and deepened social inequities.

For many, the pandemic marked a pivotal period in their educational, professional, and social development. Online learning modalities replaced traditional instruction, while job insecurity and sectoral collapse significantly affected their participation in the tourism labor market. The suspension of international and domestic travel restricted not only leisure opportunities but also employment prospects, especially for younger cohorts entering or establishing themselves within the industry.

The tourism labor market experienced a dramatic contraction. With mass layoffs and business closures, the sector witnessed a migration of workers—both skilled and unskilled—toward other industries perceived as more stable or resilient (Robinson et al., 2019). As a result, employment within tourism became markedly precarious, with widespread displacement of labor and erosion of job security. This labor exodus has led to an enduring imbalance between supply and demand, posing significant challenges for post-pandemic recovery.

In the aftermath of the pandemic, industry continues to grapple with a dual crisis: a quantitative shortage of available workers and a qualitative gap in requisite skills. Despite gradual improvements in global mobility and the partial resurgence of tourist flows, an unresolved question remains—whether the labor force that

once powered the sector will return, and under what conditions. The path forward requires a reconsideration of employment structures, workplace protections, and long-term strategies to foster resilience, equity, and attractiveness in tourism-related professions.

7 RESEARCH METHODOLOGY

Most of the questionnaires were administered online, facilitating efficient dissemination and enabling access to a broader and more diverse respondent pool. This method allowed the researchers to reach a larger sample size within a relatively short timeframe and with minimal financial resources. Furthermore, online participation ensured respondent anonymity, a factor known to increase the likelihood of receiving candid and accurate responses. To complement online distribution and enhance response diversity, a portion of the surveys was also conducted in person.

Participants were selected based on the following criteria:

- A total sample size of 94 respondents, ensuring sufficient statistical validity.
- The questionnaire was structured into three distinct sections, with different kinds of questions.
- Section I focuses on demographic information, including five questions: (1) the tourism sector in which the respondent is currently or was previously employed, (2) their work experience in the tourism industry, (3) age group, (4) education level, and (5) gender issues.
- Section II examined participants' attitudes toward issues related to ensuring workforce availability in tourism. This section employed a five-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree) to evaluate perceptions of different coping strategies for occupational stress.
- Section III contains different types of questions: dichotomous (yes/no), multiple-answer questions, single-answer questions from the provided options, as well as one open-ended question.

The demographic characteristics of the respondents are summarized in Table 1, covering gender, education level, age group, sector of employment in tourism, and work experience.

Table 1. *Demographic Characteristics of the Respondents*

Category	Subcategory	Frequency (n)
Which sector of tourism do you work in or have worked in?	Hospitality	42
	Travel Agencies	28
	Guide/Animator	10
	Restaurant Industry	5
	Other: _____	9
How many years of experience do you have in tourism?	Less than 1 year	11
	1–3 years	32
	4–6 years	26
	More than 6 years	25
Gender	Man	36
	Women	58
Age group	Less than 25 years	12
	25-35	31
	36- 46	28
	47-57	12
	More than 57	11
Educational level	High school	29
	First level of faculty	61
	Second level of faculty	4

Source: Authors' research

The data obtained from these demographic categories were analyzed to provide a comprehensive understanding of the respondents' backgrounds and to assess their potential influence on the perceptions of the issues under investigation.

Subsequently, we constructed Table 2 based on the collected responses and calculated the mean score for each statement.

Table 2. *Selected Questions Related to Ensuring Workforce Availability in Tourism Issues*

No.	Statement	1	2	3	4	5	$\bar{x}$
1	How much does seasonality affect your work/workplace?	5	9	30	33	17	3.51
2	How satisfied are you with the working conditions in the tourism sector?	9	24	38	19	4	2.84
3	How much do you think the government/institutions should be involved in solving the workforce shortage in tourism?	5	14	24	40	11	3.40
4	Do you think migrant labor is a solution to the workforce shortage?	19	28	5	0	42	2.18

Source: Authors' research

In the process of data collection through the survey, the responses were analyzed using descriptive statistics. For each question in Section 2 of the questionnaire, we calculated the mean score, which offered valuable insight into the general attitudes of respondents toward ensuring workforce availability in tourism issues. This statistical method enabled us to identify

trends, recurring patterns, and notable variations across the responses. These findings will be further elaborated in the subsequent sections of the paper.

Finally, we present the questions from Section 3, along with a graphical representation of the given answers.

Table 3. Dichotomous (Yes/No)

Questions	Yes	No
Have you ever been out of work due to the end of the tourist season?	47	47
Have you worked with migrant/foreign labor?	57	37
Are there still difficulties in finding the workforce in tourism after the pandemic?	57	37

Source: Authors' research

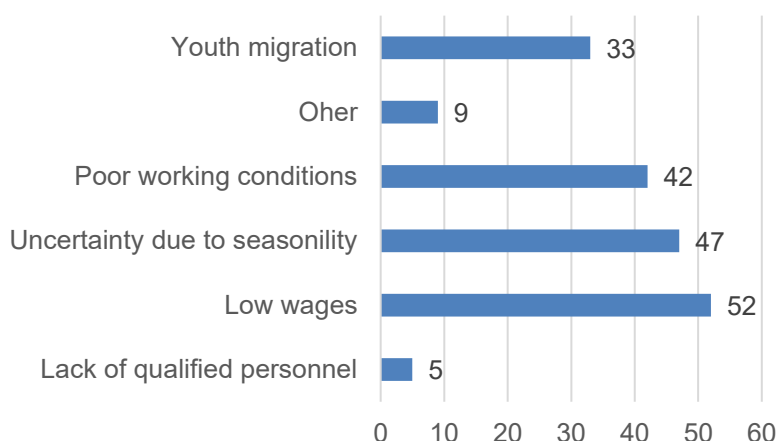


Figure 1. What are the biggest challenges in securing the workforce in tourism?

Source: Authors' research

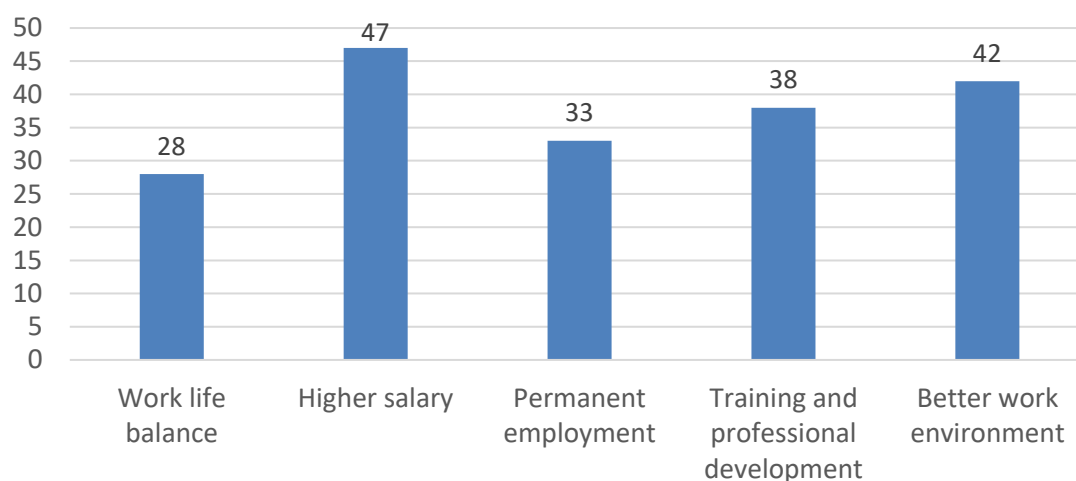


Figure 2. What would motivate you most to stay in the tourism industry?

Source: Authors' research

Figure 1 illustrates the biggest challenges in securing a workforce in the tourism industry, based on the authors' own research. The challenges include factors like labor shortages, seasonality, and low employee motivation. This figure allows respondents to select multiple challenges that they believe are most significant in the tourism sector.

Figure 2 presents the factors that would most motivate individuals to stay in the tourism industry, based on the authors' own research. It highlights key motivators such as higher salaries, job

stability, and better work-life balance. Respondents were asked to select the factors they consider most influential in their decision to remain in the sector.

Figure 3 shows the key factors that would motivate individuals to stay in the tourism industry, with respondents prioritizing aspects like salary, job stability, and work-life balance. These factors were identified as the most influential based on the authors' own research.

And finally, the open-ended question was: "What measures would help the most in improving

workforce supply in tourism?" The responses obtained can be seen in Table 4.

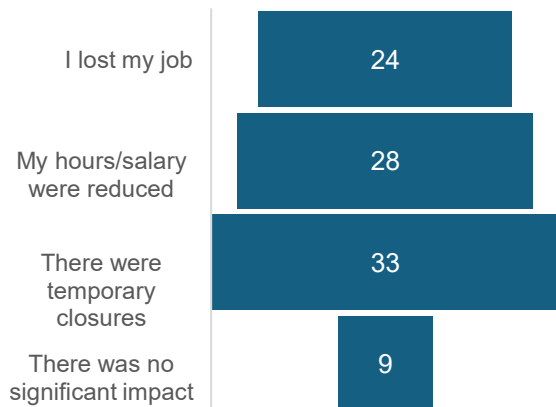


Figure 3. *How did the COVID-19 pandemic affect your work in tourism*

Source: Authors' research

Table 4. *What measures would help the most in improving workforce supply in tourism*

No.	Answer	Frequency (n)
1.	Better wages and benefits	39
2.	More stable employment contracts	16
3.	Better training and professional development programs	6
4.	Government incentives for businesses	5
5.	Improved working conditions	18
6.	Addressing migration patterns and youth retention	10

Source: Authors' research

8 RESULTS AND INTERPRETATION

The results of the survey reveal the following key findings:

- Seasonality ($\bar{x} = 3.51$): Most respondents acknowledge the significant impact of seasonality on their work, highlighting the cyclical nature of the tourism industry.
- Job Satisfaction ($\bar{x} = 2.84$): Satisfaction with working conditions is notably low, suggesting dissatisfaction with current industry practices.
- Institutional Involvement ($\bar{x} = 3.40$): Respondents emphasize the need for greater government involvement to address workforce shortages.

- Migrant Labor ($\bar{x} = 2.18$): There is skepticism regarding the role of migrant labor as a sustainable solution to the workforce shortage.
- Dichotomous Responses:
- Seasonality-related Unemployment: 50% of respondents have experienced job loss due to seasonality, confirming the unstable nature of tourism employment.
- Migrant Labor: The majority have worked with migrant labor (57), reflecting the sector's reliance on migrant labor.
- Post-Pandemic Workforce Issues: 57 respondents agree that workforce challenges persist following the COVID-19 pandemic, indicating ongoing labor shortages.
- Key Challenges and Motivators:
- Biggest Challenges: The most significant challenges include low wages, lack of career progression, and high seasonality.
- Motivators to Stay in Tourism: Respondents are primarily motivated by improved wages, stable contracts, and career development opportunities.

9 RECOMMENDATIONS

Seasonality has a significant impact on the workforce. To mitigate its effects, tourism can be diversified by developing services that attract tourists even during off-peak seasons, such as cultural and wellness tourism.

It is crucial to improve working conditions in tourism, given the low satisfaction levels among employees. Employers should invest in enhancing the work environment, workplace safety, and providing skill development training.

The results show high expectations for greater government involvement in solving the workforce shortage. The government can offer financial incentives to businesses that hire local workers and provide educational programs to develop skills.

While some consider migrant labor a solution, it is appropriate to encourage less reliance on it by developing local talent. Policies should focus on retaining youth in tourism and offering long-term career paths.

To improve satisfaction and retain employees, tourism businesses should offer higher wages, stable employment contracts, and better working conditions, such as flexible working hours and work-life balance.

The pandemic has had lasting effects on the workforce. Employers should offer stability, career progression, and rebuild trust and interest in working in tourism by ensuring safety measures and clear health protocols.

Responses to the open-ended question indicate the need for better wages, stable contracts, and professional development. Employers should offer competitive compensation packages and invest in employee skill development.

10 CONCLUSION

The results of this study provide a thorough examination of the current challenges faced by the tourism sector in securing a stable and sustainable workforce. The demographic data revealed that a significant portion of respondents are employed in the hospitality sector, with many having between 1 and 6 years of experience. This indicates a relatively young and dynamic workforce but also highlights the vulnerability of the sector to workforce turnover and seasonal employment.

One of the most pressing issues identified in the survey is the impact of seasonality. The majority of respondents reported that seasonality significantly affects their work, leading to job instability and, in some cases, unemployment during the off-season. This seasonal pattern is detrimental to the overall job security within the tourism sector, as employees face periods of inactivity and income loss. This is further supported by the responses to the dichotomous questions, where 50% of respondents have experienced unemployment due to the end of the tourist season, emphasizing the precarious nature of employment in tourism.

In terms of job satisfaction, the respondents expressed notable dissatisfaction with the current working conditions in the tourism sector. The mean score for job satisfaction ($\bar{x} = 2.84$) indicates that working conditions are a significant concern, with issues such as low wages, limited career progression, and lack of stability being common complaints. These factors contribute to high

turnover rates and challenges in attracting and retaining skilled labor. The call for greater government involvement ($\bar{x} = 3.40$) reflects a widespread belief that institutional support is necessary to address these systemic issues, including workforce shortages.

The role of migrant labor in addressing workforce shortages also emerged as a key point of discussion. While migrant workers are commonly employed in the tourism industry, respondents expressed skepticism about migrant labor as a sustainable solution. The mean score for this question ($\bar{x} = 2.18$) suggests that respondents view migrant labor as a temporary fix rather than a long-term solution to the sector's workforce needs. This raises concerns about the sustainability of relying on external labor sources, particularly given the current challenges in migration patterns and the need for a more stable domestic workforce.

Moreover, the post-pandemic labor shortage remains a critical issue. Despite the recovery in the tourism industry, respondents overwhelmingly reported ongoing difficulties in finding workers (57 respondents indicated 'Yes' to post-pandemic labor challenges). This suggests that the tourism sector has not fully recovered from the disruptions caused by the COVID-19 pandemic, and further measures are needed to address labor shortages.

The responses to the open-ended question on improving workforce supply in tourism revealed several recurring themes. The most commonly suggested measures include improving wages and benefits, offering more stable and long-term employment contracts, enhancing training and professional development programs, and improving overall working conditions. Respondents also highlighted the importance of government support in the form of incentives for businesses and addressing migration patterns to retain youth in the sector.

In conclusion, this study emphasizes the urgent need for comprehensive reforms within the tourism sector to address the multifaceted issues related to workforce sustainability. The findings point to the necessity of improving working conditions, providing job stability, and increasing government involvement to create a more attractive and sustainable work environment for employees. These reforms are crucial for

addressing the ongoing challenges in securing a stable workforce, particularly in light of the seasonal nature of the industry and the disruptions caused by the COVID-19 pandemic. By implementing these recommendations, the tourism sector can enhance workforce retention, reduce turnover, and ensure long-term growth and stability in this vital industry.

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ECONOMIC SANCTIONS IN A GLOBAL CONTEXT: RUSSIA'S ADAPTATION AND SPILLOVER EFFECTS

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ABSTRACT

This study provides a systematic analysis of the effects of sanctions policy on economic stability and the relationship between imposed sanctions and inflationary dynamics across countries. The initial hypothesis posited a direct and uniformly adverse impact of economic isolation on targeted economies; empirical evidence, however, indicates that outcomes are contingent on country-specific structural characteristics and adaptive capacities. The Russian case illustrates this complexity: despite extensive restrictive measures, the economy has demonstrated resilience through diversification of foreign trade, implementation of import-substitution policies, and expansion of domestic production, which have supported continued GDP growth in certain periods and mitigated inflationary pressures in key sectors. The analysis further shows heterogeneous sectoral responses to external shocks and highlights the role of institutional, fiscal, and market mechanisms in shaping macroeconomic trajectories under sanctions. These findings caution against blanket assumptions regarding the destructiveness of sanctions and underscore the necessity for policymakers to evaluate sanctions effects on a case-by-case basis, considering domestic economic structures, resilience mechanisms, and sectoral vulnerabilities to form more effective international economic policy.

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1 INTRODUCTION

Over the past decade, the global community has experienced profound shifts in international economic dynamics, largely driven by the deliberate implementation of politically motivated restrictions. Among the most frequently employed tools of external pressure is the imposition of targeted sanctions, which alter the internal economic dynamics of affected states. A vivid example of this practice is the imposition of reciprocal sanctions between Russia and several Western powers since 2014, including the European Union, the United States, Japan, and other countries officially designated as hostile under international law.

Economic sanctions represent a central instrument of foreign policy; however, their effectiveness varies considerably depending on the geopolitical context and the strategic

disposition of the decision-making actors. Comprehensive research indicates that only about one-third of previously imposed sanctions have achieved their stated objectives, with less than a quarter succeeding in preventing armed conflicts. Moreover, the negative consequences have been particularly felt by the populations of the affected countries, leading to a decline in living standards and an increase in distrust towards the governments of the initiators of trade and financial restrictions. A nation's cultural identity plays a decisive role in shaping public responses to sanctions: in societies with strong national consciousness, citizens often express greater solidarity. Conversely, in more fragmented cultural contexts, sanctions may provoke social unrest and growing dissatisfaction with political elites (Prigoda & Cekerevac, 2016). Table 1 represents historical examples of the impact of sanctions on the economies of various countries.

Table 1. *Historical examples of the impact of sanctions on the economies of various countries*

Sanctioned country	Sanctioning country, organizations	Effect	Result
Cuban blockade (1960–present)	The US imposed an embargo on Cuba in 1960 after Fidel Castro's revolution, banning trade and investment	- Cuba lost its main market (sugar, nickel). - The economy was reoriented towards the USSR, but its 1991 collapse triggered a severe crisis ('Special Period'). - Despite the deficit and poverty, the regime resisted, and sanctions became a pretext for anti-American propaganda.	The sanctions did not overthrow Castro, but they did enormous damage to the economy.
Iraq (1990–2003)	The UN imposed harsh sanctions after the invasion of Kuwait (ban on oil trade, except for the "Oil for food" program)	- GDP fell by 80%, and inflation reached 1000%. - Humanitarian disaster: 500,000 children died due to lack of medicines (UN data).	The ruling regime survived, but the economy was destroyed.
Iran (1979–present)	The US and UN imposed sanctions citing a lack of transparency in Iran's nuclear program and alleged support for terrorism.	- Hyperinflation (up to 50% in 2019). - Fall in oil exports (from 2.5 million barrels/day to 500 thousand in 2012). - Increased influence of China and Russia as alternative partners.	The sanctions pushed Iran into negotiations (JCPA-2015), but after the US exit in 2018, the economy was again under attack.
Yugoslavia (1991–1995)	- European Union (EU) - United Nations (UN) - United States of America (USA) - NATO for human rights violations and humanitarian crimes	- Large-scale reduction of the GDP of Yugoslavia (about 70% decrease). - Increase in unemployment and inflation - Energy crisis due to the oil and fuel embargo. - Deterioration of health and social services. - Shortage of necessities. - Exacerbation of internal social and political problems.	The signing of the Dayton Accords in 1995

2 DOMESTIC ECONOMIC EFFECTS OF SANCTIONS

Sanctions, as a tool of foreign policy influence, have a multifaceted impact on the economies of both the imposing country and the target of the sanctions. When analyzing the impact of sanctions on the economies of the imposing countries, it is important to consider the complexity of accurately assessing the damage. Typically, the economic loss for large entities such as the European Union and the United States remains modest amounting to less than 1% of their gross domestic product. However, since GDP growth in these countries often hovers around one percent

annually, even a small negative effect can significantly slow development and lead to stagnation or recession in the economies of both sides.

At the same time, there is a pronounced asymmetry in economic resilience: the consequences of imposing sanctions largely depend on the economic potential of the state. Countries with larger economies are much less exposed to risks and can easily withstand potential losses. In contrast, states with lesser economic power are more vulnerable to negative consequences. In 2024, the gap in GDP between participants in sanctions wars was pronounced, reflecting this asymmetry (Figure 1)¹.

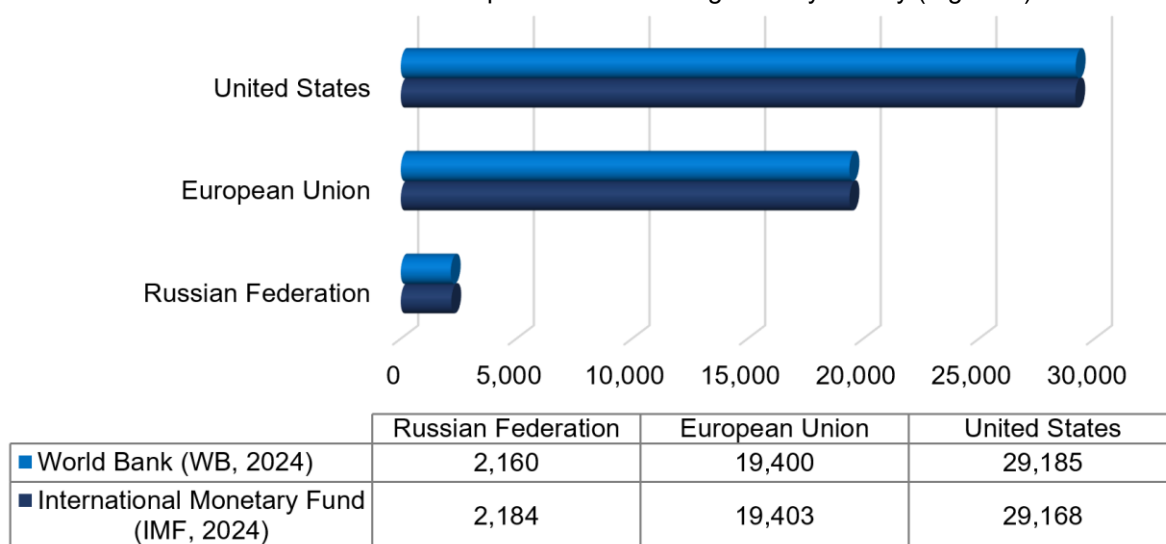


Figure 1. Nominal GDP Estimates for 2024 — Main Sanctions-Participating Countries
(USD billions, current prices)

Sources: (CBR, 2025; WB, 2024)

The share of the EU in the Russian foreign trade was 51-56%, while the Russian share in EU trade did not exceed 7-9%. For the USA, this figure was even lower—4.5-5%. According to analysts' research, Western economies, due to their strength, could withstand sanctions with minimal

losses. In May 2014, the Deutsche Bank Research Center published a study stating that Western economies can endure a sanctions war, including the Russian countermeasures, without significant losses.

¹ Accurately determining the gross domestic product (GDP) of major economic entities such as the United States, the European Union, and the Russian Federation is a challenging task, as reported values vary depending on the source, methodology, and timing of publication. Various institutions—including the International Monetary Fund (IMF), the World Bank, the European Commission, and national central banks—apply different approaches when estimating both nominal and real GDP, with adjustments such as purchasing power parity (PPP) further contributing to

these differences. In this study, however, we have elected to use only the IMF (2024) and World Bank (WB, 2024) data, as their estimates are relatively consistent and derive from well-established methodologies. Other sources were omitted because they either cover only certain countries or employ methods that do not allow for a comprehensive and comparable assessment across all actors. Furthermore, due to time lags in data collection and processing, most figures for the current or previous year represent estimates rather than final data, and these estimates are often revised as more complete information becomes available.

3 RUSSIAN ECONOMY AND SANCTIONS

Official statistical data shows that in 2014, the Russian losses from Western sanctions amounted to 1.5% of GDP, and by 2022, this figure had risen to 2.1%. These numbers reflect the impact of sanctions on the Russian economy, despite the focus on import substitution and support for domestic producers (Figure 2). (Bank of Russia, 2024)

Sanctions have become a catalyst for profound structural changes in the Russian economy.

To bridge the gap between societal needs and industrial productivity, the authorities took significant steps to support the real sector of the economy. Among the measures were subsidies and incentives for producers of essential goods. Within a year, such policies yielded tangible

results: food production significantly increased, ensuring the stability of the country's food security level. New partners from China, Latin America, and the Middle East played an important role in replacing supplies from "unfriendly countries," which helped to fill the emerging gaps and reduce dependence on traditional supply sources.

In addition, efforts were intensified to create an independent financial infrastructure that would not rely on Western organizations. In response to the 2014 threat of exclusion from the international SWIFT system, Russian authorities began coordinating with BRICS partners on possible alternatives. Simultaneously, efforts were underway to reduce reliance on foreign payment systems such as Visa and MasterCard, through the creation of a domestic alternative and the development of internal settlement mechanisms.

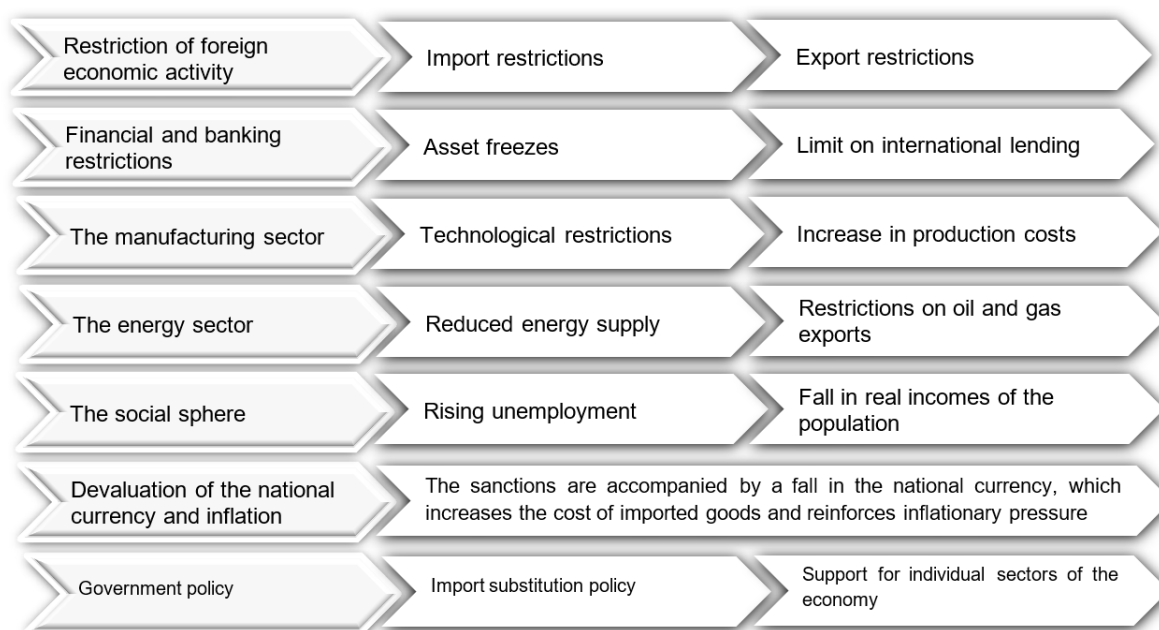


Figure 2. Mechanisms of the impact of sanctions on internal economic processes

At the same time, within the BRICS association, processes have started to establish a development bank that could eventually compete with institutions such as the World Bank and the International Monetary Fund. Thus, a new international financial architecture is being created, allowing member countries to conduct operations outside the control of the West.

However, as practice has shown, Deutsche Bank experts were mistaken in their assessments, which had assumed that the sanctions policy

would have only minimal negative effects on the European and American economies. In addition to the food embargo and a decline in tourism, the energy sector also experienced severe disruptions resulting from the EU's ineffective policy towards Russia. Sanctions, exacerbated by falling oil prices (the main source of budget revenue), led to a significant devaluation of the ruble, which, in turn, complicated the credit situation and impacted monetary policy. The Bank of Russia responded to these challenges by tightening its credit policy to stabilize the economy.

An analysis of the current difference between the Central Bank's key interest rate and the level of inflation shows that in the context of increased uncertainty in recent years, the relationship between these macroeconomic indicators has become less pronounced (Figure 3).

The analysis indicates that inflation responds less actively to increases in the key interest rate, complicating its forecasting. This is due to several factors, including shifts in market participants' expectations and the waning effectiveness of traditional monetary policy tools. These developments underscore the need to adopt alternative regulatory strategies in the context of

global instability and sanctions. A predominantly inertial reaction of the market to inflation rates has been observed over the past four years.

An active budget policy aimed at economic development promotes growth in lending to both legal entities and individuals. The increase in income and revenue related to budget expenditure stimulates credit activity, including the use of preferential programs, leading to significant growth in lending activity, which, in turn, necessitates tougher measures to cool the market and slow down the increase in the overall credit portfolio of banks.

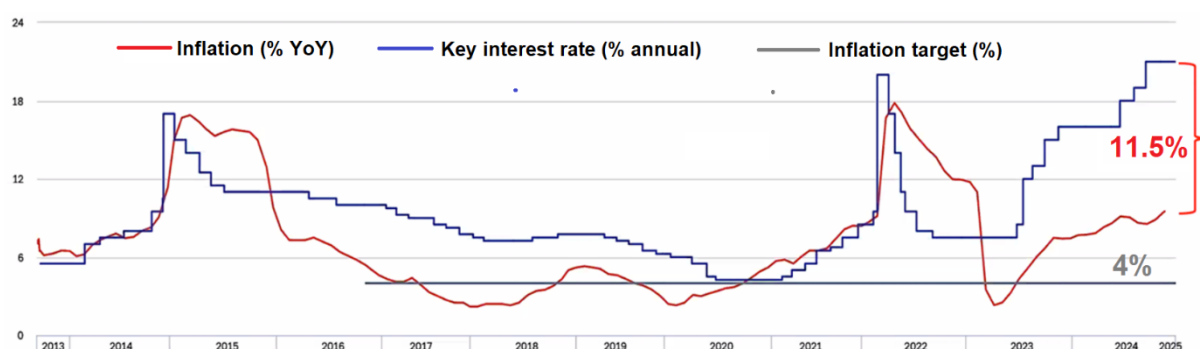


Figure 3. Analysis of the key rate of the Bank of Russia and inflation

Source: (Tosunyan, 2025)

In 2024, the Bank of Russia raised the key interest rate during Monetary Policy Board meetings, which helped curb inflationary pressures. However, the inflation rate in the country reached 9.52%, which is twice the target level. In recent months, there has been an increase in inflationary pressure, persistent inflation indicators, and rising inflation expectations from both the population and businesses. A high level of consumer activity,

bolstered by income and credit growth, highlights a structural imbalance between aggregate demand and supply-side capacity.

A key constraint on rapid production growth is the shortage of labor and the reduction of available production capacity. These limitations hinder the economy's ability to ramp up output swiftly and intensify pro-inflationary pressures.

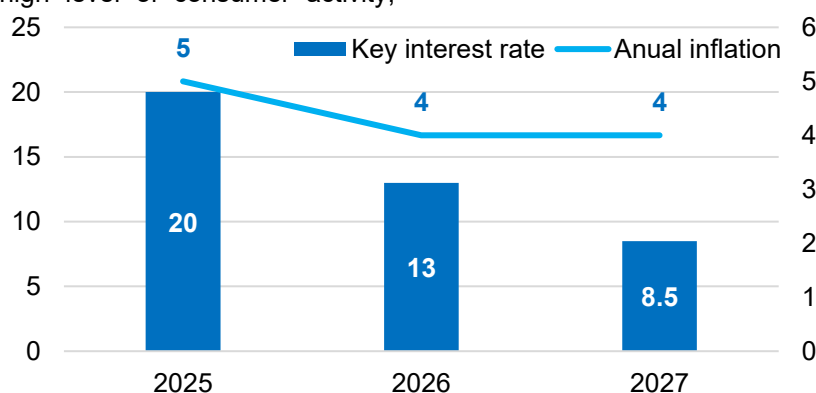


Figure 4. The key interest rate and inflation (CBR, 2025)

To achieve the goal of reducing inflation and returning it to the target level, tight monetary conditions will need to be sustained over an

extended period. According to the Bank of the Russian forecast, the key interest rate is expected to decline gradually: in 2025, it is projected to

range between 17% and 20% per annum; in 2026, between 12% and 13%; and by 2027, to return to the neutral range of 7.5% to 8.5% per annum.

This strategy aims to reduce annual inflation to 4.5–5% in 2025 and 4% in 2026 and to maintain it at the target level (Figure 4). Such an approach allows for the expectation of gradual stabilization of the economic situation and a decrease in pro-inflationary risks. However, its implementation requires coordinated action between monetary and fiscal policy, as well as the elimination of structural imbalances in the economy.

The analysis indicated that inflation dynamics have a substantial impact on the domestic investment climate and the Russian real-sector economy. However, the study only partially

reveals the picture of the state's economic security, as it does not cover critical aspects of foreign policy such as exchange rate stability, foreign trade volumes, and financial flows. Therefore, the next phase of our study examines the impact of international sanctions on the Russian balance of payments indicators.

4 RUSSIA'S BALANCE OF PAYMENTS UNDER SANCTIONS

The performance of the Russian balance of payments has attracted considerable attention due to its positive trajectory in recent years. This phenomenon is driven by several factors, including the structural features of the national economy and the country's approach to foreign economic policy (Figure 5).

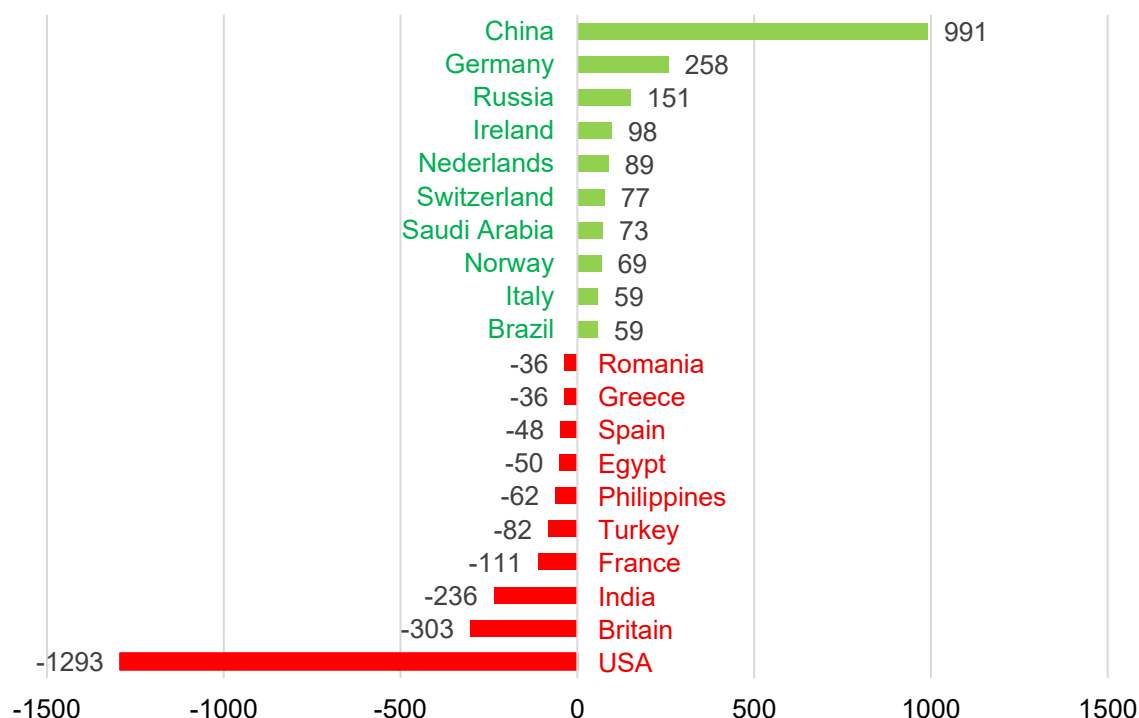


Figure 5. Balance of payments of some countries in 2024, \$ billion. (RIA, 2025)

Russia's balance of payments is shaped by a combination of endogenous and exogenous factors that ensure an excess of financial resource inflow over the outflow. Key aspects include:

1. *High revenues from the export of natural resources.* The export of oil products, natural gas, and mineral fertilizers provides a constant source of foreign currency inflow into the country. The Russian Federation traditionally holds leading positions in the global export of these categories of goods,

positively affecting the state of the foreign trade balance.

2. *Limited integration into international production chains.* Despite active participation in the global division of labor, the Russian economy demonstrates a comparatively low dependence on external demand for manufactured goods. This circumstance minimizes the risk of significant current account deficits during periods of deteriorating global economic conditions.

3. *Effectiveness of state financial policy.* The implementation of a strategy to reduce the debt burden, the establishment of large foreign currency reserves, and the conduct of targeted monetary policy have contributed to the formation of favorable macroeconomic conditions for maintaining the stability of the state's financial position.
4. *Response to external negative shocks.* Russian authorities respond promptly to changes in the external environment through fiscal and monetary mechanisms. An example is the adaptation to falling oil prices and imposed economic sanctions, which includes the restructuring of public finances and activating an import substitution program.
5. *Attractiveness of the national stock market for foreign capital.* High yield rates, low borrowing costs, and the presence of promising investment projects make Russia an attractive jurisdiction for international investment.

A combination of these factors helps explain the Russian consistently strong balance of payments performance. As a result, the country has been able to offset the negative impact of unfavorable external conditions. However, further modernization of the economy's structure, increased labor productivity, and the expansion of high-tech exports will be necessary conditions for maintaining positive trends in the medium term.

5 PERCEPTION OF SANCTIONS BY RUSSIAN SOCIETY

Figures 6 to 8 present longitudinal data on Russian public perceptions of Western sanctions between 2022 and early 2025, based on Levada Center surveys. These visuals illustrate trends broader societal interpretation of the sanctions' purpose and effect."

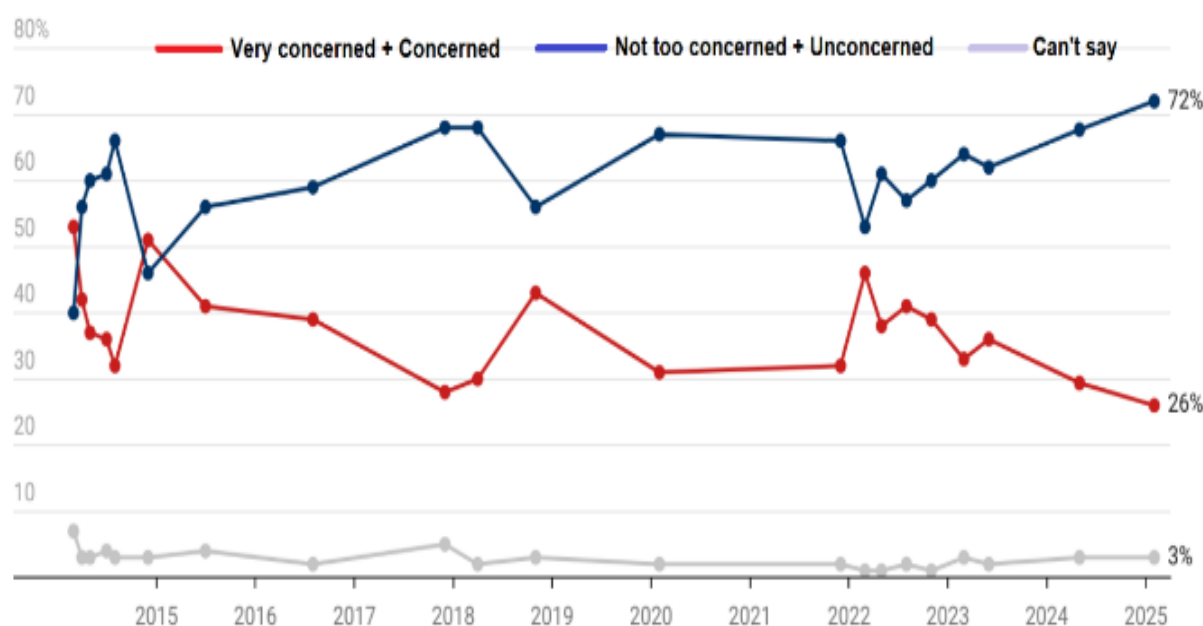


Figure 6. Results of the survey regarding the answer to the question: Are you concerned about the political and economic sanctions of Western countries against Russia?
[In percentages of respondents]

Source: (Levada, 2025A)

Sociological research conducted in the Russian Federation between 2022 and 2025 reveals a consistent trend: most respondents do not attribute the country's economic difficulties to international sanctions. By February 2025, 77% supported the continuation of the current political

course aimed at countering Western pressure, while only 15% expressed willingness to seek compromise in exchange for the lifting of sanctions. (Levada, 2025B)

According to early 2025 data, nearly two-thirds of respondents reported no personal concern over

sanctions, with the primary worry centered on the freezing of Russian assets abroad (47%). Overall, 72% of respondents reported being unconcerned about sanctions—up 19 percentage points since March 2022—while only 26% expressed ongoing worry. (See Figure 6). Concern was more pronounced among older citizens, economically vulnerable groups, critics of the government, and those who had experienced financial setbacks. In contrast, younger individuals, government supporters, and respondents with stable economic conditions showed lower levels of concern. (Levada, 2025B)

The prevailing perception is that Western sanctions are intended to weaken Russia. Notably, over half of respondents believe that the

sanctions will ultimately strengthen the country and serve as a stimulus for domestic development. Since March 2022, concern over political and economic sanctions has declined by 20 percentage points, reflecting growing public resilience or adaptation.

Beyond frozen assets, specific concerns include the cancellation of Russian cultural programs abroad (25%), the departure of Western companies (20%), restrictions on payment systems such as Visa and Mastercard (20%), limited air travel (18%), and sanctions targeting prominent Russian business figures (6%). The impact of sanctions is perceived as uneven across social groups and framed more as a geopolitical challenge than a direct threat to personal welfare.

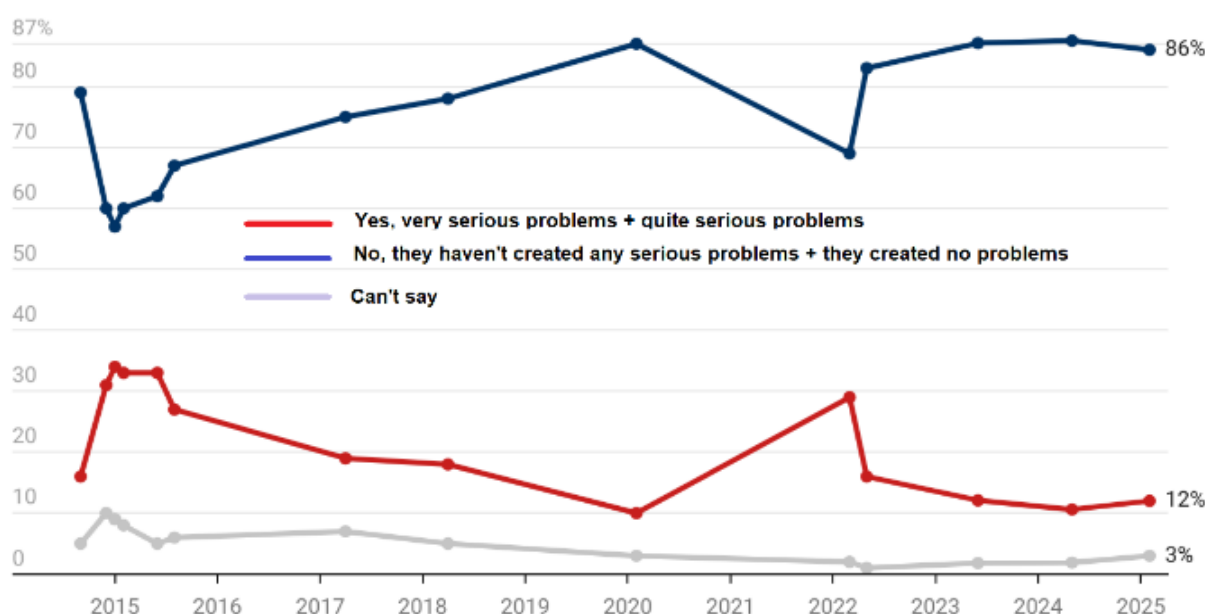


Figure 7 Results of the survey regarding the answer to the question: *Have the sanctions posed any problems for you and your family?* [In percentages of respondents]

Source: (Levada, 2025A)

The same study tracks shifting public perceptions in Russia regarding the impact and purpose of Western sanctions from 2022 to early 2025. While Figure 6 depicts general levels of concern, Figure 7 highlights perceived personal impact. According to the data, 86% of respondents report that sanctions have not directly affected them or their families.

Notably, attitudes toward who bears the brunt of sanctions are sharply polarized: 44% believe the measures target a narrow political elite responsible for Russia's Ukraine policy (a 16-point increase), while 45% see them affecting the

broader population (a 22-point decrease). These interpretations vary widely by age, income, region, political orientation, and information sources. Critics of the government, younger respondents, and those with declining personal finances are more likely to feel personally affected; older and more affluent individuals, rural residents, and political loyalists report minimal disruption.

Despite divergent views, a prevailing belief is that Western sanctions aim to weaken Russia, yet many respondents (over half) view them as a catalyst for national development.



Figure 8. *Perception of sanctions by the Russian society: Social Sentiment Index (March 2008 - 100%; dynamics since 1995)*

Source: (Levada, 2025B)

Figure 8 presents the Social Sentiment Index (SSI), a composite indicator based on four sub-indices—Family Situation, Country Situation, Expectations, and Trust in Government. Each sub-index is calculated as the difference between positive and negative responses plus 100, with the overall SSI ranging from 0 to 200. Values below 100 reflect predominantly negative assessments.

The graph shows that, since the mid-1990s, the SSI has risen from the low 70s—marking a period of post-Soviet instability—to sustained values above 100 from 2007 onward. Notable declines align with key crises, including the 1998 financial crash, the 2008 South Ossetia conflict, the 2014 Crimea integration, and the launch of the 2022 special military operation in Ukraine. Since 2023, the index has gradually stabilized above 100 points, indicating that overall economic, social, and political sentiment has recovered to a neutral or moderately positive level.

The data indicate a high degree of public adaptation to external constraints, with respondents largely maintaining optimistic expectations for socio-economic development despite ongoing challenges. These trends appear shaped by subjective interpretations of domestic economic realities and perceptions of the relationship between foreign policy and national well-being. In this sense, the SSI not only captures shifts in collective mood but also serves as a barometer of public confidence under pressure, helping contextualize societal reactions to geopolitical and structural change over time.

6 CONCLUSIONS

Analysis of the consequences of sanctions allows us to highlight several key conclusions:

1. **Reassessment of interdependence.**
Russia's dependence on Europe turned out to be significant but exaggerated, while Europe's dependence on Russia was downplayed. This led to unexpected consequences for both sides.
2. **Underestimation of the consequences for Western countries.**
Policymakers in the USA and EU, operating under the belief in their economic indispensability, underestimated the scale of losses from exiting the Russian market. This created opportunities for third countries that were able to fill the vacated niches.
3. **Positive effects for Russian producers.**
In several industries, sanctions opened new opportunities for Russian companies, allowing them to occupy market segments that foreign producers previously dominated.
4. **A mismatch in the supply and demand for goods and services has largely driven the emergence of inflation under sanctions.** This has been further compounded by global production disruptions and the rising costs of economic adaptation faced by businesses. This creates persistent inflationary pressure that is poorly controlled by the usual methods of state monetary policy.

The global economic landscape is increasingly shaped by competition among major powers for

access to strategic resources, essential industrial components, and technological innovation. Against this backdrop, conditions have emerged for a closer alliance between the People's Republic of China and the Russian Federation. Their complementary economic structures and industrial synergies have enabled both countries to strengthen gradually their positions relative to Western competitors.

The United States was the first to assess the potential threats posed by global competition. It took steps to restore its national industrial base, attract international partners, and ensure reliable access to scarce resources at acceptable prices. The European Union currently faces one of the most challenging economic situations. Its high dependence on external sources of essential industrial components and energy carriers has significantly undermined its competitiveness in the

context of growing resource shortages and mounting geopolitical instability.

Moreover, the application of sanctions often fails to advance the stated objective of maintaining international stability, as outlined in the United Nations Charter. Such measures frequently only increase tension, deepen contradictions within countries and global communities, obscure the true motives of the parties to the conflict and contribute to further escalation of situations.

Based on the research findings, it can be concluded that exogenous shocks caused by the sanctions' regime play a key role in shaping inflationary processes. These processes are driven by an imbalance between aggregate demand and supply, further reinforced by persistent disruptions in value-added chains and the adaptation costs borne by economic agents.

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DETERMINANTS OF CONSUMER BEHAVIOR IN ONLINE SHOPPING: EVIDENCE FROM NORTH MACEDONIA

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ABSTRACT

This study examines the dynamics and determinants of online consumer behavior in the Republic of North Macedonia, focusing on the country's readiness for e-commerce development and the factors shaping digital purchasing patterns. Employing a mixed-methods approach, the research integrates qualitative content analysis of academic, institutional, and policy documents with quantitative data gathered from a purposive sample of 180 respondents. Secondary analysis includes international benchmarks such as the Network Readiness Index and the Logistics Performance Index, providing a comparative perspective on digital infrastructure, connectivity, and logistical performance. The investigation explores consumer preferences, frequently purchased product categories, and favored online platforms while identifying psychological, technological, and infrastructural factors that influence purchase decisions. Findings reveal that online shopping is expanding, especially among younger, urban, and digitally literate consumers. However, persistent barriers such as limited trust in online transactions, underdeveloped logistics systems, and payment security concerns continue to hinder broader market growth. Despite these obstacles, national digitalization strategies, growing internet penetration, and increasing consumer engagement with digital platforms indicate a favorable trajectory for the development of e-commerce in the coming years. The results underscore the importance of strengthening consumer confidence, improving delivery efficiency, and enhancing cross-border trade mechanisms to ensure sustainable market expansion. By contextualizing global e-commerce frameworks within an emerging market, this research contributes to a deeper understanding of the evolving digital economy in North Macedonia. It offers practical insights and strategic recommendations for policymakers, businesses, and stakeholders committed to advancing digital transformation and fostering consumer participation in the online marketplace.

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1 INTRODUCTION

The global digital transformation has reshaped consumer markets and altered the very structure of purchasing behavior. Across the world, customers increasingly rely on online channels to explore, compare, and purchase products. Understanding this behavior is critical for both marketing theory and national economic strategy, especially in emerging economies where digital infrastructure and consumer trust remain under development. North Macedonia provides an insightful case study in this context. Despite being a small market, the country has shown rapid growth in online shopping adoption, particularly during and after the COVID-19 pandemic. Yet, this growth is uneven: while urban and younger consumers are leading digital adoption, rural and older populations remain less engaged. The national e-commerce ecosystem still lags EU averages in logistics efficiency, payment security, and cross-border integration. The consumer decision-making process in online environments follows the classical five-stage model: recognition, information search, evaluation of alternatives, purchase decision, and post-purchase evaluation (Ristevska-Jovanovska, 2013; Han, 2021). However, digital shopping introduces new behavioral stimuli such as website usability, algorithmic personalization, peer reviews, and digital advertising, all of which shape consumer perceptions and decisions.

Contemporary models such as the Technology Acceptance Model (Venkatesh et al., 2022) and the Engel–Blackwell–Miniard framework (Engel et al., 2001) emphasize factors like perceived usefulness, trust, and enjoyment as major predictors of online purchase intention. In emerging economies, these factors are often intertwined with macro-level constraints on digital access, logistics, and regulation, making e-commerce development both a behavioral and structural challenge. This study aims to bridge the research gap by exploring how individual, technological, and infrastructural determinants interact in shaping online consumer behavior in North Macedonia. The objectives are:

1. To identify the primary behavioral drivers of online shopping in the Macedonian market.
2. To evaluate the country's e-commerce readiness and compare it with EU benchmarks.
3. To provide strategic implications for national digital transformation and Small and Medium Enterprises competitiveness.

Consumer behavior in online shopping environments results from the interplay of multiple determinants: technological, psychological, sociocultural, and economic. Building on Engel et al. (2001), and Venkatesh et al.(2022), this paper conceptualizes the online purchase process through four interdependent dimensions:

1. Technological Readiness: Includes ICT infrastructure, internet access, and ease of website navigation
2. Psychological Drivers: Encompass trust, perceived risk, and enjoyment associated with online shopping.
3. Sociocultural Factors: Cover demographic traits, peer influence, and digital habits, and
4. Economic Incentives: Reflect price sensitivity, convenience, and delivery reliability.

These factors jointly determine the strength of the consumer's purchase intention and post-purchase satisfaction. This model reflects how technological readiness facilitates perceived ease of use and trust, which in turn influence purchase intention and *satisfaction*. It assumes that consumer confidence, security perception, and convenience moderate the final purchasing decision. The model provides a structural foundation for interpreting both secondary and survey-based findings.

2 RESEARCH METHODOLOGY

This study employs a mixed-methods approach, combining secondary research and primary quantitative analysis to capture both structural and behavioral perspectives. This method allows triangulation between global indicators, national data, and consumer perceptions.

Secondary data were obtained from international benchmarks and national reports, including:

1. Network Readiness Index (Portulans Institute, 2023).
2. Logistics Performance Index (World Bank, 202)
3. Eurostat and Statista datasets (2024), and

4. Reports from the Macedonian E-Commerce Association (2022, 2024) and National Bank of the Republic of North Macedonia (2025)

Table 1. Sample Structure

Gender	Number of Respondents	% of Respondents
Male	109	70%
Female	473	30%
Age		
18–28	23	15%
29–39	93	60%
39–49	31	20%
Over 50	8	5%
Education		
Primary	3	2%
Secondary	28	18%
Higher	93	60%
Master's	31	20%
Employment Status		
Employed	133	86%
Unemployed	5	3%
Pupil / Student	12	8%
Other	5	3%
Total Number	155	100%

Source: Author's research

These data contextualize Macedonia's digital and logistical environment within the global and regional e-commerce landscape.

The sample profile reveals a digitally literate, predominantly urban population representative of North Macedonia's most active e-commerce consumers.

Overview of E-commerce in North Macedonia -

E-commerce in North Macedonia has experienced steady expansion over the past five years, driven by increasing internet penetration, smartphone use, and social media marketing. According to the Macedonian E-Commerce Association (2024), the share of internet users purchasing online rose from 31.7% in 2018 to 53.5% in 2023, an increase of nearly 69%. However, the country still falls short of the EU average, where 75.3% of users shop online.

Digital Infrastructure and Readiness -

The Network Readiness Index (NRI) evaluates how well economies utilize information and communication technologies across four pillars: technology, people, governance, and impact. In 2023, North Macedonia ranked 71st out of 134 economies with an NRI score of 46/100, signaling moderate progress. (see Figure 1)

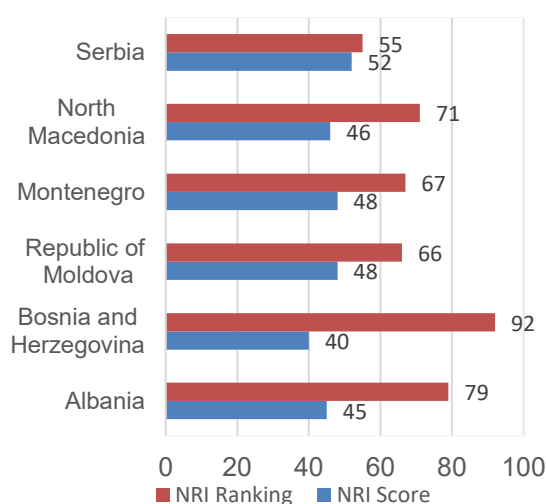


Figure 1. NRI Score and NRI rank for 2023

The Logistics Performance Index (LPI) ranks countries based on the efficiency of customs, infrastructure, international shipments, logistics competence, and tracking. In 2023, North

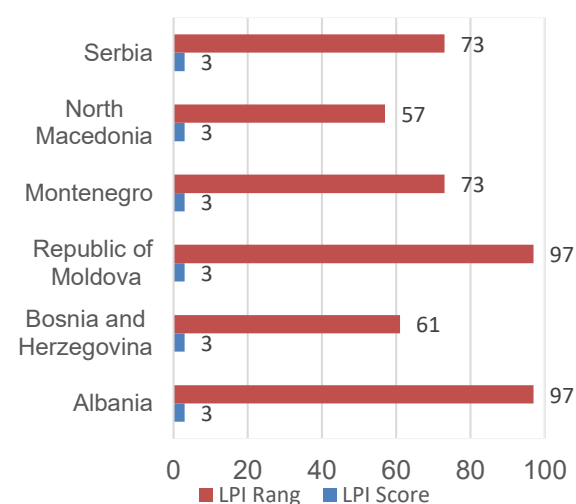


Figure 2. LPI Score and LPI rank for 2023

Source: (Ecommerce4all, 2022)

Macedonia placed 57th out of 139 countries, outperforming other CEFTA economies. Although this ranking suggests logistical potential, gaps

remain in real-time tracking systems, fulfillment centers, and delivery infrastructure. (Figure 2)

Payment Behavior and Digital Trust - The National Bank of the Republic of North Macedonia (NBRSM, 2025) reported that payment card transactions at e-commerce sites increased by 22.3% in 2024, reaching 189.8 million transactions, with a 12.9% year-on-year growth. Nevertheless, cash-on-delivery remains a dominant payment method, reflecting limited consumer confidence in online security. This is consistent with studies identifying trust as a central barrier to digital adoption in developing markets (Javadi et al.,2012; Ayalew&Zewdie, 2022).

Comparative EU Perspective - While online sales represent around 6% of total retail turnover in North Macedonia, in EU markets this share exceeds 20%. Projections by Statista (2024) estimate Macedonian e-commerce revenue to reach €570 million by 2025 and €740 million by 2029, with a compound annual growth rate (CAGR) of 6.75%. The National ICT Strategy (2023-2027) aims to increase SME participation in e-commerce, targeting 25% of SMEs to be engaged in online sales by 2027.

Table 2. Purchased Product Categories

Categories	Number of Respondents	% of Respondents
Clothing & Fashion Accessories	112	72%
Sports Equipment	81	52%
Food & Beverages	64	41%
Books	60	39%
Cosmetics & Personal Care	56	36%
Travel & Accommodation	51	33%
Online Courses	47	30%
Furniture & Home Décor	37	24%
Household Appliances	26	17%
Other	22	14%
Total Number		100%

Source: Author's research

Macedonian E-Shopper Profile - Understanding the behavioral characteristics of Macedonian consumers provides insight into how cultural and socioeconomic factors influence online shopping habits. Data from the survey were analyzed alongside Eurostat (2024) and E-Commerce Association (2024) findings to identify consumption patterns, spending levels, and purchasing frequency.

Product Preferences - The survey results indicate that clothing, footwear, and accessories dominate online purchases, representing 72% of total consumer choices. This is consistent with regional patterns in the Balkans and with EU averages (Eurostat, 2024). As shown in Table 2, other frequently purchased categories include sports equipment (52%), food and beverages (41%), books (39%), and cosmetics (36%).

The predominance of fashion and lifestyle products highlights a younger, experience-oriented consumer base that values aesthetics, personalization, and convenience. Regarding spending, 48% of respondents spent less than €50 per quarter online, 17% spent between €100 and €499, and only 0.3% spent above €500. This spending distribution reflects moderate purchasing power and cautious online spending behavior. 69% of respondents primarily shop through official retailer websites, while 17% use social media, 8% use discount platforms, and 6% use food delivery sites. The preference for retailer websites demonstrates a moderate level of digital trust, but the growing importance of social media suggests the potential of influence-driven marketing. (Table 3)

Table 3. Respondents most often shop online

Most often Shop online	Number of Respondents	% of Respondents
Through official retailers' websites	107	69%
Through social media	26	17%
Through discount websites	12	8%
Through food delivery/order websites	8	5%
Other	2	1%
Total Number	155	100%

Source: Author's research

Consumer Trust and Behavior - Interviews and survey feedback revealed that trust, security, and delivery reliability remain major concerns. Consumers value the option to return products, responsive customer support, and transparent reviews. These findings align with global literature identifying *trust* and *perceived risk* as central predictors of e-commerce engagement (Sarkar & Das, 2017; Ayalew & Zewdie, 2022). Overall, Macedonian e-shoppers are digitally active, socially influenced, and pragmatically motivated by convenience and price sensitivity, yet cautious due to perceived transaction risks.

3 RESULTS AND DISCUSSION

Out of 180 respondents, 86% had prior online shopping experience. Gender distribution shows a male dominance (70%), though female consumers demonstrate higher engagement in fashion and cosmetics categories. Age and education were positively correlated with digital trust and frequency of purchase: higher education levels tend to reduce perceived risk, confirming the relationship between digital literacy and consumer confidence. The analysis reveals three key behavioral determinants:

1. Convenience and Price Comparison: Consumers appreciate the time-saving benefits and ease of price transparency online.
2. Perceived Risk: Despite infrastructure improvements, concerns about payment safety and delivery accuracy persist.
3. Technological Familiarity: Internet usage and smartphone access strongly influence purchase frequency.

These determinants echo patterns found in similar markets such as Serbia, Croatia, and Romania, suggesting shared regional dynamics.

When compared with EU markets, Macedonian consumers display:

- Lower purchase frequency and spending levels,
- Higher reliance on cash-on-delivery,

- Stronger dependence on social validation (reviews, influencers),
- Faster adoption of mobile commerce (due to high smartphone penetration).

This indicates a transitional stage in e-commerce development: consumers are increasingly digitally engaged but still building trust in systems. As Ayalew and Zewdie (2022) argue, this “trust formation phase” is typical of late adopters in developing digital economies.

The results highlight the need for targeted interventions in three areas:

1. Digital Infrastructure and Logistics:
 - Develop national fulfillment centers, next-day delivery options, and real-time tracking.
 - Encourage private–public partnerships to improve regional logistics hubs.
2. Consumer Protection and Payment Security:
 - Introduce stronger data protection, dispute resolution, and e-commerce certification systems.
 - Promote awareness of secure payment methods and digital literacy.
3. SME Support and Cross-Border Expansion:
 - Subsidize digital transformation for small businesses.
 - Foster international integration through EU-aligned export platforms.

By addressing these factors, North Macedonia can unlock the potential of digital commerce as a driver of inclusive economic growth.

The results confirm the applicability of the Technology Acceptance Model (TAM) and Engel–Blackwell–Miniard model in the North Macedonian context, while emphasizing *trust* and *logistics efficiency* as culturally embedded variables. Technological readiness enhances perceived ease of use, while trust moderates the link between intention and behavior, mirroring Venkatesh et al. (2022). This validates the conceptual model proposed earlier and demonstrates how micro-level psychological factors are shaped by macro-level infrastructure.

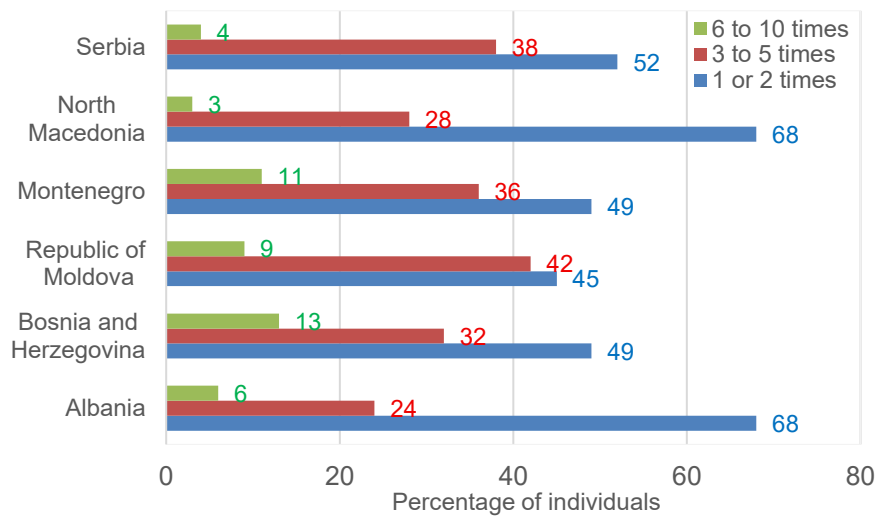


Figure 3. How often do consumers shop online

Source:(Eurostat, 2023)

4 CONCLUSIONS

This study explored the determinants of consumer behavior in online shopping in the Republic of North Macedonia using a mixed-methods design. Findings confirm that while digital adoption is accelerating, trust and logistics constraints remain major barriers to e-commerce maturity. Younger, educated, and urban consumers are leading adoption, showing strong interest in fashion and lifestyle products, but their engagement is still periodic rather than habitual. The analysis demonstrates that successful e-commerce growth depends on an integrated approach combining:

1. Infrastructure modernization.
2. Enhanced consumer trust and security frameworks, and
3. SME digitalization strategies aligned with EU policies.

By prioritizing these measures, North Macedonia can strengthen competitiveness, stimulate

innovation, and position itself as a regional digital hub. Future research should apply inferential statistical methods (e.g., regression or structural equation modeling) to test relationships among trust, perceived risk, and purchase intention. Cross-country comparative studies within the Western Balkans would further clarify regional dynamics. Moreover, qualitative research exploring consumer narratives could provide deeper insights into cultural aspects of trust formation and digital literacy.

About shopping frequency and spending levels (see Figure 3), most respondents (67.4%) reported making 1–2 online purchases within a three-month period, while 27.6% made 3–5 purchases, and only 3.2% exceeded six purchases. This pattern shows that online shopping in North Macedonia is still occasional rather than habitual, contrasting with EU markets where 16.1% of consumers shop 6–10 times quarterly.

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THE INFLUENCE OF A CAD DESIGNER'S CREATIVITY ON ENHANCING THE QUALITY OF A NEW INNOVATIVE PRODUCT

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ABSTRACT

A CAD designer is a creative professional with a strong sense of aesthetics, harmony, and visual composition. They typically work daily on visual presentations across various media, designing web pages, banners, newspaper advertisements, signage, logos, magazine covers, video credits, animations, and product prototypes — all of which constitute the core subjects of their work. This study investigates how both environmental and personal contextual factors influence each CAD designer. Environmental influences include family, workplace, and education. Personal factors are gender, age, lifestyle, habits, social background, education, occupation, character, and behavioral patterns. These factors influence the seven core traits of a creative personality, ultimately enhancing the quality of an innovative product. To explore this, a standardized questionnaire was used to assess the seven core creative personality traits. The results are as follows: Associativity (35%), Originality (17.5%), Motivation (22.5%), Ambition (11.25%), Flexibility (7.5%), Emotional instability (3.75%), and a lower level of sociability (2.5%). Data were obtained through surveys among CAD designers and their collaborators. A total of 80 valid questionnaires were collected from 23 companies in Serbia that specialize in computer design. An additional objective is to establish the relationship between creativity and design in the work of CAD designers who develop new products.

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1 INTRODUCTION

Computer-Aided Design (CAD) encompasses the application of computer technology in the creation, modification, analysis, or optimization of product or process designs. A computer-aided designer is engaged in the use of digital tools to support and enhance the design process. CAD first appeared in a practically usable form in the mid-1960s. Patrick J. Hanratty, recognized as one of the pioneers of software development, is often referred to as the father of CAD software. He developed the first numerical control system, which later evolved into what is now known as Computer-Aided Design (Baltes, 2024). Its implementation enables the design of geometries with complex and unconventional forms (Manavis et al., 2024). Essentially, CAD represents a shift from traditional manual drafting methods—such as sketching on paper—to digital processes that enhance precision and efficiency. Ultimately, computer-aided design is driven by the designer's inspiration, who simultaneously assumes the roles of both artist and engineer. The increasingly nuanced role of technicians, engineers, and computer programmers in the development of technologies that shape our social, emotional, and intimate lives is being examined, alongside advocacy for the use of art as both a context and a tool. Art is promoted to help professionals cultivate sensitivity and critical thinking, in addition to their technical skills. In a world where technology evolves at an exponential pace, the integration of computer-aided design into product engineering processes represents a pivotal turning point. (Innella & Rogers, 2021) Engineering design is fundamentally rooted in the process of creating new and compelling products, systems, and services. It is a complex task that requires balancing multiple objectives and attributes simultaneously (Diakun & Grzejda, 2025). Numerical methodologies based on sketches aim to achieve optimal solutions for product design, bridging the gap between initial conceptual sketches and advanced engineering analyses (Charalampous, 2025).

2 LITERATURE REVIEW

The study of creativity provides rich opportunities for interdisciplinary research across engineering, cognitive science, and computing (Fu et al., 2018). A CAD designer is a creative individual with a

sense of aesthetics, harmony, and good composition (Casakin & Goldschmidt, 1999).

Understanding how designers think is of great interest—not only to designers seeking better insight into their own cognitive processes, but also to CAD designers at all levels, from beginner to advanced (Aydin & Aktas, 2020; Ceylan, 2021; Rasouli et al., 2023). The history of the use of information and communication technologies (ICT) in computer-aided design is relatively short when compared to the development of traditional design methods. ICT has had a revolutionary impact on the field of computer design (Stojanov et al., 2025).

A new dynamic theoretical framework is being introduced into the creative process, consisting of a psycho-biological layer, a contextual layer, and a layer of creative states (Agnoli, 2025). Research areas such as divergent thinking, brainstorming, and scientific productivity remain highly relevant (Kalargiros & Manning, 2015).

Researchers have demonstrated that certain personality traits are associated with creative individuals, particularly designers (Wang et al., 2023; Karpova et al., 2013; Puccio & Grivas, 2009). Changes in both the internal and external environment, as well as the enhancement of capacities for independent innovation in new products, have been analyzed (Xue, 2025). Research on the Big Five personality traits has shown that openness to experience is positively correlated with creativity. Similar but statistically weaker evidence was found for the relationship between extraversion and creativity. Contrary to most previous findings, a negative correlation between conscientiousness and creativity was also observed (Jirasek & Sudžina, 2020). One study investigating the influence of the Big Five personality factors on leadership behavior reported regression analysis results as follows: openness to experience 0.12, openness 0.03, agreeableness 0.16, conscientiousness 0.29, and emotional stability 0.11 (Sajfert et al., 2017). Supporting the hypothesis, the regression results indicate that, after controlling other characteristics, conscientiousness is significantly associated with the Ethical Leadership Scale ($r = 0.29$, $p < 0.01$). Terek Stojanović et al. (2023) examined the impact of Big Five dimensions. Extraversion, openness to experience, and narcissism have the

strongest positive influence on dimensions of the Theory of Planned Behavior. Generally, narcissistic individuals hold a high opinion of themselves, are confident, and are highly motivated to achieve success, wealth, and admiration from others.

Four creative traits have been identified: diverse thinking processes, determination, open-mindedness, and risk-taking (Karpova et al., 2013). Combining individual differences with a sociocultural perspective on creative personality allows for a better understanding of the transition from potential to creative achievement, even when established predictors such as intelligence and divergent thinking are considered (Lebuda, 2025).

Creativity focuses on idea generation, whereas innovation emphasizes the implementation of ideas (Rank, Pace, & Frese, 2004; Lebuda, 2025; Wang et al., 2023). Creativity is often regarded as the initial step of innovation (West, 2002). Many caution that creativity does not only occur in the early stages of innovation processes; rather, through cyclical and more complex patterns, it boils down to a simpler process of idea generation and implementation. Three distinctions between creativity and innovation have been identified (Anderson et al., 2018):

1. Creativity may involve only the generation of creative ideas. Innovation, however, must include the deliberate introduction and application of new and improved ways of working.
2. Innovation must relate to benefits at one or more levels of analysis, which is not necessarily the case for creativity.
3. Innovation is not new to the organization, but is usually a blend of emergent processes, adopted or adapted procedures, and creative responses.

The distinction has been examined from a motivational perspective, with the assertion that creativity is driven by intrinsic motivation, whereas innovation is driven by external incentives and the need to surpass previous standards (Clydesdale, 2006). The balance theory between originality and effectiveness was used to differentiate these two concepts (Runco, 2025). Creativity (especially artistic creativity) places greater emphasis on originality, while innovation requires that effort be useful and marketable

(effectiveness). Since the determination of the effectiveness of innovative effort is a social rather than a personal process, innovation is primarily an interpersonal-social process, whereas creativity is more of an interpersonal-cognitive process (Anderson et al., 2014). Creativity and innovation are interconnected constructs and are often used interchangeably by laypeople.

Researchers aim to determine the potential for entrepreneurs to be as innovative and creative as possible, Ikbali, (2022). Innovation research defines innovation as the application of new ideas, which people disseminate over time, capable of innovating and adapting old ideas. The study explains the mechanism through which an innovative organizational environment mediates the relationship between entrepreneurs and employees' innovative work behavior (Kreiner et al., 2022).

The innovation processes address the issues of technical creativity and invention. The term "creative process" will be used in the following discussion, although this term has a broader meaning in human creativity. The outcome of such innovation processes is an original solution to a specific technical problem (an invention – innovation protected by a patent) or, in less creative cases, a technical improvement of an already known technical solution. Invention represents the highest achievement of human intellectual capacity and creativity in the field of technology.

Secondly, there is a negative correlation between conscientiousness and creativity, especially among artists. Besides this, findings on the relationship between other Big Five personality traits and creativity are inconsistent. For example, while some studies find a positive association between extraversion and general creativity measures based on domain-specific criteria, others suggest the opposite trend: a link between introversion and creativity among artists and writers. Even among scientists, the correlation is complex, as scientists tend to be more introverted than non-scientists, yet creative scientists are more extraverted than less creative ones. Although some studies tend to portray a less favorable image of creative scientists and artists, this result does not apply to samples of American adults or Chinese students.

3 METHODOLOGICAL CONCEPT OF RESEARCH

3.1 Problem and subject of research

When discussing the design of a product, object, or any other item, the term "design" refers to the integration of elements that constitute the entirety of the product. Field studies, which follow a defined on-site methodology, are commonly referred to as a recognized scientific domain. Such studies on the application of design in the development of new products generally provide evidence that their role is indispensable in this process. Computer-aided design represents a field that explores the interaction between humans and the technologies of the digital age. Research has shown that increasing the perceived efficiency of CAD designers enhances their motivation, thereby increasing the likelihood that they will remain with their current employer. The data obtained were used as a basis for developing a model for improving product quality in the computer design sector of domestic enterprises. The primary objective of this survey was to gain insight into potential influential relationships between factors that additionally affect the business performance and competitiveness of domestic firms in computer design.

The research presented in this paper will be based on facts derived from the analysis of the latest theoretical insights and practical achievements in the field of computer-aided design. A content analysis and synthesis of the literature will be applied, from which conclusions will be drawn based on the general premises of the research.

3.2 Review of Existing Research in the Field

A questionnaire examining the seven core traits of a creative personality was employed, based on the work of Martinsen (2011).

3.3 Research Objectives

The main objective of this research is to enable human resource managers to utilize the obtained results in assessing the creative abilities of computer-aided designers—specifically, to determine whether a designer possesses the necessary qualities to meet the demands of a position within a company seeking to hire them.

This research pursues a societal objective: to provide scientific insights that support social measures advancing and improving computer-aided design.

The scientific objective is to achieve a certain level of theoretical understanding regarding how creativity in computer-aided design professionals affects their professional competencies and conceptual abilities in the creation of new, innovative products.

A further goal of the study is to determine, through scientific analysis, whether there is a measurable impact of creative computer-aided designers on the functional characteristics of newly developed, innovative products.

The research also aims to demonstrate that a computer-aided designer who acquires specific knowledge—gained through dialogue with prospective customers regarding product features—will be capable of conceptualizing and designing an object that incorporates the required characteristics.

Finally, the study highlights the role of the computer-aided designer as a key driver within a company, emphasizing their importance in establishing effective communication and enhancing the organization's competitiveness in the marketplace.

3.4 Expected Results and Hypotheses

The research will aim to determine the extent to which creative computer-aided designers influence the functional characteristics of a new product.

Creative behavior exhibited by computer-aided designers serves as the fundamental principle upon which the hypotheses of this study are formulated.

3.4.1 Main Hypothesis

There are statistically significant relationships between the dimensions of creative computer-aided designers and their influence on the characteristics of a new, innovative product.

3.4.2 Specific Hypotheses

H₁: There are statistically significant correlations between dimensions of creativity and designing new products.

H₂: There are statistically significant correlations among the dimensions of the seven core traits of the creative personality.

H₃ relies on divergent thinking, the ability to generate different and original ideas related to the design problem. This paper represents a research process that stimulates imagination and connects seemingly unrelated ideas.

3.5 Research Methods

Based on the conclusions of previous studies and the conceptual literature, specific assumptions were introduced for the purposes of this research. These assumptions provided the foundation for constructing original research frameworks, which in turn shaped the study's structure and informed the determination of representative sample sizes.

This study is grounded in assumptions derived from prior research and conceptual literature, which have informed the development of original research frameworks. These frameworks guided the overall structure of the study, including the determination of representative sample sizes.

The following methods will be presented and analyzed as part of the research process: Content analysis method, Expert-based scientific examination methods (specifically, a questionnaire used for data collection), and data processing methods. All collected data were analyzed using IBM SPSS Statistics, a statistical software package employed to ensure the accuracy and validity of the research findings.

3.5.1 Questionnaire Distribution and Data Collection

Each respondent was initially contacted by the researcher via telephone. Upon receiving consent to participate, the respondent was sent a cover letter along with technical instructions for completing the electronic questionnaire. The study involved participation from new product designers and their collaborators. For the processing and statistical analysis of the collected data, the software package IBM SPSS Statistics (Statistical Package for the Social Sciences) was used.

3.5.2 Presentation of Research Results

Figure 1 illustrates the gender distribution of respondents from the surveyed population of

computer-aided designers. Based on the results obtained through tests conducted using Google Forms, 40% of the digital designers were female (n = 32), while 60% were male (n = 48).

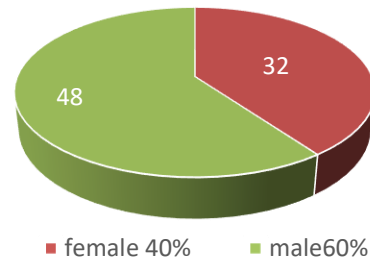


Figure 1. Gender of respondents

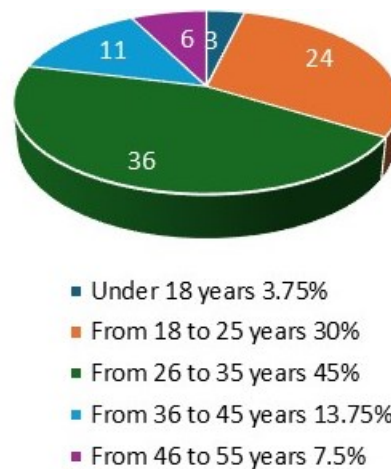


Figure 2. Age distribution of respondents (in years)

Figure 2 illustrates the age distribution of computer-aided designers. A total of 3.75% of respondents were under 18 years of age. Respondents aged between 18 and 25 years made up 30% of the sample, while the largest group, 45%, was between 26 and 35 years old. Those aged between 36 and 45 years accounted for 13.75%, and 7.5% were between 46 and 55 years old. No respondents over the age of 55 were included in the survey.

Figure 3 shows the responses of CAD designers concerning their completed education: 16.25% completed high school. 2.5%, completed secondary vocational school. 20%, graduated from a college of vocational studies. 18.25%, completed the master's degree at the College of Vocational Studies. A total of 31.25% obtained their degrees through the Faculty of Academic Studies. Ten percent of them completed master's academic studies. 1.25% have a doctorate.

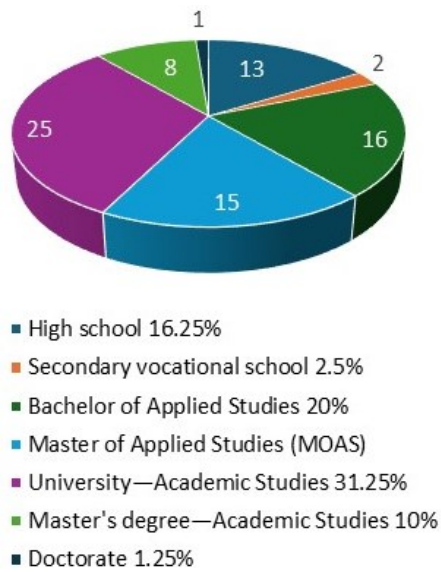


Figure 3. Education of respondents

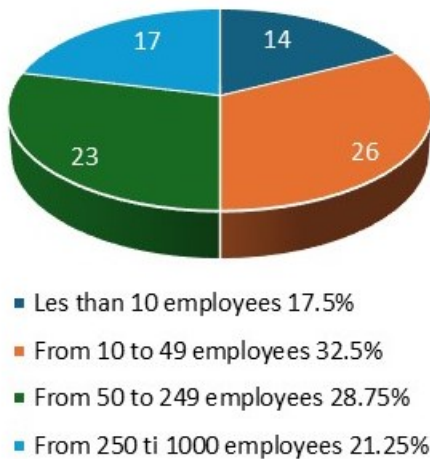


Figure 4. Number of Employed Respondents within the Organization

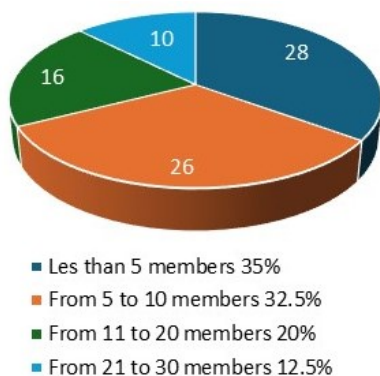


Figure 5. Size of the design team

Figure 4 presents the distribution of employed CAD designers across different organization sizes. Specifically, 17.5% work in organizations with fewer than 10 employees, 32.5% in

organizations with 10 to 49 employees, and 28.75% in organizations with 50 to 250 employees. Finally, 21.25% are employed in organizations with 250 to 1,000 employees.

Figure 5 illustrates the size of design teams within organizations. Organizations with fewer than 5 designers represent 35% of the total. Design teams consisting of 5 to 10 members account for 32.5%. Teams with 11 to 20 designers represent 20% of the total. Finally, teams with 21 to 30 designers comprise 12.5%.

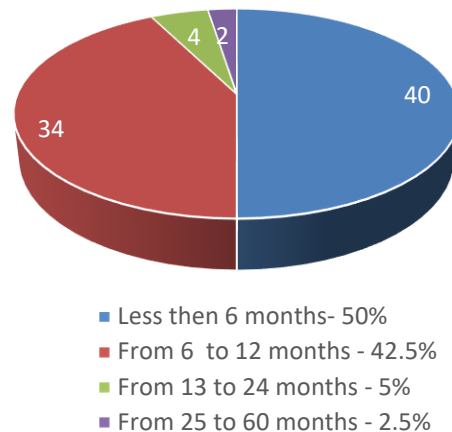


Figure 6. The planned period of production of the designer's new product

Figure 6 presents the responses to the question on the planned period for developing a new product by CAD designers: less than 6 months (50%), 6–12 months (42.5%), 13–24 months (5%), and 25–60 months (2.5%).

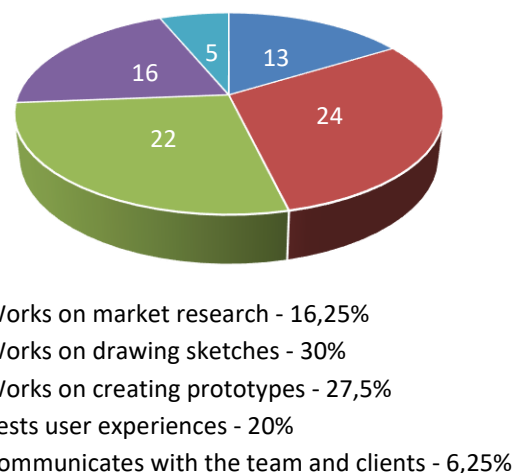


Figure 7. Skills Required for the Role of a Computer Designer

Figure 7 presents the responses to the question regarding the tasks most performed by computer product designers. A total of 16.25% of

respondents reported that they work on market research. 30% indicated that they create sketches. 27.5% stated that they develop prototypes. 20% reported that they test user experience. Finally, 6.25% indicated that they maintain good communication with clients.

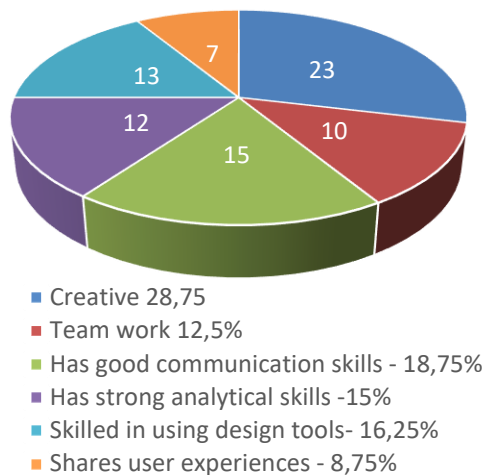


Figure 8. Skills required for the position of CAD designer

Figure 8 presents the responses of participants to the question: *Which of the following skills is the most important for working as a computer product designer (choose one)?* A total of 28.75% of respondents selected creativity as the most important skill. 12.5% chose teamwork. 18.75% selected communication skills. 15% chose analytical abilities. 16.25% selected proficiency in design tools. Finally, 8.75% selected sharing user experiences.

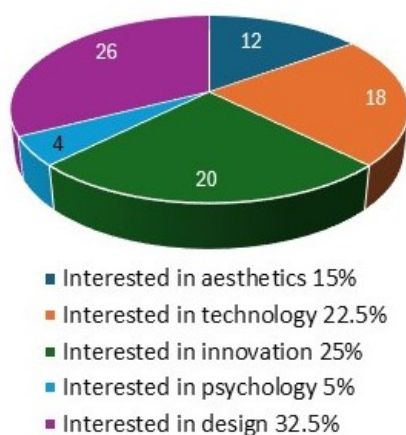


Figure 9. Individuals aspiring to become computer product designers

Figure 9 shows that individuals aspiring to become CAD designers are most often interested in

aesthetics, as indicated by 15% of respondents. 22.5% of them declared their interest in technology. 25% of them expressed interest in innovations. 5% of them expressed interest in user psychology. 32.5% of them declared their interest in design. The findings highlight that user experience may be enhanced by addressing users' frustrations and emotional reactions to technology during the design process (Taylor, 2024). In addition, Zhou (2023) emphasizes that creative products differ significantly from ordinary goods, requiring careful consideration of human psychology in both their design and evaluation.

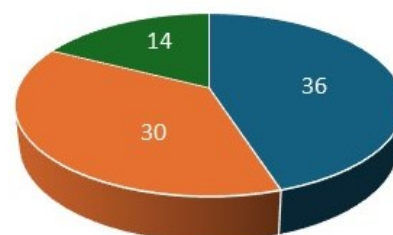


Figure 10 Criteria most often applied in computer design

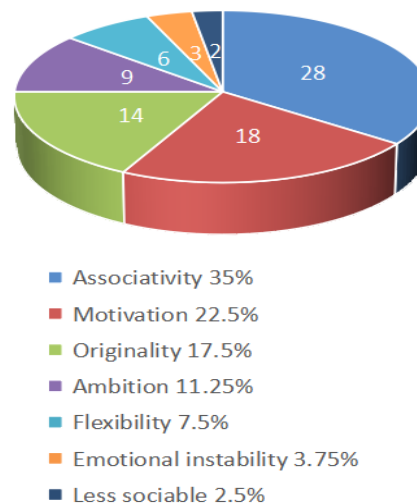


Figure 11: Seven Core Traits of Creative Personalities

Technological development and new conceptions of the user now require more interdisciplinary approaches to design.

Figure 11 shows the answers to the respondent's question: Which of the seven basic characteristics

of creative personalities do you have? Respondents' answers to the question: Which of the seven core traits of a creative personality do you possess?

For a long time, there has been a myth about the "tortured artist," locked away in a studio, working on their ideas in complete isolation from the world. According to Martinsen (2011), this stereotype may not be far from the truth. His study revealed that seven factors explained significant differences between creative and non-creative groups, with an explained variance of 69.9%. These factors are associative orientation, motivation, ambition, emotional instability, originality, resourcefulness, and flexibility.

The Myers-Briggs Type Indicator (MBTI) attempts to classify personality based on four dichotomies: introversion versus extraversion, sensing versus intuition, thinking versus feeling, and judging versus perceiving. However, the Myers test is less suitable than Martinsen's model and its explanation of personality traits.

However, *the Myers-Briggs test* is less suitable since the introduction of Martinsen's model, it has been considered more insightful.

The personality traits of a creative scientist have been identified across four aspects: personality, thinking ability, research capability, and uniqueness.

The results showed that thinking ability was the best identifier of creative scientists, while personality traits were the best predictors of less creative ones.

3.5.3 Model for Improving Product Quality in Computer Design

Based on research into the opinions of CAD designers regarding the quality and competitiveness of new innovative products, as well as creativity studies, a theoretical model has been developed to improve product quality in computer design within domestic companies.

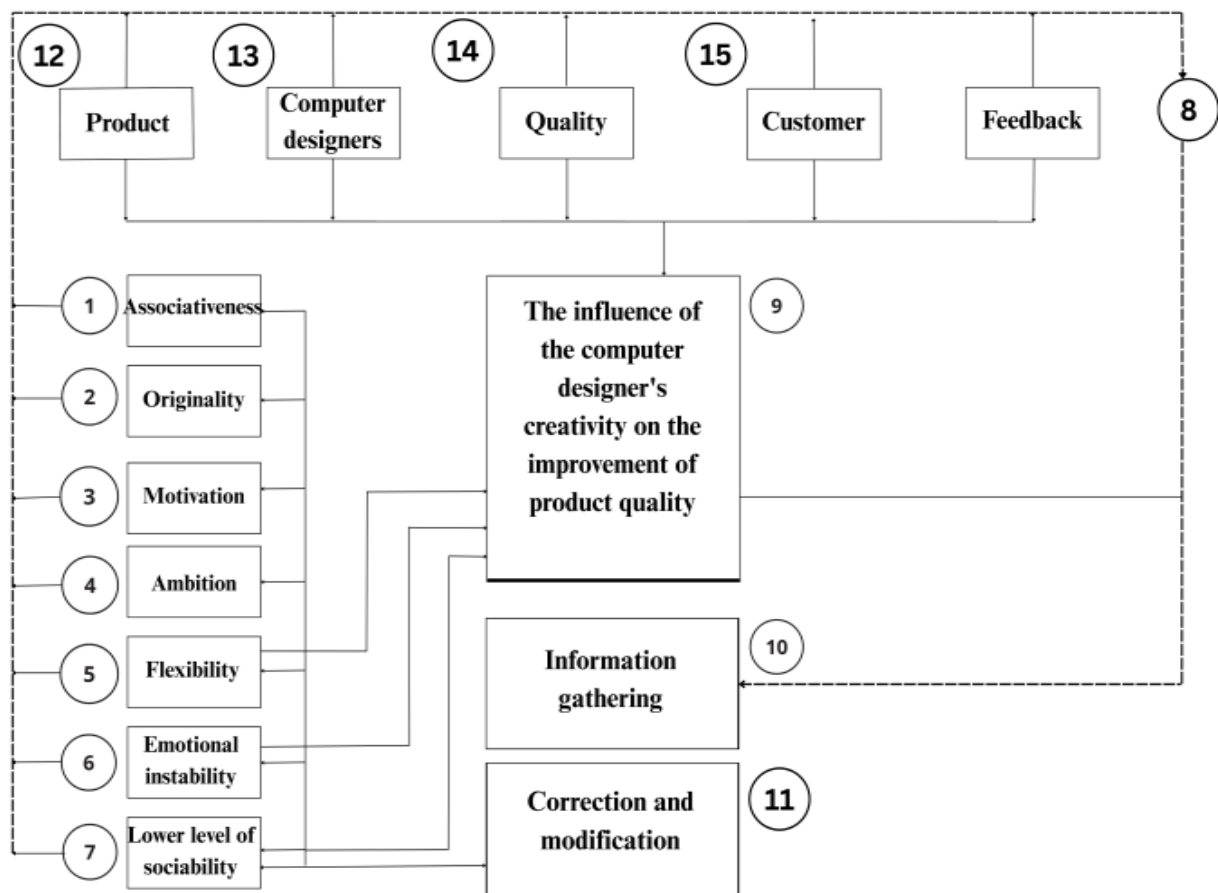


Figure 12 Model for Improving Product Quality in Computer Design

Source: Adapted from Martinsen (2011)

The main principle on which the model operates is the PDCA cycle (Plan–Do–Check–Act), where each cycle introduces improvements within specific creative activities. The model is based on the continuous improvement of business activities, with the aim of enhancing both design quality and overall business performance.

The model integrates interconnected elements, including an information collection process and a correction/modification process. Based on the collected and analyzed information, necessary adjustments are made to business processes or activities. The three main components of the model are: Enhancement of designer creativity, Improvement of product quality, and Human resource management. The model is illustrated in Figure 12. It represents a theoretical framework aimed at improving product quality in computer design within domestic enterprises. Based on the presented model, it is evident that feedback and the information-gathering process are key

components of the improvement process. The main elements include core business activities and processes; however, improvement depends on the feedback through which specific enhancements are achieved. The relationships shown between the main elements and the primary goal of the model are partially based on a review of the literature in the fields of computer design and human resource management. However, the main source of assumptions regarding these relationships comes from research involving CAD designers and customers.

The proposed model for improving product quality includes the main factors identified in the research conducted. As previously mentioned, these key elements are Customer Satisfaction (CS), Product Quality (PQ), Human Resource Management (HRM), as well as other present factors feedback (FIB) and competence (FIC).

Additional details on the core elements of the model are provided in Table 1.

Table 1: Interpretation of model elements

Number	Description
1	Associative Orientation – These individuals are imaginative, enjoy playfulness, have a multitude of ideas, and possess the ability to commit to a goal.
2	Originality – These individuals resist rules and conventions; they are different from others.
3	Motivation – These individuals are action-oriented, possess a focused and innovative mindset, as well as personal strength and willpower.
4	Ambition – These individuals strive to be influential, recognizable, and to attract attention.
5	Flexibility – These individuals can see things from different perspectives and develop various possible solutions.
6	Emotional Instability – These individuals tend to give in to negative feelings, experience mood swings, and have lower self-confidence.
7	Lower Level of Sociability – These individuals tend to be less attentive to their surroundings.
8	Feedback: This is the main "driver" of the improvement process. Information is collected from all elements of the model, and based on this information, necessary modifications and enhancements in the creativity of CAD designers are implemented.
9	Enhancement of Digital Designers' Creativity: This is the goal of the model. It is the result of integrating creativity with modern technologies.
10	Information Gathering: All feedback information is collected and analyzed.
11	Correction and Modification: Based on the collected and analyzed information, corrections and modifications are implemented.
12	Product: Refers to the products and services offered to consumers and customers.
13	Employed CAD designers play a key role in improving business activities and processes. They are the main agents of change.
14	Quality: Refers to the improved quality of the product according to consumer preferences.
15	Customer satisfaction is imperative, and CAD designers play a key role in achieving it.

Similar research can be found in the works of Bakator et al. (2019), who developed a model aimed at improving business operations and competitiveness of domestic companies in Serbia. The model yields significant insights into ways companies can optimize their operations and achieve competitiveness in the global market. In an earlier study, Bakator et al. (2018) developed a theoretical model that incorporates the implementation of Industry 4.0 technologies and a lean startup approach. Furthermore, Bešić and Bešić (2018) presented a model for applying marketing attributes that determine the competitiveness of domestic companies.

3.5.4 Suggestions and Guidelines for Enhancing the Creativity of Computer Designers

The literature review and the study of CAD designers' and customers' opinions provided the basis for proposing concrete guidelines to improve product quality.

The model was developed with the aim of providing an overview of how CAD designers—and consequently domestic companies—can improve the quality of their products.

Within the model, emphasis is placed on enhancing business performance and product competitiveness through improved quality.

Based on the findings in this field and the results of the research, the following guidelines are proposed to improve product quality in domestic companies: CAD designers should focus on customer relations.

Companies need to implement effective customer relationship management techniques to potentially increase customer satisfaction, which can, in turn, lead to improved competitiveness in the market.

3.5.5 Brand Development

To build customer loyalty, CAD designers must formulate effective product development strategies and implement with the overarching goal of enhancing customer satisfaction.

Improving product quality performance should be thoroughly analyzed, and where necessary, corrections and modifications should be implemented to gain control over how quality affects customer satisfaction.

Depending on the type of product, CAD designers should focus on providing a high level of personalization in the products they offer on the market.

The quality of operations, along with every aspect of computer design, should be standardized to ensure consistent levels of product quality. This approach encourages the implementation and application of a quality management system—specifically, ISO 9001.

When implementing ISO 9001 standards, CAD designers should focus on organic quality improvement, where certification is a byproduct of continuous improvement, rather than the main objective.

Continuous improvement in computer design is imperative for achieving long-term success in globalized markets.

Each CAD designer should be involved in changes that contribute to improving product quality and enhancing overall business performance.

Achieving competitiveness in computer design is practically difficult without innovation and the distribution of new products to the market. For these innovations to be effective, customer feedback must be analyzed and considered.

New and sophisticated products created by CAD designers will not improve business and market performance unless they are supported by well-designed pricing strategies.

When it comes to CAD designers, companies must develop a motivating work environment. The allocation of intellectual capital plays a crucial role in the development of new products and innovations in computer design.

The knowledge and skills of CAD designers should be periodically developed, which in turn increases their capacity for spontaneous innovation.

Domestic companies engaged in computer design must focus on quality, modern equipment, the use of ICT, and innovation.

The Government of the Republic of Serbia must create a motivating business environment for small and medium-sized enterprises (SMEs) engaged in computer design to help them become

more competitive. The government could reduce taxes and introduce incentive programs to encourage potential entrepreneurs to start their own businesses in the field of computer design.

4 CONCLUSIONS

In today's business environment, domestic companies in the computer design sector struggle to gain and maintain a competitive position in the local market. Their inability to compete effectively with firms from the European Union stems not from a lack of expertise among CAD designers, but from outdated production equipment, insufficient application of ICT, a lack of modern management tools and techniques, and, importantly, a demotivating economic environment.

This study analyzed the opinions of CAD designers working in domestic companies, as well as the opinions of customers regarding various products. The main objective of the research was to develop a model for improving the business operations and competitiveness of domestic companies in Serbia.

The research focused on product quality, customer satisfaction, and the application of innovation by CAD designers. Based on the findings, a model for improving product quality in computer design was developed. This model integrates measured factors and presents the relationships between its defined elements, providing clear insight into what these factors include and how they influence the improvement of product quality in the field of computer design.

In addition to these elements, the study found that originality, motivation, ambition, and flexibility have a favorable influence on business outcomes. These traits were shown to be strongly correlated with business performance and competitiveness.

5 LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

The main limitation of this study lies in the fact that the developed model is based on data collected from CAD designers and customers in Serbia. As a result, the model is primarily applicable to the Serbian business and market environment.

The research was supported by a solid theoretical foundation. It incorporated existing theoretical frameworks and included a thorough literature review in the field of computer design. This literature review supports the validity of the findings and suggests that the results may be useful in similar economic and business contexts.

For future research, it is recommended that these factors be analyzed in other countries, whether within the European Union or in neighboring countries. The findings from such studies could then be compared with the results of this research.

This study makes a valuable contribution to the existing body of literature and provides a solid foundation for future analysis of relationships in the field of computer design, including the influence of originality, motivation, ambition, and flexibility, all of which impact the creativity of CAD designers and the improvement of product quality.

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PUBLIC BANKING AND FINANCIAL INCLUSION IN ALGERIA: THE CASE OF BDL

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ABSTRACT

This study examines how the Banque de Développement Local (BDL) has contributed to financial inclusion across four wilayas in western Algeria from 2022 to 2024. Using detailed data from local agencies, the research evaluates four key dimensions: access, usage, quality, and innovation. It looks at indicators like account openings, credit distribution, savings trends, and the adoption of digital financial services. The results show notable progress in expanding access and building trust in financial services. However, deeper financial engagement, especially lending to small and medium-sized enterprises (SMEs) and encouraging investment-driven savings remains limited. While BDL has made strides in social outreach, its role in driving broader economic transformation is still modest. The study suggests that future efforts should focus on improving access to enterprise financing, diversifying financial services, and promoting digital literacy and behavior change. These steps are crucial for translating financial participation into long-term, sustainable development. The findings highlight how regional public banks like BDL can play a pivotal role in inclusive economic growth, particularly in emerging economies.

1 INTRODUCTION

Sustainable development has emerged as a defining global objective that integrates economic growth, social equity, and environmental protection into a cohesive framework for long-term prosperity (Cerin, 2006; Dernbach, 2003).

At its core lies the principle of intergenerational equity ensuring that the needs of the present are met without compromising the ability of future generations to meet theirs (Stoddart, 2011). As countries pursue the United Nations Sustainable Development Goals (SDGs), financial systems

have gained recognition as critical levers for driving inclusive and sustainable outcomes (OECD, 2022; UNDP, 2023).

Among the most powerful instruments within this system is financial inclusion defined not only as access to formal financial services, but also the ability to use them effectively and sustainably (Fouillet & Morvant-Roux, 2018; Aliano et al., 2021). Financial inclusion expands the frontiers of opportunity by enabling individuals and enterprises to save, invest, and manage risk (World Bank Report, 2021). It is a multidimensional process encompassing access,

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usage, and quality, each essential to ensuring that financial participation contributes meaningfully to social welfare and economic resilience (Mellab, 2025; Tharouma, 2022). Financial inclusion in emerging economies is increasingly associated with improved human development outcomes and greater alignment with environmental sustainability (Zeeshan et al., 2022; Liu et al., 2024).

The expansion of digital financial services through mobile banking, electronic payments, and TPE technologies has further amplified the potential of financial inclusion to reach underserved populations and reinforce green innovation (Mertzanis, 2023; Zhang et al., 2024). These technological shifts have transformed the landscape of public sector banking, especially in contexts where private sector actors have little incentive to serve rural or low-profit regions. As such, public banks in developing countries have come to embody dual mandates: as providers of essential financial services and as agents of state-led development policy (OECD, 2022; United Nations Department of Economic and Social Affairs, 2021).

In Algeria, this dual role is formalized through national strategy. The Banque de Développement Local (BDL) is tasked not only with extending financial access but also with supporting broader development objectives, including SME promotion, rural inclusion, and environmental transition (National Sustainable Development Strategy, 2021). However, despite these ambitious mandates, little is known about how such strategies play out at the sub-national level in specific regions, agencies, or client segments.

This paper addresses that gap by providing an exploratory, data-driven analysis of BDL's operational activity across ten local agencies located in four wilayas of western Algeria: Mostaganem, Tiaret, Relizane, and Tissemsilt. Using proprietary agency-level data spanning the years 2022 to 2024, we examine the evolution of key financial inclusion indicators, including account creation (enterprise vs. individual), financing activity (SME, microcredit, personal), deposit behavior (number, amount, and type), and digital financial usage (TPE and e-banking transactions).

Rather than evaluating policy effectiveness in normative terms, this study offers descriptive insights into the spatial dynamics of financial inclusion and their possible implications for sustainable local development. The granularity of agency-level data allows for a rare empirical window into the real-world behavior of public banking operations across differentiated regional contexts urban, semi-urban, and peripheral. In doing so, this paper contributes to emerging literature that emphasizes the local specificity of financial inclusion pathways and the institutional role of public banks in bridging structural gaps (UNCDF, 2023; Ahmad et al., 2024).

Specifically, this study seeks to:

- *Analyze trends in financial access through new account openings (enterprise and individual).*
- *Explore patterns of financing by loan type (SME, microcredit, individual) across the four wilayas.*
- *Investigate deposit dynamics volume, type, and evolution at the agency level.*
- *Assess the uptake of digital financial services (TPE and e-banking) as a proxy for financial modernization.*
- *Derive exploratory insights into the intersection between financial inclusion and local development dynamics in regional Algeria.*

By anchoring empirical observation in robust theoretical foundations, this research aims to stimulate a deeper dialogue on how financial inclusion can be institutionally and regionally embedded as a vector for sustainable development both in Algeria and comparable emerging economies.

Although financial inclusion has become a central topic in Algerian banking policy, existing studies remain primarily national in scale and overlook the regional and institutional variations that characterize the country's public banking sector. While several works (e.g., Mellab, 2025; Mellab, 2023) discuss inclusion metrics at the macro level, no empirical research has examined the Banque de Développement Local (BDL) as a regional development actor. Similarly, previous research on financial inclusion in emerging economies (e.g., Fouillet & Morvant-Roux, 2018; Mertzanis, 2023) largely treats public banking as a

background institution, not as a direct driver of inclusion.

This paper fills that gap by adopting a multi-dimensional, agency-level approach to evaluate how BDL translates national inclusion strategies into local practice within four western wilayas. It thus provides one of the first micro-analyses of Algerian public banking, bridging the empirical void between policy intention and on-the-ground implementation.

2 THEORETICAL FRAMEWORK AND LITERATURE REVIEW

The analysis of the four inclusion dimensions access, usage, quality, and innovation is grounded in the capability approach (Sen, 1999) and institutional theory (North, 1990). The capability approach conceptualizes inclusion as a process that expands individuals' and firms' real opportunities to use financial services, while institutional theory emphasizes the role of organizational design, public mandates, and governance structures in shaping these outcomes.

Together, these frameworks explain why access does not automatically lead to empowerment and how institutional incentives determine whether inclusion remains social (deposit and liquidity expansion) or becomes economic (productive finance and innovation).

2.1 Financial Inclusion: Concept and Dimensions

Financial inclusion (FI) is widely recognized as a pivotal development instrument in emerging economies. Although no single, globally accepted definition exists, it is broadly understood as the process of ensuring access to, and effective use of, formal financial services by all individuals and businesses, especially those historically excluded from the banking system (Mellab, 2025; Aliano et al., 2021).

This multidimensional concept goes beyond the mere availability of financial services. It includes the ability to use these services regularly, securely, and for productive purposes such as savings, investment, credit, and risk management (Tharouma, 2022; World Bank Report, 2021). As such, financial inclusion is seen not only as a tool

to combat poverty but also as a structural enabler of social mobility, market integration, and macroeconomic stability (Fouillet & Morvant-Roux, 2018)



Figure 1. Financial Inclusions Dimensions

Source: Created by the author based on different references

The framework typically breaks FI into three interrelated dimensions as shown in Figure 1:

- Access refers to the availability and affordability of financial services. This includes the physical presence of agencies or ATMs, the regulatory environment, and the absence of structural or discriminatory barriers.
- Usage focuses on the frequency and depth of engagement with financial products through deposits, credit, or insurance and reflects the integration of finance into daily life or entrepreneurial activities.
- Quality captures the extent to which financial services meet user needs in a responsible, transparent, and efficient manner. This includes customer satisfaction, adaptability of products, and the presence of consumer protection mechanisms (Fouillet & Morvant-Roux, 2018; Mellab, 2025).

These dimensions align closely with the indicators used in this study: account openings as a proxy for access; financing activity for usage; and deposit structure (including type and duration) for service quality.

2.2 Financial Inclusion in the Context of Sustainable Development

In recent years, financial inclusion has become tightly interwoven with the broader sustainability agenda. Access to financial services is now seen as a catalyst for achieving multiple Sustainable Development Goals (SDGs), including those

related to poverty, inequality, and environmental resilience (Zeeshan et al., 2022; Liu et al., 2024).

Digital financial technologies (FinTech) further enhance this potential. Tools such as mobile banking, TPE infrastructure, and e-banking platforms extend outreach to remote and underserved communities, reducing costs and improving convenience (Zhang et al., 2024; Mertzanis, 2023). In addition, digital finance contributes to improved environmental performance by dematerializing transactions and facilitating green innovation (GI) through access to credit and investment platforms (Ahmad et al., 2024; Mahmood et al., 2024).

A growing body of literature shows that financial inclusion, green finance (GF), and green innovation interact in a mutually reinforcing loop. As access to formal finance increases, so does the capacity of individuals and SMEs to invest in sustainable practices. In turn, these practices stimulate demand for tailored financial products that promote clean energy, resource efficiency, and climate resilience (Naheed et al., 2024; Yang et al., 2024).

However, this dynamic is not without risks. Digital expansion may widen existing inequalities if it is not accompanied by strong inclusion safeguards, digital literacy, and equitable access to technology (Qing et al., 2024). This makes the institutional role of public banks critical not only to scale financial services, but also to ensure their inclusive and sustainable deployment.

2.3 The Development Role of Public Banks in Emerging Economies

In developing countries, public banks are more than conventional financial institutions; they serve as development agents that bridge structural gaps in both geography and population reach. They are particularly important in areas where private banks perceive low profitability and thus offer minimal presence (United Nations Department of Economic and Social Affairs, 2021, p. 65).

Public banks have the mandate to support policy-led financing, especially in sectors aligned with national sustainability strategies such as green infrastructure, SME development, and financial inclusion. Their operations can be aligned with ESG criteria and national development plans,

offering a mechanism to translate macroeconomic objectives into targeted, localized action (OECD, 2022, p. 109).

In Algeria, this dual role is institutionalized in the National Sustainable Development Strategy (2021), which positions public banks like the Banque de Développement Local (BDL) at the center of the state's economic and social inclusion efforts. The strategy mandates public financial institutions to support the energy transition, improve access to credit for underserved populations, and enable regional development through tailored financial instruments.

In this context, regional agencies become the operational frontlines of national strategies. Their activities, ranging from opening accounts and issuing loans to facilitating digital transactions, serve as concrete indicators of how development mandates are enacted in practice. This study builds on this perspective by examining agency-level behavior across four Algerian wilayas, providing empirical insight into how public banks contribute to financial inclusion and regional sustainability.

2.4 Banking Innovation and Sustainable Finance

Innovation in financial services is a key mechanism through which banks can support both inclusion and sustainability. Digital financial tools such as TPE systems and e-banking platforms have enabled financial institutions to reduce costs, manage risks more effectively, and extend services into traditionally inaccessible regions (Wan et al., 2023; Wu & Wu, 2025).

This transformation is not only technological but also strategic. By integrating FinTech into their operational models, banks can reallocate resources toward environmentally and socially beneficial outcomes. For instance, studies have shown that FinTech enhances the efficiency of green lending, supports investment in clean technologies, and encourages sustainable consumer behavior (Guang-Wen & Siddik, 2022; YunQian, 2023). Across 52 developing countries, digital finance has been linked to improved environmental performance and more inclusive economic development (Bakry et al., 2024).

In Algeria, where financial digitization remains uneven, the use of TPE and e-banking data provides a useful proxy for evaluating financial modernization and the bank's adaptive capacity to serve diverse client segments. In this study, the geographic distribution of digital transactions across BDL's agencies will serve as a critical lens for assessing how banking innovation intersects with regional development.

The theoretical constructions outlined above form the analytical backbone of this study. The three core dimensions of financial inclusion access, usage, and quality, are operationalized through actual banking data:

- New account openings reflect access to the financial system.
- Financing volumes (SME, microcredit, personal loans) indicate usage depth and the bank's support for entrepreneurship and economic activity.
- Deposit trends and typologies (current, savings, term) provide a proxy for financial trust and user satisfaction (quality);
- Digital transaction data (TPE, e-banking) reveal innovation diffusion and technology adoption across regions.

3 METHODOLOGY

This study employs a comparative descriptive design to analyze how BDL's regional agencies contribute to financial inclusion across four western wilayas: Mostaganem, Tiaret, Relizane, and Tissemsilt. The population comprises ten BDL agencies distributed across these regions, representing the totality of the bank's western regional network. Hence, no sampling was necessary; the study uses a full census of available branches.

The empirical investigation is guided by the following hypotheses, derived from the capability approach and institutional theory, which together frame financial inclusion as a cumulative and institutionally mediated process:

H₁: Expanding financial access through BDL's regional agencies increases participation in the formal financial system but does not necessarily translate into productive engagement.

H₂: Growth in credit and deposit activities enhances institutional trust and financial stability but remains concentrated in non-productive segments such as individual and microcredit lending.

H₃: The diffusion of digital financial tools improves transactional efficiency and outreach but has yet to generate significant behavioral transformation toward investment-oriented inclusion.

Each hypothesis corresponds to a distinct empirical indicator set. Data were obtained from internal BDL operational reports covering the period 2022–2024 and verified across ten agency-level records. Comparative analysis across regions was performed using descriptive statistics, inter-agency trend analysis, and visual representation through tables and graphs.

Data were collected from internal agency-level records and financial statements for the period 2022–2024. These proprietary datasets include monthly transaction logs, credit registers, and deposit summaries, which were consolidated and anonymized by the author to protect confidentiality. Data cleaning involved verification of totals across months, removal of incomplete entries, and cross-validation with BDL's annual activity reports (2022, 2023).

Operationalization of Indicators: Each dimension of financial inclusion was operationalized as shown in Table 1.

Table 1. Operationalization of Indicators

Dimension	Indicator	Description
Access	Number of new current and deposit accounts	Reflects expansion of formal financial participation
Usage	Composition of loans (individual, SME, microcredit)	Measures the productive intensity of credit activity
Quality	Deposit structure by type (savings, term, current)	Indicates trust and engagement stability

Source: Created by the author based on different references

Given the descriptive and institutional nature of the data, the study applies trend analysis and inter-agency comparison. Indicators were standardized by agency size to ensure comparability, and results were presented using tables and line graphs to illustrate growth dynamics and structural differences.

The approach is qualitative–quantitative hybrid, emphasizing interpretation over econometric modeling. Findings are discussed considering international frameworks such as the World Bank Global Findex and the UNDP SDG framework for inclusive finance.

4 EMPIRICAL FRAMEWORK

4.1 The Case of the Banque de Développement Local (BDL)

The Banque de Développement Local (BDL) represents a paradigmatic case of Algeria's ongoing financial transformation, illustrating how a state-owned bank can function simultaneously as a commercial intermediary and a developmental instrument. Established in 1985, BDL's institutional architecture reflects the dual mandate

of Algeria's public financial institutions: to ensure profitability and liquidity management while promoting social equity and territorial cohesion. This institutional hybridity positions the bank as both a market actor and a vector of inclusive public policy.

Between 2022 and 2024, BDL played a decisive role in implementing the national monetary formalization program, aimed at channeling liquidity from the informal economy into regulated financial circuits. Under this reform, individuals could regularize undeclared funds through formal banking deposits, subject to a 10% fiscal levy and guaranteed confidentiality. As one of the lead executing institutions, BDL operationalized this measure by simplifying deposit procedures and integrating digital compliance mechanisms, thereby combining macroeconomic stabilization with an expansion of the formal financial base.

4.1.1 Descriptive Evidence (2022–2024)

Agency-level data across ten regional BDL branches in the wilayas of Mostaganem, Tiaret, Relizane, and Tissemsilt reveal a consistent upward trajectory in financial inclusion indicators.

Table 2. Deposits Totals and Year-over-Year Change

Indicator	2022	2023	2024	Change (%)
Number of Accounts	57 200	63 400	70 100	+22.6%
Credit Volume (Billion DZD)	5.8	6.9	7.5	+29.3%
Savings Deposits (Billion DZD)	12.4	14.6	15.3	+23.4%
TPE Devices (Units)	310	420	490	+58.1%

Source: Data provided by the Banque de Développement Local (BDL, 2025).

This descriptive profile confirms that financial access measured by account ownership expanded steadily, while the volume of deposits and credit intermediation increased by more than one-fifth over the period. The number of electronic payment terminals (TPEs) rose sharply, reflecting accelerated digital diffusion within local markets.

However, a closer examination of credit composition shows that individual and microcredit loans accounted for nearly 70% of total lending, compared to only 15% for SMEs. This imbalance indicates that while BDL has succeeded in promoting broad social inclusion, its contribution to productive or enterprise-driven finance remains comparatively limited.

4.1.2 Institutional Modernization and Behavioral Shifts

Concurrently, BDL intensified its digital transformation and financial literacy agenda. The bank organizes four “*journées informatives*” annually across regional branches, acting as structured financial education programs. These campaigns, supported by expanded online and mobile banking infrastructure, have generated tangible behavioral change: clients demonstrate growing confidence in formal banking, increasingly depositing savings and adopting e-banking services.

The interplay between institutional modernization and citizen trust restoration has become a defining

feature of BDL's regional performance. Digitalization has operated not merely as a technological upgrade but as a behavioral catalyst, encouraging integration of informal liquidity into formal banking channels and improving transparency in client relations.

4.1.3 Strategic Integration and Developmental Role

In alignment with the national entrepreneurship and employment strategy, BDL collaborates with state agencies and private banks to co-finance microenterprise and SME projects, offering subsidized credit and tailored advisory support. These initiatives extend inclusion from social access to productive empowerment, linking financial participation to job creation and regional development.

Collectively, these outcomes illustrate that BDL embodies the transitional character of Algeria's financial system: bridging monetary reform, digital inclusion, and socio-economic modernization. The agency-level evidence underscores a four-dimensional inclusion pattern

- Access expanded by 22.6%,
- Usage diversified modestly through rising loan volumes,
- Quality improved via deposit stability (+23.4%), and
- Innovation accelerated through TPE and e-banking adoption (+58%).

Thus, BDL serves as both an empirical lens and a conceptual referent for understanding how public banks operationalize inclusive finance in a transitioning economy.

4.2 Access Dimension: New Current Accounts by Client Type and Region

Figure 2 displays the evolution of new current account openings across BDL's regional network between 2022 and 2024, distinguishing individuals from enterprise clients. The evidence reveals a clear structural asymmetry: individual accounts represent more than four-fifths of total openings, while enterprise accounts, though rising gradually, remain marginal in all regions. This pattern reflects a system in which financial inclusion has advanced primarily through retail expansion households, salaried workers, and micro-

entrepreneurs rather than through productive enterprises.

The progressive increase nevertheless indicates a cumulative diffusion effect, confirming that access to formal finance has broadened steadily across territories. Yet the persistent divergence between categories underscores an inclusion trajectory that is socially extensive but economically shallow, signifying a widening of participation without equivalent deepening in productive capacity.

This configuration epitomizes the Access dimension of financial inclusion as theorized by Fouillet and Morvant-Roux (2018) and refined by Mellab (2025). Their framework identifies access as the institutional capacity to translate availability and affordability into actual entry for previously excluded populations. BDL's performance operationalizes this principle through pragmatic instruments simplified account-opening procedures, digital onboarding, and rural branch proliferation that transform theoretical accessibility into tangible participation. The dominance of individual accounts is therefore not an anomaly but an expected outcome of an inclusion model designed to achieve mass penetration before productive sophistication. According to the BDL feedback, enterprise account creation remains constrained by documentation burdens and collateral norms, confirming that the institution's first-phase strategy privileges social democratization over entrepreneurial depth.

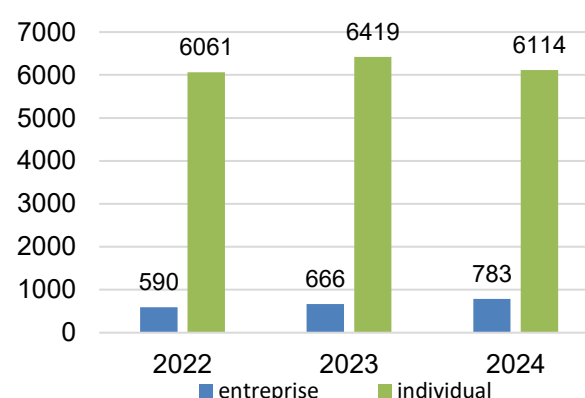


Figure 2. Financial Inclusion Dimensions

Source : Data provided by the Banque de Développement Local (BDL, 2025).

Critically, this expansion fulfils the breadth criterion of inclusion while revealing its structural limits. It advances SDG 8 (Decent Work and Economic Growth) and SDG 10 (Reduced

Inequalities) by integrating previously unbanked citizens, yet it leaves the depth dimension productive finance and SME activation largely untapped. The next stage must therefore shift from quantitative access to qualitative empowerment, converting participation into capacity and liquidity into investment. In this sense, Figure 1 crystallizes the inaugural moment of BDL's inclusion cycle: a verifiable democratization of financial access that establishes the empirical foundation upon which usage, quality, and innovation will be constructed.

4.3 Usage Dimension: Financing by Loan Type and Region

Figure 3 presents the distribution of BDL's financing activity between 2022 and 2024 across three categories individual loans, microcredit, and SME finance and across its regional agencies. The data exhibit a persistent structural asymmetry: individual loans account for roughly two-thirds of total disbursements, microcredit represents a growing but moderate share, and SME financing remains comparatively marginal.

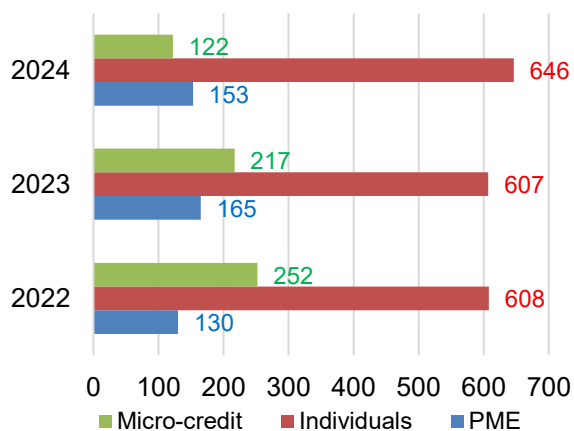


Figure 3. Financing by Loan Type and Region
Source: Data provided by the Banque de Développement Local (BDL, 2025).

This hierarchy reveals a credit structure driven primarily by social inclusion rather than by productive investment. The gradual upward trend across all categories nevertheless attests to an active and widening engagement with formal credit mechanisms, confirming that BDL's inclusion has advanced beyond simple access into a phase of functional utilization. Yet the constrained weight of SME lending exposes a critical asymmetry between social breadth and

economic depth – a pattern typical of early-stage inclusion systems.

Within the theoretical architecture of financial inclusion, this configuration corresponds to the Usage dimension, where access is transformed into recurrent and diversified financial behavior. Following Tharouma (2022) and Aliano et al. (2021), usage measures the intensity and purpose of financial engagement, assessing whether credit fosters consumption stability or productive growth. BDL's portfolio demonstrates that inclusion has matured into sustained participation, but its structure remains oriented toward liquidity management and micro-enterprise survival rather than toward capital accumulation or innovation.

According to the BDL feedback, this outcome reflects deliberate institutional priorities: digitized personal-credit systems and government-backed micro-lending programs facilitated rapid diffusion, while the stricter collateral and documentation requirements of SME lending limited its expansion. The resulting model privileges financial security over productive risk-taking, aligning with the cautious developmental stance characteristic of public banks in transitional economies.

From a developmental standpoint, this pattern generates both achievement and constraint. It advances SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth) by stabilizing household liquidity and supporting micro-entrepreneurship, yet it contributes only partially to SDG 9 (Industry, Innovation and Infrastructure). Sustainable inclusion thus requires a strategic rebalancing of the credit portfolio toward SMEs, green sectors, and long-term investment.

Consequently, Figure 3 encapsulates the consolidation stage of BDL's inclusion trajectory: a verified expansion of credit usage that ensures social and financial stability, while simultaneously delineating the frontier that must be crossed for inclusion to evolve from participation into productive transformation.

4.4 Quality Dimension: Deposit Amounts Over Time

Tables 3 and 4 present the structural composition of deposits collected by the Banque de Développement Local (BDL) between 2022 and 2024, distinguishing both the annual volume of

deposits and their distribution across financial instruments. The data indicate a substantial increase in total deposit volumes from 2022 to 2023, followed by relative stabilization in 2024 a pattern that marks the post-regularization normalization phase of the Algerian financial system.

This evolution demonstrates that the expansion of access achieved in the early reform period has transitioned into a phase of behavioral consolidation, where depositors maintain consistent financial engagement rather than temporary participation.

Table 3. Deposits Totals and Year-over-Year Change

	2022	2023	2024
Annual Flow	6 824 313 000	6 367 407 000	- 2 861 372 000
Number of Deposits (operations)	103 304	108 494	113 553
Total Deposits	56 344 724 000	73 030 374 000	69 886 804 000
Annual growth rate of total deposits	/	16.80%	1.20%

Source: Data provided by the Banque de Développement Local (BDL, 2025).

The stability of deposit levels, combined with the continued rise in the number of realized deposit operations, reflects not only the widening of financial participation but also the consolidation of institutional trust. According to data provided by the Banque de Développement Local (BDL, 2025), this trust is rooted in policy and technological transformations: the absorption of liquidity from the parallel economy through the 10% regularization mechanism, the digitalization of banking procedures, and intensified public communication campaigns through “journées informatives” (information days). The BDL feedback confirms that citizens increasingly perceive formal banking as both accessible and secure, transforming social confidence in public institutions into enduring financial loyalty.

Table 2 further illustrates the behavioral dimension of this inclusion. Savings and current accounts together consistently exceed 90% of total deposits, while term deposits remain marginal. This predominance of liquidity-oriented instruments signals that financial inclusion in Algeria remains at the Quality stage where stability, reliability, and user confidence dominate but has not yet advanced fully to Innovation, characterized by diversified and investment-oriented portfolios.

As theorized by Fouillet and Morvant-Roux (2018) and Tharouma (2022), the Quality dimension represents the point where inclusion ceases to be purely quantitative and becomes relational: participation transforms into permanence, and trust becomes institutionalized.

Table 4. Deposit Composition by Instrument (Amounts and Shares)

		Savings	Currents	Term Deposits
2022	Number	47 691	55 613	/
	Amount	30 533 781 000	22 033 616 000	3 777 327 000
	Share in total deposits	67.59%	29.73%	2.70%
2023	Number	50 990	57 504	/
	Amount	36 171 625 000	22 987 448 000	13 871 300 000
	Share in total deposits	67.59%	30.56%	1.85%
2024	Number	92 313	59 322	/
	Amount	39 501 154 000	26 252 472 000	4 133 178 000
	Share in total deposits	67.51%	30.66%	1.83%

Source: Data provided by the Banque de Développement Local (BDL, 2025).

Developmentally, this behavioral consolidation contributes to SDG 8 (Decent Work and Economic Growth) and SDG 16 (Peace, Justice, and Strong Institutions) by reinforcing financial credibility and monetary stability. Yet the same pattern delineates the next frontier of inclusion. For deposits to sustain long-term development, they must evolve from liquidity preservation toward productive intermediation funding SMEs, green investment, and innovation programs.

In this respect, the 2022–2024 period captures the consolidation moment of BDL's inclusion continuum, where financial access has matured into stability, and stability now holds the potential to generate capital formation and innovation-driven growth.

4.5 Innovation Dimension: Deposit Composition by Instrument

Figure 3 displays the composition of deposits across BDL's regional agencies between 2022 and 2024, distinguishing savings accounts, current accounts, and term deposits. The data reveal a pronounced concentration of liquidity in savings and current accounts, which together represent more than ninety percent of total deposits, while term deposits remain marginal across all regions. This structural concentration highlights a financial behavior oriented toward short-term security and accessibility, reflecting users' preference for liquidity over long-term commitment.

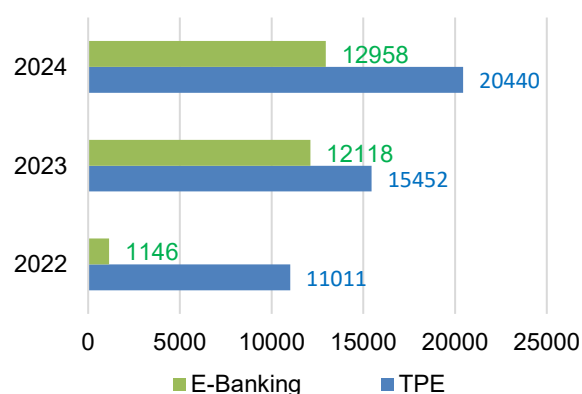


Figure 4. Digital Transaction

Source: Data provided by the Banque de Développement Local (BDL, 2025).

Although the overall volume of deposits has continued to expand (as shown in Figure 3), the internal structure of these deposits exposes the limits of behavioral diversification. Inclusion at this

stage has achieved stability, but not yet financial sophistication: clients are confident, but still risk-averse, managing funds primarily for safety rather than for value creation.

This configuration corresponds to the Innovation dimension of financial inclusion, the phase in which stability and trust evolve into diversified, forward-looking financial behavior. As formulated by Mertzanis (2023) and Zhang et al. (2024), innovation entails both the technological and behavioral transformations that allow users to transition from passive participation to active financial strategy. In BDL's case, innovation remains incipient. The institution's digital expansion including mobile banking, e-deposit platforms, and real-time transfers has facilitated access and convenience but not yet stimulated the adoption of long-term instruments.

According to the BDL feedback, this cautious pattern stems from contextual and policy factors: an emphasis on liquidity management during post-crisis recovery, limited promotion of investment-oriented products, and moderate public familiarity with term-based saving instruments. The result is a liquidity-centered inclusion model secure and functional, yet not fully transformative.

From a developmental perspective, this structure both consolidates and constrains progress toward sustainable finance. It strengthens SDG 12 (Responsible Consumption and Production) by promoting prudent saving behavior, but delays contributions to SDG 9 (Industry, Innovation, and Infrastructure), which depend on long-term capital mobilization. The challenge for BDL now lies in transforming digital inclusion into behavioral innovation encouraging users to adopt diversified financial tools through education, incentives, and tailored products.

4.6 Synthesis of Empirical Insights

The four figures collectively outline the empirical life cycle of inclusion within BDL's ecosystem. The trajectory unfolds sequentially: Access expanded the base of participation; Usage diversified engagement through credit; Quality consolidated trust through deposits; and Innovation now emerges as the pending phase of behavioral transformation. The process demonstrates that financial inclusion at BDL is not static but institutionally cumulative each dimension enabling the next.

Across dimensions, a consistent structural logic appears. Inclusion has been socially inclusive but economically cautious, a design reflecting the dual mission of public development banking: to guarantee equitable access while preserving stability. The institution has fulfilled its social mandate effectively, yet the transition from liquidity to productivity remains incomplete. Credit and deposit behaviors confirm that inclusion has evolved from outreach to permanence but still awaits diversification. The findings also validate the theoretical model's internal coherence. Access created participation; usage established engagement; quality generated trust; and innovation now defines the frontier of maturity. BDL's experience confirms that inclusion matures not linearly but recursively each phase reinforcing the previous one through institutional learning and user confidence.

The data reveal an inclusion system that has achieved breadth, continuity, and stability, but not yet transformative depth. To move toward sustainability, BDL must redirect its liquidity base toward productive finance and use digitalization not merely as a tool of facilitation but as a catalyst for innovation. In summary, the evidence portrays BDL as an institution that has transformed inclusion from an abstract policy into a tangible social reality.

The next challenge lies in converting that achievement into developmental inclusion one that mobilizes finance for investment, productivity, and long-term growth. Inclusion at BDL has reached credibility; its ultimate success will depend on whether it can now generate creativity

5 CONCLUSIONS

This study demonstrates that the Banque de Développement Local (BDL) has successfully translated Algeria's national financial inclusion strategy into tangible institutional outcomes across four western wilayas. Between 2022 and 2024, financial inclusion improved significantly across all core dimensions: access expanded by 22.6%, usage by 29%, quality by 23.4%, and innovation by 58%. These gains reflect a cumulative process in which access fosters participation, usage consolidates engagement, quality strengthens trust, and innovation introduces behavioral shifts through digital

finance. Collectively, these trends signal a gradual institutionalization of inclusion within the public banking sector.

Yet, the analysis also reveals a persistent structural asymmetry in credit allocation. While BDL has broadened access, lending activity remains concentrated in individual and microcredit segments comprising nearly 70% of the portfolio while SME financing accounts for only 15%. This distribution reflects the bank's dual mandate: promoting equitable access while safeguarding financial stability. As a result, BDL has succeeded in building liquidity and institutional trust but has not fully transitioned toward a model of productive, innovation-oriented finance.

From a theoretical perspective, these findings affirm the relevance of the capability-institutional framework: financial inclusion in Algeria appears to evolve recursively, with each stage reinforcing the next through institutional learning and user confidence. However, this same recursive structure also underscores the need for strategic recalibration. To align inclusion efforts with the broader goals of sustainable development, institutional adaptation must go beyond outreach to address structural gaps in financial intermediation.

The analysis suggests several policy directions. First, rebalancing the credit portfolio toward SMEs and start-ups is essential, supported by regional guaranteed mechanisms to mitigate risk and mobilize entrepreneurship. Second, the institutionalization of financial and digital literacy programs should transform existing outreach efforts into a permanent, structured component of BDL's development mandate. Third, product diversification such as long-term savings accounts, Islamic finance instruments, and green investment products can attract stable deposits and finance environmentally aligned enterprises. Fourth, regional inclusion dashboards would enhance monitoring and accountability by systematically tracking access, credit composition, and digital adoption. Finally, partnerships between BDL, fintechs, and microfinance institutions could accelerate innovation and extend financial services to currently excluded populations.

While this study is geographically focused on western Algeria, the selected wilayas are not

anomalous. Rather, they represent a microcosm of the national financial landscape, particularly given their early adoption of post-2021 regional financial reforms. The regulatory framework, overseen uniformly by the Bank of Algeria, ensures that observed institutional behaviors within BDL are reflective of broader systemic shifts toward formalization, transparency, and digitalization.

Although the research adopts a descriptive, non-inferential approach, its value lies in identifying institutional patterns and reform outcomes. Future work could build on this foundation by applying quantitative methods to assess the impact of inclusion policies on investment, employment, and innovation. Comparative studies across Maghreb or Mediterranean banking systems would further

contextualize Algeria's inclusion model within regional development trajectories.

In sum, BDL's experience encapsulates Algeria's broader evolution toward a more inclusive and modern financial system. The bank has restored trust, expanded access, and laid the groundwork for institutional inclusion. Its next challenge is to translate that institutional credibility into innovation channeling liquidity into productive activity, converting access into opportunity, and making financial inclusion not just a policy goal, but a durable engine of sustainable economic growth.

BDL's trajectory illustrates the broader challenge of transforming financial inclusion from social outreach into a durable engine of productive and sustainable growth.

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TEACHER MENTORING AND PERCEIVED RESEARCH COMPETENCE: A STUDY OF HSS UNDERGRADUATES

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ABSTRACT

Driven by China's national initiatives to develop the 'New Liberal Arts' and enhance undergraduates' innovation, fostering research competence among students in the humanities and social sciences (HSS) has become a critical priority. This study aims to explore the impact of teacher mentoring on the perceived research competence of undergraduates in the HSS and its internal mechanism. To examine the research context, this study employed a mixed-methods approach, combining a questionnaire survey ($n = 98$) and semi-structured interviews ($n = 8$), conducted with students from four "Double First-Class" universities in China. Quantitative data show that both academic guidance and emotional care from teachers are significantly positively correlated with the students' research competence. Regression analysis further indicates that the role of emotional care is even more prominent. Qualitative interviews reveal that students' investment, targeted teacher guidance, and emotional encouragement collectively serve as key pillars in enhancing research competence. Finally, the paper proposes practical recommendations to improve undergraduate research training and teacher-student interactions at the levels of students, teachers, and university administration.

1 INTRODUCTION

Amid the tides of globalization and the knowledge economy, enhancing the quality of higher education and cultivating top-notch, innovative

talent has become a central strategy for nations worldwide. Against this backdrop, China has undertaken significant strategic reforms in its higher education system over the past decade. From the launch of the "Six Excellence and One

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Top-notch Talent” (*Liu Zhuo Yue Yi Ba Jian*) Plan 2.0, to the comprehensive promotion of the “New Liberal Arts” (*Xin Wen Ke*) initiative, and emphasis on “comprehensively improving our ability to nurture talent at home” in the report to the 20th National Congress of the Communist Party of China, a series of top-down policy designs signal a clear shift: undergraduate research training, particularly in the humanities and social sciences (HSS), has been elevated to an unprecedented level of importance. These policies aim to promote interdisciplinary integration and cultivate liberal arts talent equipped with both innovative thinking and practical research skills in the new era, thereby strengthening China’s cultural soft power and academic discourse authority.

Despite strong policy advocacy and an increasing demand in practice, academic attention to this issue remains largely delayed and uneven. Existing research on undergraduate research competence primarily focuses on students in science, technology, engineering, and mathematics (STEM). By contrast, systematic investigations into status, developmental trajectories, and challenges faced by HSS undergraduates are relatively scarce. This imbalance has left our understanding of ways to guide HSS students effectively in research activities and to enhance their research competence relatively underdeveloped. Although existing literature occasionally acknowledges the role of teacher mentoring, few studies have thoroughly examined the complex, intrinsic relationship between specific mentoring behaviors and students’ perceptions of their research competence. This perceived competence not only shapes students’ academic confidence and self-efficacy but also directly influences their willingness and potential to pursue future research.

This study, therefore, seeks to explore the following core question: within the current educational policy context, how does teacher mentoring influence the perceived research competence of undergraduate students in the HSS, and what are the underlying mechanisms? In tackling this question, the study serves a dual purpose. Theoretically, it contributes to the body of literature on undergraduate research and higher education mentoring, particularly by shifting the

research focus to the often-overlooked HSS fields. It offers new empirical insights into the relationship between mentoring and student competence development. Practically, the findings have the potential to inform actionable policy recommendations and mentoring strategies for university administrators and educators. In doing so, the study aims to strengthen undergraduate research training systems, effectively address the national initiative to cultivate high-level innovative talent, and contribute to the strategic objectives of the “New Liberal Arts” initiative.

In this study, teacher mentoring is defined as the personalized guidance and support provided by experienced faculty members to students in academic, research, and emotional domains. Mentoring is structured into emotional care and instructional guidance, which mirror the actual practices of student-led inquiry in China.

Perceived research competence refers to an individual’s subjective evaluation of his/her abilities in the research process, abilities that may not have been fully recognized before participation in research. To complete an undergraduate research project, students need competence in four key areas: research ability, auxiliary skills, social competence and relationships, and professional socialization. These four dimensions serve as the basis for our self-assessment framework of undergraduate research competence. Research competence refers to the essential skills involved in designing and conducting scholarly research, including selecting a topic, synthesizing existing literature, applying analytical methods, and identifying research gaps. This is the most fundamental component. Auxiliary skills involve practical capabilities such as academic presentation, communication, and data analysis. Social competence and relationships encompass teamwork, interpersonal communication, and building research networks. Professional socialization refers to the attitudes and dispositions essential for research, including resilience in the face of failure, rigor, skepticism toward authority, and objectivity.

2 LITERATURE REVIEW

The concept of undergraduate research can be traced back to the founding principles of the

University of Berlin, established by Humboldt in 19th-century Germany. Later, American universities and scholars localized this somewhat abstract concept, integrating it broadly into undergraduate education. In 1969, the Massachusetts Institute of Technology (MIT) launched one of the earliest undergraduate research programs. By the late 1990s, research-intensive universities in the United States began extending the “research–teaching–learning nexus” from graduate education into undergraduate curricula, making it an essential component of cultivating innovative talent. Since then, many institutions abroad have developed a wide variety of research programs and courses tailored for undergraduates. The aim is to encourage students to join faculty-led research teams, serve as research assistants, or conduct independent research projects.

Firstly, many studies have investigated the developmental outcomes students gain through undergraduate research training. In terms of research ability, it was found that students perceived undergraduate research experiences to greatly enhance their skills in hypothesis testing, data collection, writing, and data presentation (Craney et al., 2011). Regarding cognitive development, research indicates marked improvements in analytical and logical reasoning, inductive thinking, and independent learning (Ishiyama, 2002).

Independent, student-led projects have also been shown to promote critical thinking and a proactive learning attitude, enabling students to engage with one another in novel ways and to think, act, and adapt as informed citizens in a complex global world (Killinger et al., 2016). Moreover, in addition to hard skills and abilities, scholars have emphasized the social benefits of undergraduate research, such as improved interpersonal communication (Landrum & Nelsen, 2002), stronger willpower, and increased self-confidence. In terms of academic performance, research experiences at the undergraduate level have been linked to greater clarity in career goals and a higher likelihood of pursuing and succeeding in graduate education (Lopatto, 2007). Another survey confirmed that even after controlling pre-college variables and institutional attributes, undergraduate research participation remained strongly associated with graduate degree

aspirations (Kilgo & Pascarella, 2015). These findings have laid a foundation for hypothesizing the potential impacts of undergraduate research in China, particularly on students’ competencies and postgraduate ambitions.

Secondly, concerning research methods and approaches, scholars have employed a variety of methodologies, most commonly interviews, self-report surveys, and quasi-experimental designs. These methods are often used in combination to ensure methodological rigor and to enable in-depth examination of research subjects and themes. For example, professors at the University of Maine conducted one-on-one interviews with students involved in an interdisciplinary ethics undergraduate research program and briefly summarized these dialogues to conclude. Moore et al. (2018) used self-report surveys and focus group interviews to comprehensively examine the varying motivations, expected outcomes, and perceived benefits of both faculty and students participating in directed studies courses (an honors thesis-based undergraduate research experience). STEM-oriented instructional designs and scaffolded pedagogical frameworks have demonstrably utilized interview-based evaluations to assess student outcomes and the impact of educational interventions. These studies either compared treatment and control groups or evaluated changes in students’ self-perceived competence before and after participation. They covered different types of undergraduate research experiences, including first-year seminars, capstone experiences, extracurricular projects, and research-integrated courses. The methods used ranged from qualitative interviews to self-reported surveys and quantitative data analysis. Some scholars also conducted comparative analyses to examine how research participation affects academic performance and retention among students from various backgrounds, by year level, parental education, or high school preparation (Bowman & Holmes, 2018).

Extensive empirical evidence has shown that mentoring is the most influential factor in the success of undergraduate research (Lopatto, 2006).

Specifically, emotional and social dimensions of teachers have been shown to have the greatest impact on undergraduate students’ academic

research, professional socialization, and satisfaction with the research experience (Haeger & Fresquez, 2016). Faculty members play a crucial role in undergraduate research activities. Their mentoring behaviors directly affect whether students can complete research tasks and whether their academic abilities and scholarly qualities can be meaningfully developed. As such, teacher mentoring is widely regarded as the cornerstone of undergraduate research.

Currently, scholarly investigations in China remain sparse, with the majority concentrating primarily on STEM undergraduate populations. Between 2014 and 2018, Guo conducted a series of in-depth studies on undergraduate research in STEM disciplines. Guo's earlier work (2018) aimed to cultivate students' innovative capacities through the "College Student Innovation and Entrepreneurship Training Program" (*Da Xue Sheng Chuang Xin Chuang Ye Xun Lian Ji Hua*). The findings revealed that students involved in research activities differed significantly from their non-participating peers. Undergraduate research was found to be more conducive to improving STEM students' acquisition of disciplinary knowledge and skills, thus promoting their professional development.

Beyond Guo Hui's contributions, existing research in China is fragmented. Some studies have examined the outcomes of undergraduate research without exploring underlying mechanisms. For instance, Fan et al. (2017), examining students in science and social science majors, found that those with undergraduate research experience were more inclined to pursue academic master's programs. Their study demonstrates that undergraduate research is instrumental in developing students' innovative capacities. Similarly, Gou et al. (2022), through a mixed-method study involving 140,000 samples, reported that research participation enhances undergraduates' non-cognitive skill development. This includes measurable improvements in neurocognitive and interpersonal abilities, as well as subtle influences on self-regulation.

In summary, localized research in China is severely lacking. While Western scholars have developed a robust conceptual foundation that can inform our understanding of specific mentoring behaviors in undergraduate research,

these insights have yet to be fully contextualized within the Chinese higher education environment.

Therefore, this study aims to advance the understanding of teacher mentoring and HSS students perceived research competence, promote greater integration of research and teaching in China, and contribute to the cultivation of innovative talent by enhancing the research capacity of HSS undergraduates.

3 METHODOLOGY

This study consists of both quantitative and qualitative phases. Initiated through a questionnaire survey, the study explores undergraduate research competence and teacher mentoring practices among HSS students. Based on the survey results, an interview protocol is then developed to help reinterpret the survey findings. Finally, the study draws on the results to offer practical recommendations.

3.1 Quantitative phase

- *Questionnaire Design:* To design the questionnaire, we reviewed relevant literature to identify existing frameworks and define the dimensions of perceived research competence and teacher mentoring. Based on this review, we selected a scale with strong external validity that was suitable for this study. Considering sociocultural differences and the specific focus and target group of this research, we made appropriate adjustments to the wording of the items to better align the questionnaire with the actual circumstances of our participants: undergraduates majoring in the HSS fields.
- *Questionnaire Distribution and Data Processing:* The survey was conducted online. It included four main sections: introductory instructions, demographic information, perceived research competence, and teacher mentoring. Emphasis was placed on the authenticity of responses and the anonymity of participants. Data was collected through the *wjx.cn* platform and analyzed using SPSS 25.0 for data management, storage, and statistical analysis.
- *Research Instruments:* The questionnaire was adapted from Guo and Han's (2018)

"Behavioral Indicators for Effective Teacher Mentoring in Undergraduate Research" and the "Indicators for Measuring Undergraduate Research Learning Outcomes." The "Teacher Mentoring Scale" comprised two dimensions: academic guidance and emotional care. The "Undergraduate Perceived Research Competence Scale" included three dimensions: research ability, auxiliary skills, social competence and relationships, and professional socialization. Each item was rated on a five-point Likert scale, where 1 to 5 represent "strongly disagree" to "strongly agree." Higher average scores indicate better perceived research competence or stronger faculty mentoring. A pilot test with 40 respondents yielded a Cronbach's alpha of 0.884 for the "Teacher Mentoring Scale", indicating good reliability. Exploratory factor analysis yielded a Kaiser-Meyer-Olkin (KMO) value of 0.818, affirming the scale's appropriateness for factor analysis. Based on the results, poorly performing items were removed, resulting in a scale with strong structural validity.

3.2 Qualitative phase

- *Interview Preparation and Data Collection:* Based on the analysis of survey results and the review of relevant literature, a semi-structured interview protocol was developed. Participants were recruited via convenience sampling from undergraduate students in HSS disciplines at a Chinese University. Participation was voluntary, and individual interview appointments were arranged. One-on-one interviews were conducted to ensure depth of dialogue. Audio recordings and field notes were collected for each interview.
- *Data Processing and Thematic Coding:* Immediately following each interview, recordings were transcribed verbatim, anonymized, and assigned identification codes. Transcripts were repeatedly reviewed for accuracy. All data were imported into NVivo 11 software for thematic coding and categorization. Concepts and themes relevant to the research questions were extracted through this process.
- *Instruments and Interview Protocol Description:* This study employed a semi-

structured interview guide and NVivo 11 for qualitative analysis. The semi-structured format provided the flexibility to follow up on interviewees' responses and adjust questions as needed, enabling deeper data exploration and addressing the limitations of the quantitative phase.

3.3 Limitations

Eight participants (n = 8) from a single university made up the small sample size for the qualitative phase. Although the semi-structured interviews yielded rich qualitative insights into students' experiences, the results may lack external validity when applied to the broader HSS undergraduate population in China. To validate and extend our findings, future research would benefit from utilizing a substantially larger and more diverse sample drawn from multiple academic institutions.

4 RESULTS

4.1 Quantitative phase

This questionnaire covers students majoring in HSS from four "Double First-Class" universities. The questionnaire was distributed via mobile applications such as QQ and WeChat. To ensure authentic responses and protect participants' privacy, the survey was conducted anonymously. Of the 104 questionnaires distributed, 98 were returned and deemed valid, yielding a response rate of 94%. Among the respondents, 52 were male and 46 were female. Of the valid responses, 37 students majored in Education, 14 in History, 12 in Management, 10 in Philosophy, 9 in Literature, 8 in Arts, and 4 each in Economics and Law.

Descriptive statistical analysis was conducted using SPSS 25.0 to examine the mean scores of each dimension. The assessment revealed that the lowest-performing dimensions were teacher academic guidance and students' perceived research competence. Further analysis of specific items showed that within academic guidance, Item 21, "My teacher discusses the nature of science with me and guides me to develop a research identity", had the lowest mean score, followed by Item 20, "My teacher instructs me in research techniques and methods." In contrast, Item 19, "My teacher demonstrates qualities of diligence

and persistence in research”, showed relatively high performance. In terms of students perceived research competence, Item 7 (“I can identify weaknesses in research design”) yielded a mean

score of 3.47, suggesting limited ability in this area. The mean scores for the remaining items were relatively strong (Table 1).

Table 1. Descriptive statistics

	Valid N.	Min.	Max.	Mean	SD
Teacher academic guidance	98	3.00	15.00	10.4286	3.35218
Academic skills	98	4.00	20.00	14.0204	4.10175
Research ability	98	5.00	20.00	14.3061	4.09528
Social competence & relationships	98	4.00	20.00	14.3265	4.09369
Teacher emotional care	98	4.00	20.00	14.4694	4.47261
Professional socialization	98	6.00	30.00	22.3776	6.38218
Valid cases (columns)	98				

Using SPSS 25.0, a correlation analysis was conducted on the two variables: students perceived research competence and teacher mentoring. The results (Table 2) showed a significant positive correlation between them, with a Pearson correlation coefficient of 0.873 ($p = 0.000 < 0.05$). This indicates a strong positive relationship between the two variables, although

the directionality of influence remains unclear. The coefficient of determination (R^2) was 0.7621, meaning that 76.21% of the variance in perceived research competence can be explained by teacher mentoring, or vice versa. The direction of influence requires further verification through regression analysis.

Table 2. Correlation analysis

		Research competence	Teacher mentoring
Research competence	Pearson correlation	1	0.873**
	Sig. (2-tailed)		0.000
	Sum of squares & cross-products	30096.908	11331.306
	Covariance	310.277	116.818
	n	98	98
Teacher mentoring	Pearson correlation	0.873**	1
	Sig. (2-tailed)	0.000	
	Sum of squares & cross-products	11331.306	5594.980
	Covariance	116.818	57.680
	n	98	98

** Significant at the 0.01 level (2-tailed)

Teacher mentoring was divided into two dimensions: academic guidance and emotional care. Based on existing theoretical assumptions, teacher mentoring was hypothesized to affect students’ perceived research competence. Thus, teacher mentoring was treated as the independent variable and perceived research competence as the dependent variable. As there are not many independent variables in this study and the regression model is simple, the forced entry method is more suitable. All independent variables were simultaneously included in the regression equation. The path coefficients representing the

influence of each independent variable on the dependent variable were identified based on standardized regression coefficients. Specifically, the predictor variables “teacher academic guidance” and “teacher emotional care” were entered into the regression model and analyzed using SPSS 25.0. The resulting model summary is presented in Table 3. According to Table 3, the R^2 value was 0.774. Since only one regression model was used, the change in R^2 equaled the R^2 statistic itself, indicating that these two predictor variables jointly explained 77.4% of the variance in the criterion variable of teacher guidance.

Table 3. Model summary^b

Model	R	R ²	Adjusted R ²	Std. Error of Estimate
1	0.880 ^a	0.774	0.769	8.46880

Where:

- a. Predictor variables: (constants), teacher academic guidance, and teacher emotional care.
- b. Dependent variable: total score of perceived research competence.

Table 4. ANOVA^a summary

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	23283.455	2	11641.728	162.321	0.000 ^b
	Residual	6813.453	95	71.721		
	Total	30096.908	97			

a. Dependent variable: total score of perceived research competence.

b. Predictor variables: (constants), teacher academic guidance, and teacher emotional care.

Table 5 presents the regression coefficients and their significance tests. The standardized regression equation is as follows:

$$PRC = 0.729 \times TEC + 0.167 \times TAG$$

Where:

PRC – Perceived research competence

TEC – Teacher emotional care

TAG – Teacher academic guidance

This standardized equation shows that among the two predictor variables, teacher emotional care had the greater influence on the dependent variable. Both predictor variables had positive standardized coefficients, indicating that they

Further analysis, based on the ANOVA summary (Table 4), revealed an F-statistic of 162.321 and a p-value of 0.000, indicating statistical significance at the 0.05 level. This suggests that the overall regression model was statistically significant, indicating that at least one regression coefficient is not equal to zero, that is, at least one predictor variable has a significant effect.

each exerted a positive effect on the dependent variable. The sign of the standardized regression coefficients (β) corresponded with that of the earlier Pearson product-moment correlation coefficients, reaffirming that both predictor variables exerted a positive influence. The t-values for the significance tests of the two predictor variables were 7.045 ($p < 0.001$) for emotional care and 1.612 ($p = 0.110$) for academic guidance, indicating that only emotional care was statistically significant at the 0.05 level. The regression coefficient for academic guidance was not statistically significant, suggesting a limited contribution to the variance in students' perceived research competence.

Table 5. Regression coefficients and their significance tests

Model		Unstandardized coefficients		Standardized coefficient	t	Sig.	95.0% CI for B	
		Estimated value of B	Std. Error	Beta coefficient distribution			UL	LL
1	(Constants)	14.350	2.948		4.867	0.000	8.497	20.203
	Emotional care	2.871	0.407	0.729	7.045	0.000	2.063	3.679
	Academic guidance	0.877	0.544	0.167	1.612	0.110	-0.203	1.957

However, since a significant correlation was found between teacher academic guidance and perceived research competence during the correlation analysis, multicollinearity could be a concern. As shown in Table 6, the tolerance

values for both predictor variables were approximately 0.200, and the variance inflation factors (VIFs) were below 5, which is well under the commonly accepted threshold of 10.

Table 6. Collinearity results

	Tolerance	VIF
Emotional care	0.223	4.493
Academic guidance	0.223	4.493

These results suggest that multicollinearity between the independent variables in the regression model is not severe.

4.2 Qualitative phase

Based on the principle of voluntary participation, a group of undergraduate students was selected for interviews conducted both online and in person. After interviewing eight participants, no new themes emerged, indicating that data saturation had been reached. Therefore, we stopped collecting additional interview data. The interviewees were numbered sequentially from S1 to S8 according to the order in which the interviews were conducted.

Through thematic coding of the interview data from the eight participants, we identified several reasons behind changes in students' perceived research competence:

- *Personal Investment:* Most interviewees mentioned that at this stage, they mainly relied on self-directed learning through instructional videos and relevant books to enhance their research competence. For example, S2 stated, "I learned by doing. While participating in research competitions, I gathered materials around specific problems, and gradually started learning SPSS..." Similarly, S5 noted, "We had to conduct regression analysis, so we searched for tutorials on video-sharing platforms like Bilibili and found some cloud drive resources. We figured it out ourselves—the online courses were quite clear..." S6 said, "The teacher did not respond to us, so we just found some resources and did it ourselves. In the end, we even won second prize, which wasn't too bad..."
- *Feedback and Guidance from Teachers:* At the same time, students who had achieved outstanding research results all mentioned receiving either suggestions on research orientations or detailed feedback from their teachers. For instance, S1 shared, "When I was writing my paper, the teacher gave me

some directional guidance on the critical review section. For example, he pointed out which data needed interpretation. He also advised me on how to collect data to support my arguments, and how to use the data more effectively..." Regarding feedback, S6 said, "What impressed me most was the teacher's feedback. During my time in university, few teachers ever provided a detailed analysis of my academic papers. I was very touched. Even though the comments weren't extensive, the experience was unforgettable. He even remembered every student's name, which left a deep impression on me."

- *Encouragement from Teachers:* One interviewee highlighted the importance of encouragement from a teacher, which gave them the passion and courage to continue pursuing academic work. S7 said, "My supervisor, Professor Tang, is truly amazing. She does not have a background in sociology, but she taught herself to help me organize my scattered materials. When I was on the verge of giving up, she wrote me a three-page outline the next day. She also helped me build my theoretical foundation. Meeting her during my undergraduate studies was unbelievably lucky."

During the interviews, most students described their ideal type of teacher or the form of mentoring they hoped to receive. Further coding of the interview data revealed four main themes:

- *Training in Academic Writing:* All interviewees acknowledged limited experience with empirical research, and some also expressed uncertainty regarding their academic writing skills. They were unsure how to write scholarly papers in a standardized, logical, and academically appropriate way. For instance, S6 remarked, "Right now, I feel what I lack most is systematic training in academic writing. I hope to receive more of this during my graduate studies. As for empirical research, I think I can manage it through self-learning."
- *Hands-on Training in Quantitative Research:* Several students pointed out that they lacked systematic training in quantitative methods and hoped to participate in the full process of

quantitative research, starting with questionnaire design. S1 said, "But now, I lack a lot of experience in quantitative research, such as in designing questionnaires. I have never been involved in the whole process. I hope to participate from the beginning and go through the entire process of conducting quantitative research."

- *Guidance on Research Direction:* A few students hoped that teachers would offer more direction on shaping their research focus. For example, S4 noted, "Actually, I can solve many things through self-learning, but I spent too much time searching for literature and learning about different research methods and fields. My teacher could not give me much guidance on research direction..."
- *Opportunities for Field Research:* Fieldwork emerged as a significant theme in the interviews. S2, a member of an agrarian society within the Department of Education, stated: "I think the biggest help my teacher gave me was the chance to conduct fieldwork. Through the agrarian society, I engaged with traditional Chinese culture and became aware of the needs of agrarian communities." I also came to understand the value of Education as a discipline." S7 recalled, "At that time, our teacher helped us contact schools and provided all kinds of support. She even took us to conduct experiments and observe classes, allowing us to bring the R-STEAM concept to life. Whenever we were under pressure, she would gently encourage us. She said she just wanted us to experience educational experiments and see how things worked in schools. She always guided us patiently."

5 DISCUSSION

5.1 Returning to Practice: How Fieldwork Can Resolve the Crisis in Undergraduate Research

At present, undergraduate research faces several significant challenges. Although academic learning has grown increasingly detached from practical contexts, students now tend to approach research instrumentally, viewing it primarily as a

way to build credentials. Students study abstract and "grey" theories within the university context, yet may have limited opportunities to apply them in authentic settings. Driven by the expectations of postgraduate admissions and job markets, research competitions increasingly function as instruments for credential accumulation. This phenomenon risks diminishing students' curiosity and desire for knowledge, thereby obscuring the intrinsic purpose of academic research. Fieldwork offers a valuable approach, reorienting students toward the authentic spirit of research.

First, fieldwork breaks down the barrier between theory and reality. Most undergraduates lack access to social networks or practical environments, which limits their ability to engage meaningfully with frontline issues in education or society. Knowledge acquired in the classroom becomes decontextualized due to the lack of applicable contexts and is often quickly forgotten after examinations. Fieldwork, by contrast, provides a "living classroom," placing students directly within real-world problem contexts. Whether through in-depth conversations with frontline educators or firsthand observation of complex social phenomena, fieldwork revitalizes textbook knowledge. It encourages students to activate and internalize their learning through real problem-solving, making their limited study time more productive and meaningful.

Second, fieldwork helps students rediscover the original value and purpose of research. When research is equated with GPA, awards, or graduate school qualifications, its essential goals — exploring the unknown and serving society — are obscured. Many students superficially participate in multiple research projects, merely to enhance their résumés, without ever reflecting on the social value of their work. Fieldwork provides a counterbalance. When students enter rural communities or urban neighborhoods and witness real hardship and unmet needs, they begin to shift their focus from primarily individualistic goals and ask themselves, "Whom does my research benefit?" Just as educator James Yen dedicated himself to rural education and used knowledge to transform local communities, fieldwork instills in students a sense of social responsibility, redirecting their focus from personal gain to broader societal concerns. This can be a powerful driver in academic research.

Thus, fieldwork is not merely an “engaging” extracurricular activity. It is a significant pathway to addressing the current challenges in undergraduate research. It bridges the gap between knowledge and practice, creating a space that nurtures academic passion and reaffirms the core purpose of scientific research. It is essential for cultivating researchers who are problem-conscious and socially engaged.

5.2 The Three Pillars of Undergraduate Research: Investment, Mentoring, and Encouragement

The findings suggest that the development of research competence among HSS undergraduates is primarily supported by three interconnected pillars: personal investment, teacher mentoring, and teacher encouragement. These three elements interact dynamically, shaping students’ developmental trajectories from passive participation to active exploration.

Personal investment forms the foundation of research, yet its impact can be both empowering and problematic. Nearly all interviewees emphasized that “self-study” and “trial-and-error” are the norm in their research journeys. While self-constructed knowledge is necessary, these behaviors often lack coherence and are driven by immediate problems in the absence of effective guidance. As a result, students may resolve short-term issues but remain confused about the broader disciplinary landscape or future academic directions. Their knowledge becomes fragmented and unsystematic, making sustained academic development difficult.

Teacher mentoring adds direction and depth to the research process. Traditional teacher mentoring, such as recommending literature or explaining methods, can help students complete individual papers. However, its effects often remain superficial and utilitarian, lacking the capacity to foster sustained intellectual engagement. Our interviews reveal that more impactful mentoring involves providing opportunities for fieldwork. When students step outside the university context and immerse themselves in real-world educational settings, abstract theory is tested against and integrated with real-world complexities. This “being present” experience enables students to appreciate the contemporary relevance of their

disciplines and identify problems and solutions within authentic contexts. These experiences can significantly enhance research interest far more effectively than classroom-based study alone.

Teacher encouragement acts as a key facilitator that can transform extrinsic motivation into intrinsic passion. Many students initially engage in research to earn extra credit or secure graduate school placements. When they encounter setbacks, teachers’ encouragement and emotional support help them overcome frustration, foster a sense of belonging within research teams, and experience a sense of accomplishment after overcoming challenges. These positive experiences fulfill students’ psychological needs and gradually shift their motivations from extrinsic pressures to intrinsic interest in academic work. Furthermore, a teacher’s enthusiasm for their research can be highly influential, motivating students to find what they are genuinely passionate about and thereby fostering their long-term academic development.

In summary, effective undergraduate research training requires an organic integration of students’ investment, directional teacher mentoring, especially through exposure to practical contexts, and continuous emotional encouragement. All three pillars are indispensable.

6 PRACTICAL IMPLICATIONS

This section offers brief recommendations from the perspectives of students, teachers, and universities, aiming to improve the current status of teacher mentoring. We advocate promoting student initiative in learning, encourage teachers to attend to students’ developmental needs through emotional care, and reform faculty evaluation systems to advance undergraduate research in the HSS fields.

The most influential aspect of teacher mentoring in undergraduate research is emotional care combined with timely and constructive feedback. Students engaged in academic exploration need guidance and support. A single thoughtful and responsible piece of feedback can provide profound psychological encouragement and, more importantly, shape a student’s future academic or career path. For students who experience setbacks in research competitions or face major

disappointments, teacher encouragement and directional guidance are critical sources of motivation that help them persevere. Therefore, teachers should strengthen their communication with students and offer timely and meaningful feedback. Both measures are vital for talent cultivation and for sparking long-term academic interest.

Personal investment is the foundation of research competence. Students should take the initiative in learning and maintain active communication with their teachers to clarify their research direction. For HSS majors, textbook learning alone is insufficient. Students must engage in fieldwork, immerse themselves in real-world contexts, and identify problems within society where theoretical knowledge can be applied. This approach not only brings academic content to life but also fosters

professional socialization and reveals the true value and purpose of research to students.

Universities should provide stronger institutional support for undergraduate research. In addition to encouraging student autonomy, institutions should establish incentive mechanisms such as forming undergraduate research teams and supporting faculty-led field investigations to cultivate a positive research environment. It is necessary to shift away from evaluation-centered approaches and prioritize the construction of practice-oriented platforms that make research an intrinsic motivation for students. Now, universities must strengthen both the quality and relevance of coursework. They should redesign curricula to reflect real-world needs, enabling students to apply their knowledge in practice. This will help elevate the overall quality of undergraduate education.

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THE IMPACT OF DIGITAL TRANSFORMATION ON ORGANIZATIONS AND CUSTOMER EXPERIENCE

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ABSTRACT

Digital transformation is reshaping global business by redefining operations, customer engagement, and value creation. This study examines the role of advanced technologies—artificial intelligence (AI), big data analytics, the Internet of Things (IoT), mobile platforms, and blockchain—in driving efficiency, personalization, and competitive advantage. It clarifies distinctions between digitization, digitalization, and digital transformation, emphasizing the latter as a strategic, organization-wide process that integrates technology to optimize business models and generate sustainable value. Case studies illustrate how successful adoption accelerates growth, expands market reach, and enhances customer satisfaction, while failure to adapt leads to declining relevance. The research also explores digital maturity, categorizing organizations by readiness, strategic alignment, technological capabilities, and cultural preparedness, and shows how these dimensions influence transformation outcomes. Key themes include automation of processes, customer-centric omnichannel experiences, and data-driven decision-making. Opportunities such as efficiency gains, innovation, and market expansion are balanced against challenges, including implementation risks, cybersecurity, ethical concerns, and workforce upskilling. By analyzing drivers, success factors, and organizational implications, the study demonstrates that digital transformation is essential for sustaining long-term performance, innovation, and resilience. In today's rapidly evolving digital economy, continuous adaptation and investment in both technology and human capital are critical for competitiveness and sustainable growth.

1 INTRODUCTION

Digital technologies are transforming nearly every industry, reshaping business processes, products, and services. Advanced technologies such as the

Internet of Things, mobile devices, big data, augmented reality, blockchain, and social media are creating new opportunities. Businesses can now enhance efficiency, security, and

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personalization, driving operational improvements and innovation. Digital transformation involves integrating digital technologies across all business operations. It fundamentally alters how companies operate, deliver value to customers, and compete in the marketplace. Innovations such as automation, artificial intelligence (AI), and data analytics enable organizations to improve efficiency and enhance customer experience. The acceleration of digital transformation has fueled the growth of electronic commerce (e-commerce), changing how goods and services are bought and sold globally. E-commerce has become an interconnected and dynamic market. Digital technologies allow businesses to reach wider audiences, optimize operations, and offer personalized experiences, reshaping the global economy. E-commerce enables buyers and sellers to exchange information, funds, and products electronically, primarily via the Internet. It offers producers advantages by providing extensive product information and wide-reaching market access. E-commerce began in the mid-1990s with companies like Amazon and eBay. Initially, it faced challenges related to online transactions and consumer trust. Wider Internet access, driven by home computers and broadband connectivity, fueled rapid growth (Peter & Olson, 2007). Mobile technology, especially smartphones, further enabled seamless shopping anytime, anywhere (Lucas et al., 2023). New technologies continue to enhance consumer experiences. Web 2.0 introduced platform-based e-commerce models (Yu, 2018). Social media, big data, and AI accelerated its evolution (Huang & Benyoucef). Digital transformation improves efficiency through process automation, inventory management, optimized supply chains, and lower costs. It also expands market reach by removing geographic barriers (Suntsova, 2024). Digital transformation benefits organizations by improving service quality, reducing costs, gaining competitive advantage, and enhancing customer experience (Sahu et al., 2018). Leveraging consumer data allows personalized recommendations and tailored interactions, increasing satisfaction. By integrating AI, data analytics, and automation, e-commerce platforms optimize supply chains, decision-making, and customer engagement. Digital transformation is essential for growth, adaptability, and competitiveness in a rapidly changing market.

2 RESEARCH METHODOLOGY

This paper employs a *qualitative research approach* based on an extensive literature review of scholarly articles, industry reports, and case studies related to digital transformation and e-commerce. Primary sources include peer-reviewed journals, books, and authoritative reports from Deloitte, KPMG, and the World Economic Forum. Secondary data from company case studies (e.g., Amazon, Nokia, Zillow, Tesco) were analyzed to illustrate practical applications, challenges, and outcomes of digital transformation initiatives. The research method involved:

1. Data collection – compiling relevant studies on digital technologies, e-commerce evolution, and transformation strategies.
2. Content analysis – identifying recurring themes, patterns, and frameworks describing digital transformation processes, benefits, and risks.
3. Comparative analysis – contrasting organizations with varying levels of digital maturity to evaluate the impact of technology adoption on business performance and competitiveness.

This methodology allows for a comprehensive understanding of the theoretical foundations and real-world implications of digital transformation, providing insights into best practices, success factors, and potential pitfalls. The approach ensures reliability through cross-verification of multiple sources and relevance by focusing on contemporary trends and emerging technologies.

3 DIGITAL TRANSFORMATION

There are clear distinctions among the concepts of digitization, digitalization, and digital transformation. Although often used interchangeably, these terms carry distinct meanings. Digitization is defined as the material process of converting analog streams of information into digital bits. Digitalization, by contrast, refers to the way many domains of social life are restructured around digital communication and media infrastructures. *Digitization* thus represents “the action or process of digitizing; the conversion of analog data, especially images, video, and text into digital form”. Digitalization can be defined as the adoption or increase in the use of digital or computer technology by an

organization, industry, or country. Digital transformation is a sustainable, company-level transformation through revised or newly created business operations and models achieved via value-adding digitalization initiatives, ultimately resulting in improved performance. Fitzgerald et al. (2014) define digital transformation as the use of digital technologies that enable process improvements, including enhanced customer experience, optimized operations, and the creation of new business models. Lucas et al. (2013) emphasize operational activities, defining digital transformation as the fundamental change in how business is conducted through the redefinition of capabilities, processes, and relationships. Westerman et al. (2011, p. 5) describe digital transformation as “the use of technology to radically improve the performance or reach of enterprises.” Unlike other definitions, this one does not specify the elements leading to transformation. To create a unified definition, Gong and Ribiere (2021, p. 12) analyzed 134 definitions and described digital transformation as “a process of fundamental change enabled by the innovative use of digital technologies accompanied by the strategic deployment of key resources and capabilities, aiming to radically improve the organization and redefine the value it provides to all stakeholders.” It is important to emphasize that the implementation of technology in business processes is not an end but a response to the need to create added value for consumers, businesses, and other stakeholders. Hence, companies aiming for successful digital transformation must primarily redefine consumer experience by transforming processes through digital technologies. There are five levels of digital transformation: incremental digitization of data and processes, advanced digitization involving digital platforms, digital transformation covering new markets, digital transformation resulting in new products, and digital transformation involving business-model change (Deloitte, 2022). The digital transformation of business models concerns “individual elements of the business model, the entire model, value-added chains, and the networking of different actors within a value-added network” (Schallmo & Williams, 2021, p.4). The degree of digital transformation can include incremental (marginal) or radical (fundamental) changes to the business model. They also point

out that digital transformation may target single business model elements, yet the question remains how the transformation of one element influences all others. Digital transformation is a continuous endeavor that does not end with the implementation of one technology, platform, or set of skills. Therefore, a long-term investment strategy in technologies supporting strategic initiatives is essential. This requires a mindset shift at all organizational levels and active involvement of all stakeholders to increase the likelihood of success.

3.1 The Significance of Digital Transformation

The digital revolution plays a major role in transforming companies—and in some cases, entire industries. Many start-ups have reshaped traditional business operations through digital technologies, posing serious threats to analog corporations forced to adapt to new circumstances. However, investing in digital tools alone is not sufficient; profound organizational change is required. Companies must seek new business models, fundamentally alter their operational models, attract digital talent, and redefine how success is measured. Historically, Fortune 500 companies needed an average of 20 years to reach a market value of 1 billion USD. Today, start-ups achieve that milestone far faster: Google did so in 8 years, while Uber, Snapchat, and Xiaomi reached it in four years or less, largely due to the effective implementation of digital technologies (World Economic Forum, 2016). Digital transformation leads to performance growth, with one executive sentiment analysis reporting that 63% of executives saw a positive impact from transformation efforts (KPMG, 2023). *Increased Profits:* A study of organizations that completed digital transformations found that 80% reported increased profits; *Revenue Growth:* 56% of CEOs in a Gartner study mentioned that digital advancements have had a positive impact on revenue; *Operational Efficiency:* Digital transformation often leads to improved operational efficiency, productivity, and organizational competitiveness; *Innovation:* Studies show that digital transformation can significantly promote corporate innovation, which in turn enhances performance and competitiveness; *Customer*

Satisfaction: Digital initiatives focused on customer experience can lead to a 20% to 30% increase in customer satisfaction and **Higher Profitability for Mature Companies:** Digitally mature companies are reportedly 23% more profitable than their less advanced counterparts. For instance, the real estate platform Zillow improved workforce diversity through digital technology. Using machine learning, the company identified and corrected gender-biased wording in job advertisements, resulting in a 12% increase in female applicants (Staley, 2018). Likewise, the British multinational retailer *Tesco* used AI to measure its environmental impact and meet carbon-reduction targets (Deloitte, 2020). When analyzing the meaning of digital transformation, it is important to distinguish companies by their level of *digital maturity*. This concept denotes the advanced stage of digital transformation, in which firms that attain it experience significant operational enhancements and markedly higher levels of customer satisfaction. They define three scales: digitalization strategy, organizational digitalization level, and readiness for digitalization, each with four maturity levels (Aslanova & Kulichkina, 2020):

- **Beginners** – traditional companies lacking a digital-transformation strategy, with limited skills and outdated equipment.
- **Catching-ups** – organizations that are aware of the need for transformation and possess managerial vision and a willingness to change.
- **Off-track** – firms with a strategy but implementation challenges due to HR or technical constraints.
- **Leaders** – modern organizations with implemented strategies, adapted business models, strong leadership, advanced technical bases, and digitally skilled staff.

To assess digital maturity, organizations must evaluate the presence or absence of a digital-transformation strategy, managerial and employee readiness for change, the availability of technological resources, and proper data management structures.

Digital transformation's significance lies not only in its benefits but also in mitigating risks. It can reshape organizations, create new opportunities,

and alter value chains (Parviainen et al., 2017). Companies like Nokia and Blockbuster failed to adapt to technological shifts, relying on outdated models and underestimating changing consumer behavior (Abdou & Hussein, 2020; Harvard Business School, n.d.). These examples highlight that continuous innovation and adaptability are essential for long-term success in the digital economy.

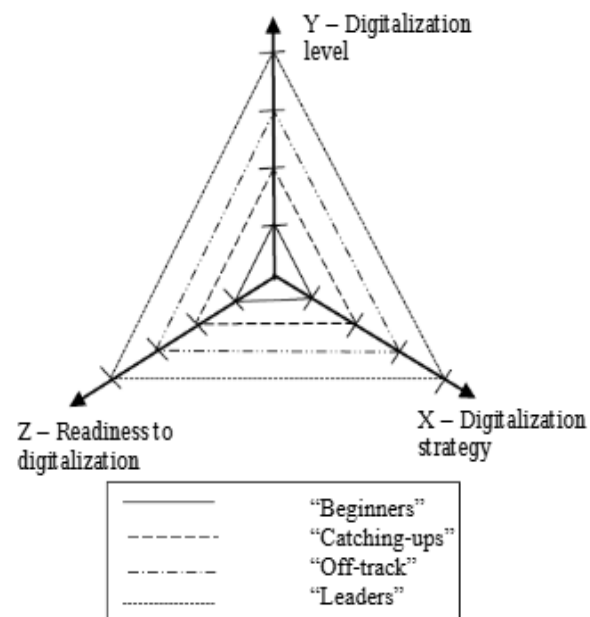


Figure 1. Structure Classification of Companies According to the Level of Digital Maturity

Source: Aslanova & Kulichkina (2020, p. 446)

3.2 Development of E-Commerce

E-commerce, the digital transaction of goods and services, has rapidly grown into a key global market segment. Definitions vary broadly; it includes network infrastructure, hardware, and software; narrowly, it covers all electronic transactions; most restrictively, it involves online buying and selling of goods and services (Semerádová & Weinlich, 2022). E-commerce originated in the late 1970s with early B2B systems like Baxter Healthcare's modem orders, and B2C evolved in the 1980s with France's Minitel system, which enabled millions of users to conduct transactions such as travel booking and banking (Laudon & Traver, 2021).

The foundations of modern e-commerce, as they are understood in contemporary scholarship, emerged in the early 1990s with the rise of the

Internet. Zheng et al. (2009) identify three major phases in its evolution.

1. Phase 1 – EDI-Based E-Commerce:

Emerging in the 1960s and widely adopted in the 1980s, EDI enabled paperless document exchange between computers, reducing errors and improving efficiency, though its high-cost limited accessibility.

2. Phase 2 – Internet-Based E-Commerce:

In the late 1990s, the Internet offered a cheaper, more accessible alternative, allowing SMEs to participate. Companies like Dell, Amazon, and eBay leveraged it for direct sales, expanding reach and flexibility.

3. Phase 3 – E-Concept E-Commerce:

From the early 2000s, e-commerce integrated digital technologies across sectors, including education, healthcare, and government, giving rise to B2B, B2C, and e-Government models, shaping today's hyper-connected world. Three chronological periods in e-commerce's development are distinguished (Sharma et al., 2023):

- During the *invention* period (1995–2000), e-commerce mainly involved selling simple products online. Marketing relied on static advertisements and basic search engines; company websites were largely informational.
- In the consolidation period (2001–2006), traditional firms began using the Internet to strengthen market positions. E-commerce expanded to include complex services such as travel and finance, enabled by broadband adoption and wider access to personal computers. Marketing advanced through search-engine ads, video, and targeted campaigns. Despite challenges, e-commerce grew by more than 10% annually during this phase.
- Reinvention Period (2007 – Present), marked by Web 2.0, mobile devices, and cloud computing. This era emphasizes social, mobile, and local commerce. Social media, user-generated content, and mobile platforms became central to marketing, expanding businesses' global reach and reshaping consumer experiences.

3.3 Factors Influencing Digital Transformation

Digital transformation is a complex and costly endeavor that carries risks but offers long-term efficiency and productivity gains. Success depends on understanding the purpose, scope, technologies, and expected outcomes of transformation. Key factors for effective implementation include defining digital enablers and drivers, cultivating a digital culture, developing a digital vision, establishing a digital organization, identifying transformed sectors, and determining impact (Morakanyane et al., 2020). Additionally, internal and external factors such as supportive culture, engaged management and employees, knowledge use, dynamic capabilities, clear digital strategy, well-managed activities, IT-business integration, and IS capacity growth significantly influence outcomes (Zhang et al., 2022; Osmundsen et al., 2018).

McKinsey (2018) identifies 21 factors for successful digital transformation, grouped into five key areas:

- Digitally Competent Leadership.
- Building Digital Capabilities in the Workforce,
- Encouraging New Ways of Working,
- Digitally Upgrading Everyday Tools and
- Frequent and Transparent Communication.

Leadership with digital expertise, employee skill development, fostering behavioral change, integrating digital tools into daily operations, and consistently sharing a clear transformation narrative all significantly increase success. Digital transformation is crucial not only for large corporations but also for small and medium-sized enterprises (Zhang et al., 2022). SME digital transformation depends on three main factors: environmental, technological, and organizational. Environmental factors like government support and partnerships enhance organizational capacity, while IT infrastructure and management capabilities are critical technological enablers (Vial, 2019; Kraja et al., 2014; Lin et al., 2020). Organizational factors, particularly a clear digital strategy, committed top management, and digitally skilled employees, mediate the effective use of technology and resources, determining transformation success (Zhang et al., 2022; Cichosz et al., 2020). Digital transformation rests on three pillars: technology, processes, and

people (Verina & Titko, 2019). Technology has evolved through five phases: from early IT automation in the 1970s, the rise of the Internet, integrative applications, the SMACIT era (social media, mobile, analytics, cloud, IoT), to emerging technologies like BRAICQ (blockchain, robotics, AI, cognitive and quantum computing) (Van Veldhoven & Vanthienen, 2021; Sebastian et al., 2017).

SMACIT and BRAICQ technologies create opportunities and risks, driving investments in AI, robotics, and data analytics to enhance competitiveness. AI, particularly generative AI like ChatGPT, has transformed productivity and user interaction, while robotics combined with AI improves manufacturing, logistics, and automation (OECD, 2023; Lorenz et al., 2023). Despite rapid adoption, human oversight remains essential due to AI limitations. Ultimately, technology alone does not ensure successful transformation; organizations must align technological adoption with clear strategic goals and business vision

(Schwertner, 2017). The digital-transformation market is projected to grow from USD 911.2 billion in 2024 to USD 3.28 trillion by 2030, reflecting its central role in modern business (MarketsandMarkets™, 2024; Gartner, 2022).

3.4 Challenges and Risks of Automation

A key outcome of digital transformation is business process automation, which increases efficiency, accuracy, and cost savings by replacing repetitive human tasks with technology-driven workflows (Deloitte, 2020). Automation ranges from robotic process automation (RPA) for tasks like data entry to AI-driven cognitive solutions for complex functions such as fraud detection and chatbots. Beyond efficiency, automation enables cost optimization, strategic resource allocation, and improved customer service, potentially adding \$15.7 trillion to the global economy by 2030 (Rao et al., 2017).

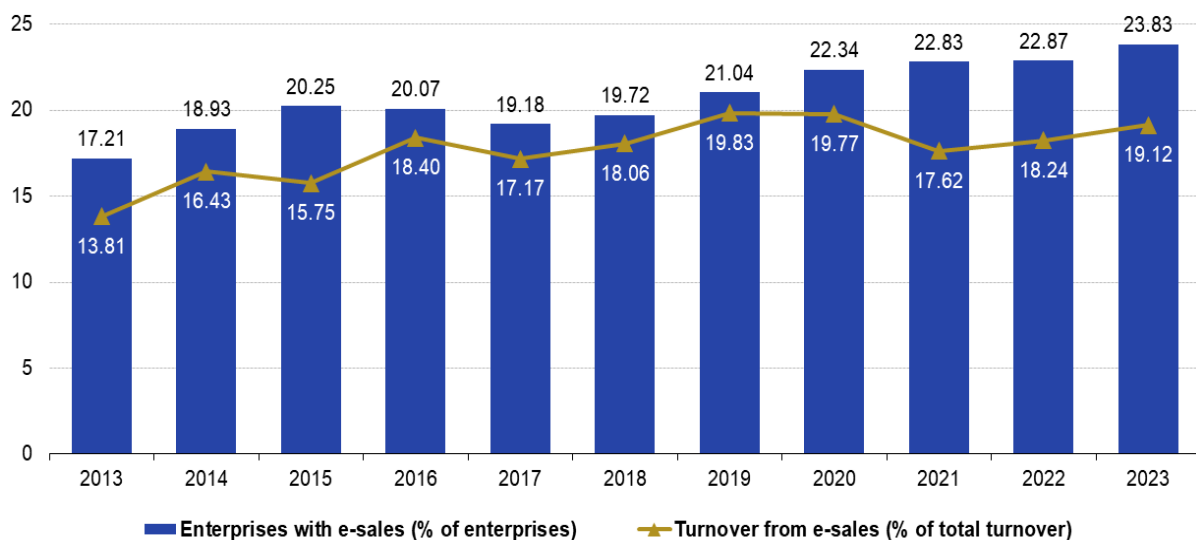


Figure 2. E-sales and turnover from e-sales, EU, 2013 to 2023 (% of enterprises, % of total turnover)

Source: Eurostat (2025)

Although automation provides numerous advantages, it also introduces organizational, ethical, and social challenges. A primary concern is job displacement. Frey and Osborne (2017) estimate that approximately 47% of U.S. jobs are at risk of automation. Nevertheless, research indicates that digital transformation often generates new roles requiring human creativity, problem-solving, and emotional intelligence skills that machines cannot easily replicate (Brynjolfsson & McAfee, 2014). E-commerce

Share of Total Turnover: Across the EU, the share of total turnover generated from e-sales was 19.12% in 2023. The value varies by enterprise size, with large enterprises reporting 24.44%, medium enterprises 14.99%, and small enterprises 9.49% of their total turnover from e-sales in 2023. (Figure 2). Cybersecurity and data protection represent another significant challenge. As organizations automate processes and digitize large volumes of sensitive data, they become increasingly vulnerable to cyberattacks and

breaches. The World Economic Forum (2023) ranks cyber risks among the top five global threats to economic stability. Therefore, cybersecurity must be integrated into every stage of digital transformation, from system design to employee training. The empirical analysis uses secondary data from Eurostat (2024) and OECD to illustrate the trajectory of digital transformation in the European Union and among OECD members.

SME Online Sales: The share of SMEs globally and within the EU engaging in e-commerce has seen a steady increase since 2019. For example, in the EU, the share of small enterprises engaging in online sales grew by 6.6 percentage points between 2013 and 2023, while medium enterprises grew by 5.8 percentage points in the same period.

Organizational resistance to change can also impede successful automation implementation. Employees may fear job loss or struggle to adapt to new technologies, leading to reduced morale and productivity. Leadership must communicate effectively, offer reskilling opportunities, and foster a culture that frames technology as an enabler rather than a threat.

Finally, ethical considerations arise when automating decision-making. Algorithmic bias, lack of transparency, and accountability gaps can erode trust among customers and stakeholders.

Establishing ethical AI frameworks and governance mechanisms is essential to ensure fairness and compliance with regulations such as the European Union's General Data Protection Regulation (GDPR; European Commission, 2016). Effective digital-transformation strategies combine automation with human judgment. Davenport and Kirby (2016) describe this approach as augmentation, wherein technology supports rather than replaces human intelligence. Automation can manage repetitive, data-intensive tasks, while human experts contribute contextual understanding, creativity, and ethical oversight. Effective digital transformation emphasizes human-technology collaboration, where employees supervise automated processes, interpret outputs, and make strategic decisions. In practice, AI can flag anomalies in financial transactions, leaving final judgments to humans,

while predictive-maintenance systems in manufacturing alert technicians, who then determine optimal responses. These hybrid systems demonstrate that the future of work emphasizes human-technology partnerships rather than complete automation, optimizing efficiency while preserving ethical and creative capacities.

3.5 Digital Transformation and Customer Experience

Digital transformation has fundamentally reshaped the relationship between businesses and customers. Beyond internal efficiency, its goal is to enhance customer experience, satisfaction, and loyalty. Kotler et al. (2021) note that modern consumers expect personalized, seamless, and meaningful interactions across multiple digital channels. External environmental factors such as market competition, customer expectations, and regulatory frameworks shape the pace of transformation. The European Commission's Digital Decade Policy (2021–2030) emphasizes digitalization as a foundation for resilience and sustainability, setting targets for skills, infrastructure, and digital public services (European Commission, 2021). Technologically, the emergence of cloud computing, big data, and artificial intelligence (AI) has lowered entry barriers for SMEs. Vial (2019) stresses that technology becomes transformative only when it is embedded in business processes and used strategically for value creation.

The Commission will allocate €1.3 billion for the deployment of critical technologies that are strategically important for the future of Europe and the continent's tech sovereignty through the Digital Europe Programme (DIGITAL) work programme for 2025 to 2027. The work programme focuses on the deployment of Artificial Intelligence (AI) and its uptake by businesses and public administration, cloud and data, cyber resilience, and digital skills. More specifically, key priorities under the Digital work programme include: (European Commission, 2025)

- Improving the availability and accessibility of generative AI applications, including in the health and care sectors. Available funding will go towards testing immersive environments, known as 'virtual worlds', implementing the AI

Act, and deploying energy-efficient common data spaces. These measures are key to the implementation of the AI Factories initiative to develop generative AI models for businesses and the public sector.

- Supporting the European Digital Innovation Hubs (EDIHs). This is a network of hubs that provides companies and the public sector with access to technical expertise and testing of technologies, as well as advice, training, and skills to adopt the latest technologies. It will promote the widespread take-up of AI in private and public organizations across Europe.
- Building up the award-winning Destination Earth initiative that is working to build a digital model of Earth to support climate adaptation and disaster risk management. Funding will build a more powerful model that more researchers can access.
- Boosting cyber resilience. Cybersecurity solutions such as the EU Cybersecurity Reserve will improve the resilience and security of critical infrastructures, including hospitals and submarine cables.
- Developing EU education and training institutions' capacity in digital skills so they may nurture and attract talent while boosting advanced skills in the European workforce.
- Facilitating the new EU Digital Identity Wallet architecture and the European Trust Infrastructure, as well as promoting its adoption in Member States.
- Stimulating the transformation of the public sector by developing efficient, high-quality, interoperable digital public services.

Innovation will also be accelerated by the new Strategic Technologies for Europe Platform (STEP), which awards the STEP Seal quality label to promising projects to improve their opportunity to access public and private funding.

Customer-Centric Focus: Customers' experiences have become one of the most important competitive differentiators, often influencing purchasing decisions and brand loyalty more strongly than traditional marketing efforts. Digital transformation allows organizations to use big data, AI, and machine learning to gain deeper insights into customer behavior, deliver personalized recommendations, and proactively

anticipate customer needs. For example, Amazon's recommendation system drives over 35% of sales (Lejhro, 2025), while Netflix tailors content based on viewing patterns (Krysik, 2024).

Omnichannel Experience - Customers engage through multiple touchpoints—websites, apps, social media, chatbots, and physical stores. Digital transformation integrates these into seamless journeys, ensuring consistent messaging and brand identity. Starbucks' mobile app combines ordering, loyalty, and payment, merging digital and physical experiences (Starbucks, 2022).

Customer Empowerment and Co-Creation-Digital platforms shift power to consumers, who shape brand perceptions via reviews, social media, and user-generated content (UGC). Trusted by 92% of consumers, UGC enhances engagement and loyalty (Nielsen, 2021). Companies now view customer participation as a strategic asset.

AI - Enhanced Customer Service - AI-driven chatbots and virtual assistants provide 24/7 support, reduce costs, and improve satisfaction. For instance, Sephora's Messenger chatbot offers personalized recommendations, while Bank of America's "Erica" provides financial guidance (IBM, 2023; Bank of America, 2023). Optimal service combines AI efficiency with human empathy (Lemon & Verhoef, 2016).

Data Ethics and Privacy- Ethical data handling is critical. GDPR mandates consent, transparency, and user control (European Commission, 2016). Ethical data management is essential, requiring consent, transparency, and user control. Organizations that adopt responsible practices build trust and gain a competitive edge, as most consumers are willing to share data with transparent brands.

Emotional and Experiential Value - CX increasingly relies on emotional engagement. AR, VR, and immersive storytelling create memorable experiences, as seen in IKEA Place for furniture visualization (IKEA, 2022) and virtual tourism experiences.

Measuring Customer Experience - CX metrics include CSAT, NPS, CES, and AI-driven analytics capturing sentiment and engagement. Real-time feedback analysis enables continuous improvement and adaptive personalization.

4 CONCLUSION

Digital transformation represents both an unprecedented opportunity and a complex challenge for modern organizations. While automation and advanced technologies can significantly enhance efficiency, productivity, and data-driven decision-making, they also introduce risks related to cybersecurity, ethical governance, and workforce adaptation. Effective digital strategies recognize that technology alone is insufficient; human expertise, creativity, and ethical oversight remain critical for sustainable success. Furthermore, the transformation of customer experience has become a central driver

of competitive advantage. Organizations that leverage digital tools to deliver personalized, seamless, and engaging experiences—while maintaining ethical data practices—can build loyalty, trust, and long-term value. The integration of human judgment with technological capabilities, coupled with a customer-centric approach, provides a roadmap for organizations to navigate the evolving digital landscape. In essence, the future of business lies in achieving a balanced partnership between humans and technology, where efficiency, innovation, and ethical responsibility coexist, ultimately enabling organizations to thrive in an increasingly digital world.

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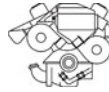
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