

ECOLOGICAL AND ECONOMIC RISKS OF USING GASOLINE, ELECTRIC, HYBRID, AND HYDROGEN-POWERED VEHICLES

Zoran Cekerevac

Independent Researcher, Portimão, Portugal

<https://orcid.org/0000-0003-2972-2472>

Lyudmila Prigoda

Maykop State Technological University, Maykop, Russian Federation

<https://orcid.org/0000-0002-4762-3892>



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Abstract

The automotive industry, a cornerstone of economic development, faces significant transitions driven by stringent environmental regulations and technological advancements. This paper examines the economic and ecological risks of various vehicle propulsion systems, including gasoline, electrical, hybrid, and hydrogen drives. Gasoline engines, while economically stable, pose environmental and health challenges. Electric vehicles, supported by state incentives, have a growing market share but encounter issues related to infrastructure and high costs. Hybrid cars, blending gasoline and electric technologies, inherit risks from both systems. Despite their potential for clean energy, hydrogen-powered vehicles require substantial technological advancements and infrastructure investment. The analysis highlights the necessity for continuous research and development to mitigate these risks and leverage the benefits of each propulsion type. Although it is beneficial for reducing pollution, the shift towards electric and hydrogen vehicles must consider the entire lifecycle impact, from raw material extraction to vehicle use. The authors emphasize that the sharing economy, combined with the reorganization of public transportation, is the only permanent solution to air and environmental pollution problems. Other solutions, while helpful, are considered temporary and partial. Significant changes in transportation organization and vehicle use are essential to achieve sustainable development and effectively address urban traffic issues. By focusing on holistic and sustainable solutions, the automotive industry can navigate the challenges of transitioning to greener technologies while maintaining economic stability.

Keywords: Propulsion systems, Environmental regulations, Technological advancements, Economic risks, Hydrogen vehicles, Electric vehicles, Sustainability, Public transportation

Address of the author:
Zoran Cekerevac
[✉ zoran@cekerevac.eu](mailto:zoran@cekerevac.eu)

1 INTRODUCTION

The modern world is increasingly recognizing the serious impact of environmental pollution on human life and survival, especially since pollutants

can unexpectedly spread to uninhabited and industrially undeveloped areas. Historically, air pollution in developed countries was mainly caused by sulfur dioxide and soot from low-quality fossil fuels until the mid-20th century. Despite improvements, many cities still face significant pollution from these energy sources. The rise in motor vehicles in the 1960s introduced new pollutants, including lead, nitrogen oxides, and unburned hydrocarbons. As technology advanced, stricter emission standards were applied, leading manufacturers to improve fuel injection systems and eliminate carburetors. This resulted in better fuel quality and reduced harmful emissions. Over the past fifty years, the global number of registered vehicles has dramatically increased—by more than 11 times—exceeding 1.45 billion (OICA, 2025). This increase in vehicle numbers correlates with rising air pollution levels, causing concern for human health. By the beginning of the 21st century, pollution control focus shifted from lead and sulfur dioxide to carbon dioxide, nitrogen oxides, and unburned hydrocarbons. Technological advancements have mitigated the latter two using catalysts, but the challenge of reducing carbon dioxide emissions remains significant. For diesel engines, particulate matter is also a major concern. All these components still contribute to overall air quality issues. Cars are an integral part of modern life. The choice of vehicle and type of drive plays a key role in the life of car owners. In this article, we will compare various types of vehicle propulsion primarily based on their overall impact on the environment and the budgets of vehicle owners and the community.

We will analyze examples of cars with gasoline, electric, hybrid, and hydrogen drives. We will focus on the latest models Renault ZOE, Clio, and Clio Hybrid, which are very similar in size and comfort in terms of what they offer the user. Although they are among the favorite cars of many owners, we will not consider diesel engines here because they are or will soon be "banned" from the central parts of many cities worldwide. These bans are part of a broader movement towards more sustainable forms of transportation, and many cities offer incentives for the transition to electric vehicles and other clean technologies. Justified or not? We will not analyze that at this moment. In the absence of an equivalent hydrogen-powered vehicle, we will

consider the Hyundai Nexa as an example and the risks associated with the procurement and exploitation of hydrogen vehicles.

1.1 Spark ignition engines

Based on available information, it can be said that vehicles with Otto engines (Spark Ignition engines – SI) are dominant, powering about 60% to 70% of the total number of passenger vehicles worldwide. The share of diesel engines (Compression Ignition – CI) is particularly notable in Europe, where they have long been popular due to their efficiency. Recently, there has been a decline in demand due to stricter environmental regulations. Globally, diesel vehicles make up 30% to 40% of all passenger vehicles. For trucks and buses, the situation is quite different, with diesel engines making up around 90% and 80 - 90% respectively. For construction and agricultural machinery, the shares are about 95% and 90% respectively. Diesel engines dominate the commercial transport and heavy machinery sectors due to their power, efficiency, and durability. Despite increasing pressures due to environmental regulations, their usage remains high in these sectors. Additionally, about 90% of military vehicles use diesel power. Considering this, one might question the justification for attacking diesel car engines.

Vehicles with SI engines use fossil- or synthetic fuels. The production process involves drilling, transporting, and refining oil, which has a significant environmental impact. SI engines are less efficient than diesel engines but are known for their high efficiency and long range. Unfortunately, they emit harmful gases such as carbon monoxide (CO), carbon dioxide (CO₂), unburned hydrocarbons (HC), and nitrogen oxides (NO_x). Catalysts are used to reduce the emission of harmful gases by:

- Breaking down nitrogen oxides into nitrogen and oxygen
- Oxidizing unburned hydrocarbons into carbon dioxide and water
- Oxidizing carbon monoxide into carbon dioxide

Based on available information, it is estimated that the global distribution of different fuels used for powering vehicles with Otto engines is as follows:

- Gasoline: about 80%
- LPG (liquefied petroleum gas): about 10%

- CNG (compressed natural gas): about 5%
- Alcohol (ethanol, methanol): about 3%
- Hydrogen: about 2%

Gasoline is the dominant fuel for SI engine vehicles. Given its prevalence, we have chosen it for comparative analysis. LPG and CNG are becoming increasingly popular due to their environmental benefits, but their future use remains uncertain. Alcohol is used in smaller quantities, often in blends with gasoline. Hydrogen is still in the development phase, and its current use is minimal. However, many expect its usage to grow with technological and infrastructure advancements. These estimates vary depending on the region and local energy and environmental policies.

1.2 Electric Motors

Instead of internal combustion engines, electric vehicles use one or more electric motors for propulsion. To ensure sufficient range, a high-capacity rechargeable battery is needed. While CI engines enable vehicle mobility of more than 1000 km without problems, modern batteries combined with electric motors cannot offer a similar range. Aware of these shortcomings, electric vehicle manufacturers continuously work on improving the quality of electric motors and batteries, facing the need for constant compromises. For example, improving vehicle range or charging speed can

compromise battery durability or lifespan. Currently, lithium-ion batteries are considered the best technical solution, but their production is expensive, and the lithium extraction process significantly harms the environment. Some manufacturers of lithium-metal batteries claim to have found a way to prevent fires and dendrites, enabling easier ion passage without degrading battery performance. These new batteries could become significantly cheaper, allowing electric vehicles to compete with gasoline cars. One advantage of electric propulsion is the substantially lower number of moving parts, which makes vehicle maintenance easier and reduces operating costs. Electric motor propulsion enables efficient energy regeneration during braking.

Various models of electric motors are used for vehicle propulsion. For example, Tesla's second-generation Roadster uses three permanent magnet synchronous motors (PMSM). The power of all three electric motors is 746 kW, and the efficiency ranges from 90-97% depending on specific operating conditions and motor design (Bruce, 2024). Rimac Concept One uses four water-cooled synchronous motors (LCSM) with a power of 913 kW and an efficiency of 97%. Renault ZOE uses two types of Externally Excited Synchronous Motors (EESM), R110 with 80 kW and R135 with 100 kW. The efficiency of these motors is around 90%. (Renault, 2021a)

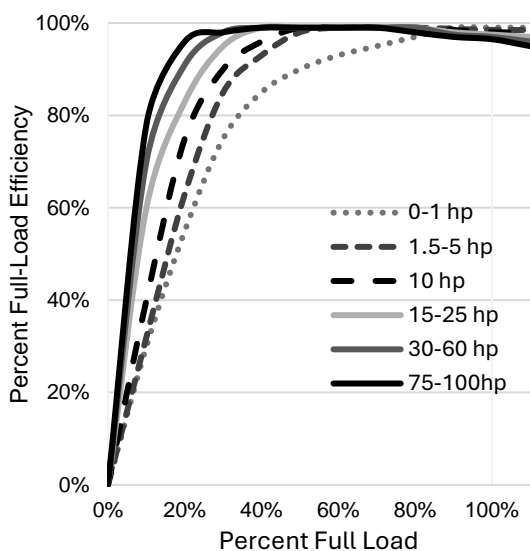


Fig. 1 Motor Part-Load Efficiency¹
 (as a Function of % Full-Load Efficiency)

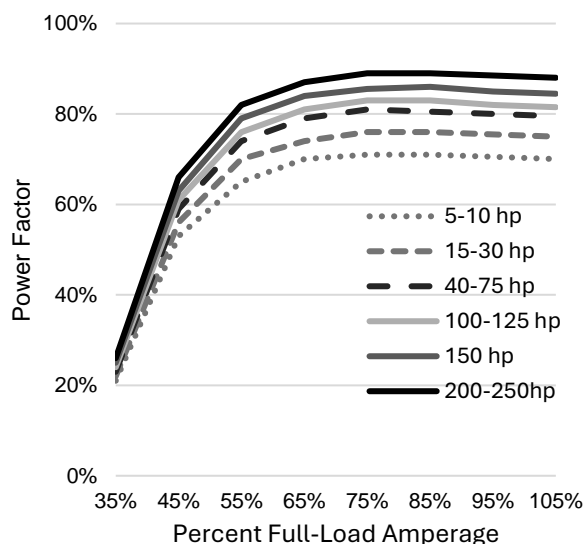


Fig. 2 Motor Power Factor
 (as a Function of % Full-Load Amperage)
 Source: Authors based on (DOE, 2014)

¹ 1 hp = 0.7457 kW; 1 kW = 1.341 hp

Most electric motors are designed to operate at 50% to 100% of their rated load. Maximum efficiency is usually around 75%. For example, a 100-kW motor has an acceptable operating range of 50 to 100 kW. The expected maximum efficiency is around 75 kW. Motor efficiency tends to drop significantly below about 50% load. This can vary from motor to motor, but it can be said that higher-power motors have a wider field of high efficiency, as shown in Figure 1. Figure 2 shows that as the load decreases, the power factor tends to drop earlier but less steeply than efficiency.

Electric cars use energy from rechargeable batteries. This energy can come from various sources, including renewable sources like solar and wind power plants, or conventional power plants that use fossil fuels. Electric cars have no exhaust emissions, making them more environmentally friendly alternatives, but batteries and electricity production can have a significant environmental footprint.

1.3 Hybrid Engines

Hybrid vehicle drives combine a gasoline engine with an electric motor. These systems can be:

- *Series hybrids*: The electric motor is the main driver, while the gasoline engine serves to charge the batteries.
- *Parallel hybrids*: The gasoline engine and electric motor can work together or separately, directly acting on the drive wheels.
- *Series-parallel hybrids*: It is a combination of the previous two systems; it optimizes the use of both engines

Within these types of hybrids, there are different operating modes that the vehicle can use depending on driving conditions, such as:

- *Electric mode*: The vehicle uses only the electric motor, usually at lower speeds or when driving in the city.
- *Gasoline engine mode*: This is when the vehicle uses only the gasoline engine, usually at higher speeds or when more power is needed.
- *Combined mode*: When both engines work together to optimize fuel consumption and performance or when additional power is needed.
- *Regenerative braking*: When the vehicle uses braking to charge the batteries.

Hybrid drives allow for better fuel consumption, lower emissions, and quieter driving than conventional internal combustion engines. They offer a compromise between range and environmental friendliness. The Renault Clio Hybrid analyzed here uses a parallel hybrid system.

1.4 Hydrogen Drives

Hydrogen-powered cars use hydrogen as fuel. Hydrogen is used in internal combustion engines or converted into electrical energy in fuel cells and then delivered to electric propulsion.

The production of hydrogen for motor vehicle propulsion can be carried out using various methods, including water electrolysis, natural gas reforming, methane pyrolysis, production from biomass and biogas, and thermal water splitting. Water electrolysis involves the decomposition of water using electric current and is particularly sustainable with renewable energy sources, although costs are higher. Natural gas reforming involves a chemical reaction between natural gas and water vapor, producing hydrogen and carbon dioxide. This method is economically favorable but has a negative environmental impact due to CO₂ emissions. Methane pyrolysis involves the decomposition of methane at high temperatures without oxygen, creating hydrogen and carbon. The hydrogen concentration can vary from 50-75%, and energy consumption is high, but there is potential for improving energy efficiency. Hydrogen can also be produced from biomass and biogas through anaerobic digestion or gasification, which is a sustainable method but depends on location and resource availability. Thermal water splitting uses high-temperature processes to decompose water and is still in the research phase. These methods have various economic and ecological aspects that affect their choice for hydrogen production.

Hydrogen vehicles emit water vapor during operation, making them quite environmentally friendly. However, the infrastructure for production, storage, and distribution of hydrogen is still under development. We will discuss this in more detail later.

1.4.1 Hydrogen Internal Combustion Engines

Hydrogen internal combustion engines (ICE) use hydrogen as fuel. These engines operate on the same principle as other SI engines, except hydrogen burns in the cylinders. Hydrogen was first used as fuel in engines at the end of the 19th century. There was no widespread application until World War II when Russian engineer Boris Shelishev converted about 200 GAZ-AA trucks to use hydrogen as fuel. These trucks ran cleaner and longer than those using gasoline (Wróbel, et al., 2022). After the war, there was a lull until the 1970s. From that period, the significant monograph "Neue Kraftstoffen auf der Spur" (1974) details the possibilities of using hydrogen to power vehicles. The advantage of such engines is that they do not emit CO₂ when using pure hydrogen (Nebergall, 2022). The disadvantages include increased nitrogen oxide emissions and specific conditions required for storing hydrogen in vehicles. However, the main reason for the rare use of hydrogen today is its high production cost compared to other fuels.

1.4.2 Fuel Cells

Fuel cells (FC) convert the chemical energy of fuel into electrical energy, which can then be used for vehicle propulsion and other purposes. Based on the type of electrolyte they use, there are different types of fuel cells, such as alkaline (AFC), molten carbonate (MCFC), phosphoric acid (PAFC), polymer membrane (PEMFC), and solid oxide fuel cells (SOFC). In vehicles, the most used type of fuel cells are polymer membrane fuel cells. They produce electricity through an electrochemical reaction involving hydrogen as fuel and oxygen from the air as an oxidant (Čekerevac, 2024).

Their advantages include:

- High efficiency,
- Fast start-up,
- Low operating temperature of around 80°C, and
- Environmental friendliness, as they only produce water as a byproduct.

These characteristics make them highly environmentally friendly. Due to their features, PEMFCs have been applied in various hydrogen vehicles, including cars, buses, and forklifts. One specific aspect of fuel cells is that they have no moving parts. The absence of moving parts means fuel cells are quieter, have less wear, and are

generally more reliable than conventional internal combustion engines.

Although hydrogen fuel cells represent promising energy sources, significant challenges currently hinder their widespread use in vehicles. These challenges include:

- Lack of infrastructure for the production, storage, and distribution of hydrogen.
- High costs of hydrogen production.
- Cost of fuel cells.
- Safe storage and transport of hydrogen.
- Loss of performance during operation.
- Consumer perception. Many lack understanding and confidence in hydrogen technologies.

The low operating temperature of fuel cells is an advantage from a safety perspective, but it also presents specific problems. The operating temperature of fuel cells is lower than that of internal combustion engines. The cooling issues may arise during hot summer days. In extremely low winter temperatures, problems may occur with how to heat the fuel cell to its minimum operating temperature. (Čekerevac, 2024) This situation is like the issue with batteries in purely electric vehicles.

1.4.3 Major Manufacturers of Hydrogen-Powered Vehicles

Research on the use of hydrogen for vehicle propulsion continues, but there are also hydrogen vehicles in mass production. Some of the current leading manufacturers of hydrogen-powered cars include:

- **BMW:** BMW had the Hydrogen 7 model, which used a hydrogen internal combustion engine that could also run on gasoline (Peres, 2006). Nowadays, BMW has turned to models like the BMW iX5 Hydrogen, which uses hydrogen fuel cells instead of internal combustion engines (BMW, 2024)
- **Nissan:** Nissan has the model X-Trail FCV. (HCN, 2015)
- **Toyota:** The Toyota Mirai is one of the most well-known fuel cell vehicles. (Saunders, 2021)
- **Hyundai:** Hyundai has a Nexo model, which uses fuel cells. (Hyundai, Nexo, 2024)
- **Honda:** Honda has the Clarity Fuel Cell model. (Honda, 2024)

- **Renault:** Renault unveiled Emblème, a dual-power energy system combining a 40-kWh battery with a 30-kW hydrogen fuel cell at the 2024 Paris Motor Show. (Lister, 2024)
- **Mazda:** Mazda is developing a hydrogen internal combustion engine, which could use hydrogen as fuel for a completely new vehicle model, likely as a successor to the RX-8 model (Glon, 2021).

2 COMPARISON OF VEHICLE CHARACTERISTICS

For this analysis, we have selected three vehicles from the same manufacturer that are very similar in size and the comfort they provide for the driver and passengers. Unless otherwise stated, the data on the ZOE and Clio vehicles analyzed in this paper were sourced from the Autoscout24.de website (Clio; ZOE, 2025). We chose approximately the same level of equipment to avoid price differences due to equipment variations.

For the analysis of hydrogen vehicles, we selected the *Hyundai Nexa* (2025), which belongs to a higher class than the previous three vehicle models but is indicative enough to observe trends.

All observed vehicles were first registered between 2020 and 2025.

2.1 Key Characteristics of the Analyzed Vehicles

The key characteristics significant for understanding the analyzed vehicles are:

- **Renault ZOE.** Renault ZOE is a popular electric hatchback known for its efficiency and low emissions. Its motor power is 80 kW. Its fully charged battery provides a range of about

395 km on a single charge, with virtually no harmful emissions. That means it fully complies with Euro 6 regulations. (Laura, 2021). The ZOE achieves a maximum speed of 135 km/h, and the energy consumption is 15 kWh/100 km. Characteristics related to consumption and range depend on driving conditions.

- **Renault Clio:** Renault Clio is a popular hatchback with a 74-kW turbocharged gasoline engine that offers high performance and long range with CO₂ and other harmful gas emissions. Its fuel consumption is about 5.3 liters per 100 km, and it meets Euro 6 air pollution standards. The maximum speed it achieves is 188 km/h.
- **Renault Clio Hybrid:** Renault Clio Evolution E-Tech full hybrid combines the best features of gasoline and electric drives, allowing for reduced harmful gas emissions and low fuel consumption of about 4.3 liters per 100 km. Its 39-liter fuel tank, depending on driving conditions, provides a range of up to 925 km. The total motor power is 105 kW. The electric motor works at lower car speeds. The gasoline engine is for higher speeds. There is an option for both drives to operate together if needed. It meets Euro 6 air pollution standards. (Renault, 2024)
- **Hyundai NEXO:** Hyundai NEXO is a crossover SUV with hydrogen fuel cell propulsion, a range of up to 666 km, fast fuel filling, 120kW motor, and fuel consumption of 0.95 kg H₂/100 km, which corresponds to an energy consumption of 33.3 kWh/100 km.

2.2 Pros and Cons

The advantages and disadvantages of the drives can be summarized as shown in Table 1.

Table 1 Advantages and Disadvantages of Drive Types

Type of Drive	Advantages	Disadvantages
Electric (Renault ZOE)	<ul style="list-style-type: none"> - Zero emissions at the point of use - Low operating costs - High efficiency - Quiet operation 	<ul style="list-style-type: none"> - Limited range compared to IEC - Long charging time - Environmental impact of battery production
Gasoline (Renault Clio)	<ul style="list-style-type: none"> - High performance - Long range - High efficiency - Established infrastructure 	<ul style="list-style-type: none"> - Emissions of harmful gases (CO₂, NO_x, etc.) - Higher fuel consumption - Nonrenewable fuel - Dependency on fossil fuels

Type of Drive	Advantages	Disadvantages
Hybrid (Renault Clio Hybrid)	<ul style="list-style-type: none"> - Lower fuel consumption - Reduced emissions of harmful gases - Flexibility of two power sources 	<ul style="list-style-type: none"> - More complex technology - Higher initial costs - Higher maintenance costs
Hydrogen (Hyundai NEXO)	<ul style="list-style-type: none"> - Zero emissions during operation - Fast refueling - Long range 	<ul style="list-style-type: none"> - High production costs - Underdeveloped infrastructure - Safe storage challenges

3 IMPACT ON TRAFFIC AND SOCIETY

The application of new technologies in automobiles has a significant impact on traffic, individuals, and society. Electric cars reduce air pollution and noise in urban areas. Hybrid car drives are very complex, but they provide a solution for the transitional period. Hydrogen vehicles can be the future of ecological transport but require significant investments in development and infrastructure. While extensive knowledge about the dangers and risks of traditional Otto and diesel engines has accumulated over their long history, this is often not the case with new technologies. Risks also include the possibility of accidents in power plants and oil refineries and the impact of wars on fuel supply.

Now, we will focus on environmental and economic dangers and risks. We will consider economic risks from the perspectives of individuals, vehicle owners, and society, nationally and globally.

3.1 Environmental Risks

Traffic, roads, and the cars that drive on them have become serious sources of environmental risks and threats. Cars with fossil fuel engines emit harmful gases such as CO₂, CH, NO_x, and PM2.5. They contribute to air pollution, acid rain, and climate change. Alternative drives also pose risks related to their production and exploitation. Roads cause additional noise, loss of natural habitats, and ecosystem fragmentation. Rain washes pollutants from roads into waterways, endangering aquatic ecosystems. The consumption of fossil fuels and raw materials for vehicle production depletes natural resources and increases energy insecurity. Nowadays, it is believed that electric vehicles and other alternative technologies can reduce these environmental risks and improve the sustainability

of transportation systems. In the following, we will analyze some types of power units.

3.1.1 Gasoline Engines

While economic risks are associated with various planning and expectations, environmental risks are more straightforward to define. The main ecological hazards to the broader community from the use of gasoline engines are reflected in the following:

- Air pollution. Gasoline engines emit harmful gases such as nitrogen oxides (NO_x), carbon dioxide (CO₂), and sometimes unburned hydrocarbons (CH), carbon monoxide (CO), sulfur oxides (SO_x), and particles. These last four usually occur in cases of engine malfunction.
- Impact on public health. Harmful components of exhaust gases affect human health, and in cases of prolonged exposure, people may face serious consequences.
- Climate change. There are ongoing debates not so much about whether exhaust gases from gasoline engines affect the climate but primarily about how much they affect the climate, given there are many harmful gases emitters. The dominant emitter depends on the specific point observed on the planet. Near thermal power plants, the impact of automotive traffic is negligible.

According to available sources, gasoline CO₂ emissions, which include all stages from extraction, processing, and delivery to combustion, give the total CO₂ emission for 1 kg of gasoline of approximately 8.89 kg CO₂. (EIA, 2024) With a consumption of 5.3 liters = 3.92 kilograms, the analyzed Renault Clio releases 34.85 kg of CO₂ into the atmosphere per 100 km driven.

3.1.2 Electric Drive

Although considered a green drive, the production, use, and recycling/disposal of electric vehicles bring numerous environmental risks:

- Electric vehicles have significantly more embedded copper compared to gasoline vehicles. For example, an average electric vehicle can contain about 83 kg of copper, while a gasoline vehicle contains about 23 kilograms of copper. Electric cars require dramatically more copper for their batteries, motors, and other electrical components than gasoline vehicles (Bennett, 2022). A mitigating factor is that it is possible to recycle copper efficiently. It reduces the need to extract new raw materials and diminishes negative environmental impacts.
- The Renault ZOE battery contains about 8 kg of lithium. That amount can vary depending on the specific characteristics and battery versions (Lima, 2020).
- The production of electricity presents a particular problem for society. If the entire vehicle fleet were to be replaced with electric propulsion, likely, the current power systems of many countries would not withstand it. This claim becomes even more relevant when considering only renewable energy sources. If electric vehicles use electricity from thermal power plants, gasoline engines are more environmentally friendly than electric ones. Therefore, countries must plan investments in renewable sources.
- Today's battery packs for electric vehicles are mostly lithium-ion (Li-ion). According to current data, they make up about 95% of all batteries used in electric cars. Demand for them is constantly growing. In 2022, demand increased by 55% compared to 2021 and reached 550 GWh (IEA, 2023). Demand continued to grow in subsequent years. The problems with lithium are that it is unevenly distributed worldwide and that there is no way to obtain it without harming nature. The production of batteries requires large amounts of energy and critical raw materials, and recycling, as mentioned, is environmentally and economically demanding. Therefore, countries must continually seek better recycling processes for batteries.

- Electric drives must use electricity from renewable sources to be environmentally friendly. That creates a risk of dependence on renewable electricity sources.

We must mention that electric vehicles do not emit harmful gases at the point of use, which is beneficial for organizing urban life. However, they are associated with a range of environmental risks. However, these risks are far from the public eye. According to T&E (2022), at zero kilometers driven, a small car production, like the Renault ZOE, emits 6.85 tons of CO₂ into the air, while for a gasoline Clio, it is 4.49 tons. Regarding CO₂ emissions, the ZOE and Clio equalize at around 7.75 tons after approximately 17,000 km drive. According to our analysis, this would happen during the third year of vehicle use.

3.1.3 Hybrid Drive

Hybrid drive is one solution for reducing air pollution in cities, as it can use electric propulsion at low speeds and loads and switch to the gasoline engine on highways when more power is needed. In urban conditions, with a single battery charge, which in the case of the Renault Clio Hybrid has a capacity of 1.2 kWh, the car can travel 50-60 km using only the electric motor (Renault.pt, 2025). That includes energy regeneration that occurs during vehicle braking. That seems more than sufficient for one city drive, but after the battery discharging, it needs recharging, so gasoline engine will be active in subsequent drive.

A hybrid car consumes approximately 18% less fuel, so pollution will also be less, but it is inevitable. The efficiency of a hybrid drive can vary depending on the conditions and driving style. In principle, a hybrid vehicle pollutes the air less, but it brings with it the ecological and other problems of both gasoline and electric drives.

3.1.4 Hydrogen Drive

Although hydrogen is considered a clean and environmentally friendly fuel, its production carries significant environmental risks. Water electrolysis, used for green hydrogen, demands vast amounts of electricity, often derived from non-renewable sources. This can strain energy resources and contribute to CO₂ emissions if fossil fuels are used. Pink hydrogen, generated through nuclear energy electrolysis, poses risks linked to nuclear

waste and accidents. Blue hydrogen relies on natural gas reforming, which, despite carbon capture technology, emits CO₂ and methane, potent greenhouse gases. Gray hydrogen, produced without carbon capture, results in high CO₂ emissions, exacerbating global warming. Turquoise hydrogen, involving methane pyrolysis, generates solid carbon waste and requires significant energy, potentially from non-renewable sources. Black and brown hydrogens, derived from coal gasification, produce the highest CO₂ emissions and toxic pollutants like sulfur dioxide, harming air quality and human health. Additionally, high-temperature processes used in hydrogen production can lead to leaks, explosions, and hazardous conditions, posing severe environmental and safety risks. Thus, while hydrogen holds promise for a green future, its production methods must be carefully managed to mitigate ecological impacts (Cekerevac, 2025).

Transporting and storing hydrogen poses several environmental risks. These processes consume significant energy, often sourced from non-renewable means, thereby generating CO₂ emissions. Pipelines used for transport are prone to hydrogen embrittlement, leading to potential leaks that can result in flammable hydrogen escaping into the atmosphere, posing explosion hazards. Accidental releases during transport or storage can contribute to air pollution and greenhouse gas emissions. Moreover, liquid hydrogen transport by sea involves energy-intensive cooling systems. It also contributes to carbon emissions. The infrastructure development for hydrogen transport can lead to land use changes, potentially impacting ecosystems. Lastly, hydrogen's high flammability necessitates stringent safety measures, and any failure in these systems can lead to catastrophic environmental consequences. Managing these risks is crucial to minimizing the ecological footprint of hydrogen as an energy carrier. (Cekerevac, 2025)

Using hydrogen fuel cells and storage systems at hydrogen stations and vehicles carries several environmental risks. Leakage of hydrogen from tanks and pipelines can lead to air pollution and contribute to the formation of ground-level ozone, a harmful pollutant. The highly flammable nature of hydrogen means that accidental releases can result in fires or explosions, posing dangers to

surrounding ecosystems and communities. Additionally, the production and use of composite materials for hydrogen tanks involve energy-intensive processes, potentially increasing the carbon footprint. Cryo-compressed hydrogen tanks require significant energy to maintain low temperatures, leading to increased greenhouse gas emissions if non-renewable energy sources are used. In addition, hydrogen fuel cells require high-purity hydrogen. Necessary additional processing may generate waste and emissions. Effective safety measures and stringent monitoring are essential to mitigate these environmental hazards and ensure the sustainable use of hydrogen as an alternative fuel.

3.2 Economic Risks for Users

The decision to buy a car rests with the future owner. Many factors influence this decision. For the buyer, in addition to aesthetic considerations, the dominant factors are the purchase costs, maintenance costs, resale value of the used vehicle, and the comfort of the interior and driving experience. However, there are also external influences that can favor certain vehicles. For example, the state can offer subsidies and incentives for purchasing certain types of vehicles, specific types of drive systems, or even favoring particular vehicle models. Many countries have subsidized the purchase of electric vehicles, and initially, there were even places where owners could charge their vehicle batteries for free. Marketing campaigns also significantly influence vehicle choice and can direct buyers. For those who do not have the means or do not want to invest in a new vehicle, there is a rich supply of used vehicles. Buying a used vehicle allows for a car acquisition at significantly lower prices, but it also brings a range of risks. The more regulated the market, the lower the risks, but they always exist.

3.2.1 Electric Vehicles

Figures 3 and 4 show the results related to the prices and mileage of used Renault ZOE vehicles. Figure 3 shows that a buyer of a new vehicle needs to spend an average of 34,329 EUR. The vehicle is offered by multiple dealers, so the median price of the vehicles offered is around 32,845 EUR. The cost of the vehicle depreciates quickly, so within five years, the vehicle loses two-thirds of its value. Figure 4 shows the results of the

mileage analysis. The results for 2024 are unrealistically low because the offer for vehicles from that year included new, unsold vehicles or vehicles repurchased by dealers, which had traveled 6 to 150 km. Vehicles purchased by actual users had traveled between 3,900 and 12,300 km, but there were very few vehicles from

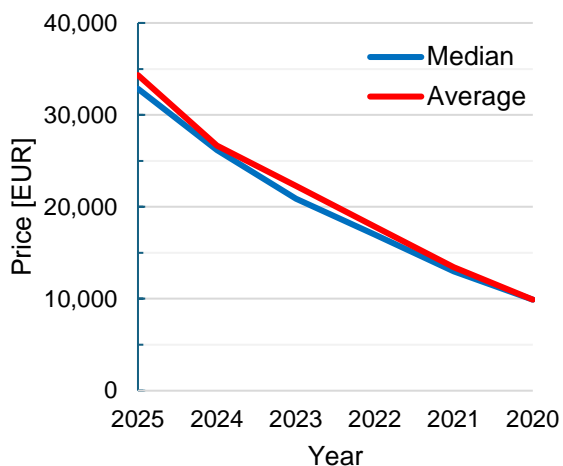


Fig. 3 Renault ZOE Prices by Production Year

If we compare the years 2021 and 2025, cars have lost an average value of 20,885 EUR and have covered an average distance of 37,315 km. This means that owners have paid 0.56 EUR/km solely based on the depreciation of their vehicles. This is a significant amount. However, new owners of these cheaper vehicles are not without risks, if they plan to drive the purchased car for a long time, they must account for the high cost of acquiring a new battery pack. The price of a new battery pack for the Renault ZOE in Germany can vary depending on the manufacturer and specific sales conditions. According to (AvtoTachki, 2022), the prices for a 41-kWh battery are around 8,000 euros. A mitigating factor is that Renault also offers the purchase of the ZOE with battery rental. In this case, the vehicle's price is lower by the value of the battery pack, and the rent is paid according to the contracted annual mileage. With a contracted mileage of 20,000 km/year, the prices equalize after approximately 64 months, and with a contracted 7,500 km/year, the prices equalize after 108 months.

If we compare the weights of the electric ZOE and the gasoline Clio, we will see that the ZOE is 376 kg heavier. That is equivalent to 4.7 average adults. This is as if four more people were continuously in the gasoline Clio.

2024 on offer. The anomaly in 2020 is a consequence of the COVID-19 pandemic and police lockdowns, during which buyers were practically unable to use their new vehicles. This also affected their future behavior and vehicle usage.

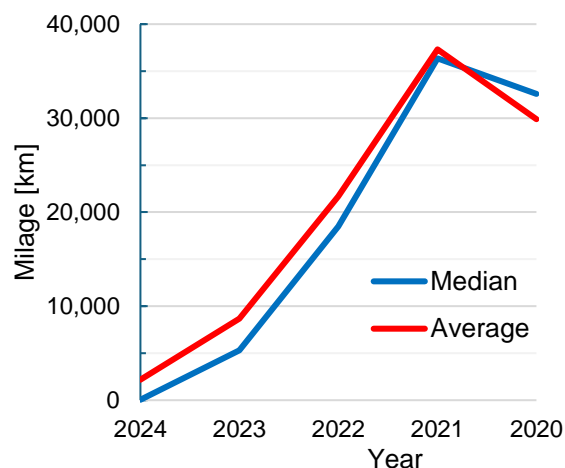


Fig. 4: Mileage by Production Year for Renault ZOE

If 16.5 kWh of electricity is needed for 100 km of traveled distance, for 0.64 EUR per kWh (Statista, 2024), the cost of 100 km based on energy costs is 10.56 EUR. The fuel cost for the gasoline Renault Clio for the same distance in the same country is 9.17 EUR.

One of the significant risks for electric car owners is water. In the event of vehicle submersion, there is a risk of battery pack explosion. In the increasingly frequent cases of floods, vehicle self-ignition is not uncommon. The situation becomes particularly unpleasant when vehicle parts are submerged in seawater. In such cases, self-ignition can occur even after drying the vehicle, sometimes even months later (Tanim, 2024). An even greater risk is in the case of a short circuit. Vehicle self-ignition can also occur due to corrosion (Rathi, 2022)

The risks for owners of electric cars are primarily economic and safety risks. Consumers can avoid these risks by carefully analyzing why they need an electric car and what they plan to do with it in a few years.

3.2.2 Cars with Gasoline Engines

In the recent past, there were two main groups of vehicle owners. One group consisted of those who wanted a comfortable drive for shorter distances and drove relatively few kilometers annually. They

bought vehicles with gasoline engines. The other group mainly consisted of those who wanted a more economical drive for longer distances and drove many kilometers annually. They bought vehicles with diesel engines. Today, the variety of available drive types has increased, and buyers of gasoline vehicles are typically:

- Businesspeople who prefer gasoline vehicles for their speed and comfort on long journeys.
- Young and sporty drivers who seek pleasure in driving and the sound that engines provide.
- Drivers who travel short distances in all weather conditions.
- Drivers who want lower initial costs, as gasoline vehicles generally have lower prices than other types.

In this analysis, we considered Renault Clio, which is not intended for top management but also appears as a vehicle for business purposes. Most of the analyzed vehicles were privately owned, so the Clio can be considered a small family car in this case.

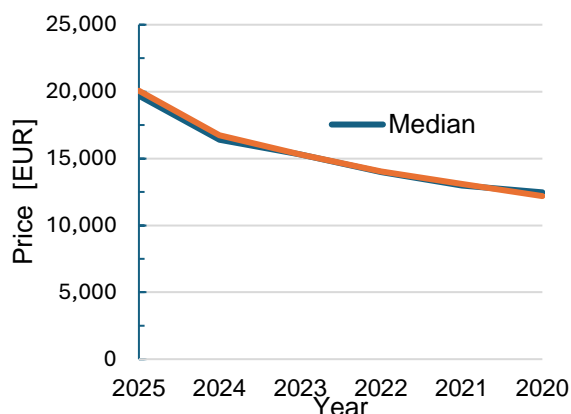


Fig. 5 Renault Clio TCE-100 Prices by Production Year

If we consider the same factors as with the Renault ZOE, we can see that the current median purchase price of the Renault Clio is around 20,000 EUR and a Clio from 2020 is worth 60% of its current price. This means the car has lost 8,000 EUR over five years of use. An average Clio from 2021 has traveled 40,764 km and during its use, its value has decreased by 6,975 EUR. If we divide this by the average number of kilometers traveled, 40,764, we get that one kilometer traveled costs the owner 0.17 EUR based on the loss of the vehicle's price. We see that one-kilometer travel costs the owner only one-third of what the owner of the Renault ZOE pays. In addition, the owner paid 14,000 EUR less for the car than the owner of the electric vehicle. When considering maintenance and fuel costs, it can be concluded that the costs of gasoline and electric drives would equalize at around one million kilometers, which small cars will not cover even in 30 years, far beyond their expected lifespan. Figures 5 and 6 show the prices of Clio vehicles with a 74-kW gasoline engine and the mileage of the cars depending on the year of manufacture

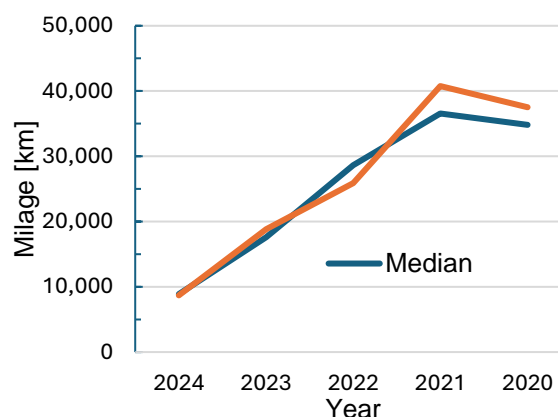


Fig. 6: Renault Clio TCE-100 Mileage by Production Year

The main risk for owners of Clio vehicles with gasoline engines is the government's actions to phase out internal combustion engines through regulations and constantly lower the allowed exhaust emission limits.

3.2.3 Hybrid Vehicles

Hybrid drive combines a gasoline engine and an electric motor. That allows for greater efficiency and reduced exhaust gas emissions. Users can generally choose between two versions:

- *Full Hybrid*, which uses both the gasoline engine and the electric motor in such a way

that both can work together or independently of each other.

- *Mild Hybrid* uses a less powerful electric motor and battery that assists the gasoline engine during driving. The electric motor cannot independently propel the car; instead, it supports the gasoline engine during acceleration and reduces fuel consumption. Mild hybrid systems are generally cheaper and less complicated than full hybrid systems but offer lower efficiency in terms of savings.

The analyzed Renault Clio Hybrid E-Tech Equilibre is a car that uses a full hybrid type of drive (ADAC, 2023). This model offers up to 80% electric driving in urban conditions, meaning that most trips can be made on electric power. It also has a total driving range of about 900 km, making it practical for families and individuals seeking a

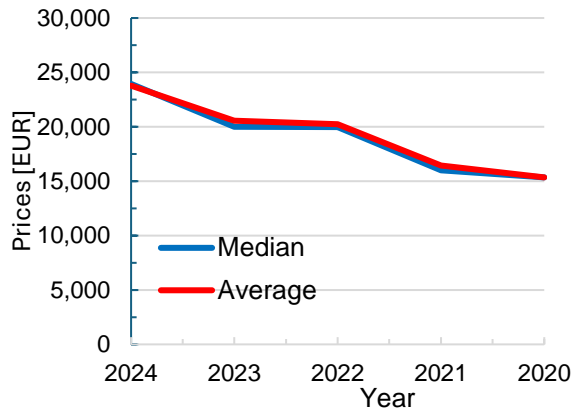


Fig. 7 Renault Clio Hybrid E-Tech Prices by Production Year

The initial price of the Clio Hybrid in 2025 is 23,490 EUR (Renault, Clio E-Tech Full Hybrid, 2024), but this base model was not included in the sample analyzed. The vehicles offered had slightly richer equipment, so the average price for 2024 was 23,782 EUR. The average price of an equivalent vehicle from 2021 was 7,349 EUR lower. The average hybrid from 2021 has traveled 32,305 km, meaning that the cost per kilometer based on vehicle depreciation was 0.227 EUR, which is 0.057 EUR more than the gasoline engine. Considering the difference in declared fuel consumption for both vehicles, we see that the hybrid vehicle will consume 0.8 liters of fuel less per 100 km. Multiplied by the price of super gasoline (1.73 EUR per liter), this results in savings of 1.384-euro cents per kilometer. From this, it can be concluded that driving a purely gasoline-powered vehicle is more cost-effective based on vehicle price depreciation and fuel consumption difference of 4.31-euro cents per kilometer. It should also be noted that the initial price of the hybrid vehicle is higher by 3,424 EUR, and the significant disadvantages of the hybrid drive mentioned in Table 1 should be considered. Primarily, the hybrid drive is significantly more complex than the gasoline drive. Additionally, the hybrid Renault Clio uses a lithium-ion battery with a capacity of 1.3 kWh (ultimateSPECS, 2023), while the gasoline Renault Clio uses a standard

compact, economical, and more environmentally friendly car for everyday use (Renault, 2024).

Figures 7 and 8 show the prices of Clio cars with a 74-kW hybrid drive and the mileage of the vehicles depending on the year of manufacture.

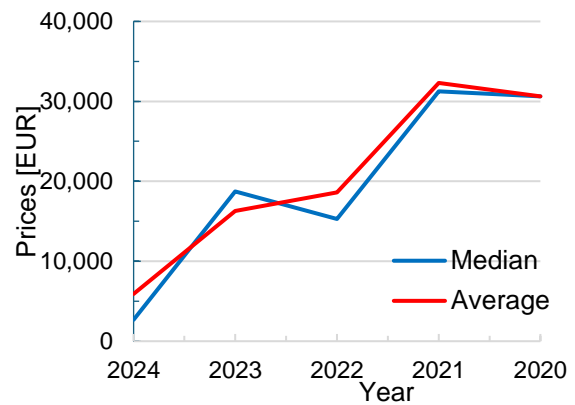


Fig. 8: Renault Clio Hybrid E-Tech Mileage by Production Year

lead-acid battery with a capacity between 41 Ah and 63 Ah (AutoDoc, 2024)

If we compare the weights of gasoline and hybrid vehicles, the Clio TCe 100 has a mass of 1,167 kg, and the Clio Hybrid E-Tech Equilibre is 1,331 kg. The difference is 164 kg, which is equivalent to the mass of two average adults.

When considering the risks to which the owner of a hybrid vehicle is exposed, we see that they can be easily avoided by not purchasing a hybrid under these conditions. If the gasoline engine and the hybrid comply with EURO6 norms, there is (currently) no justified reason to buy hybrid vehicles from the buyer's perspective. A possible reason could be to allow access to central parts of the city where hybrids are permitted, but gasoline engines do not. However, the decision to ban access to purely gasoline vehicles while allowing hybrids is very problematic because the batteries of the hybrid drive need to be charged precisely with the gasoline engine's energy.

3.2.4 Hydrogen-Powered Vehicles

A few cars use hydrogen as fuel. Most current hydrogen cars are larger vehicles, such as SUVs, crossovers, and commercial vehicles. This is because of the complexity of the system and the required size of the tank. Additionally, few countries can offer hydrogen as fuel for cars, so hydrogen vehicles are available in specific, limited

markets. Moreover, to popularize hydrogen propulsion, manufacturers provide special incentives to buyers in certain markets. For example, Hyundai offers Nexo car buyers, free hydrogen worth 15,000 USD or six years

(whichever comes first) (Gluckman, 2025). This is an important factor affecting the vehicle's price and operation costs. To ensure comparability of analyses, we will use Hyundai NEXO as an example in the German market from 2020 to 2023.

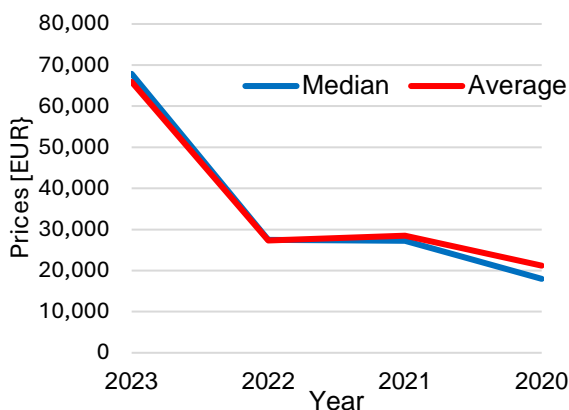


Fig. 9 Hyundai Nexo Prices by Production Year

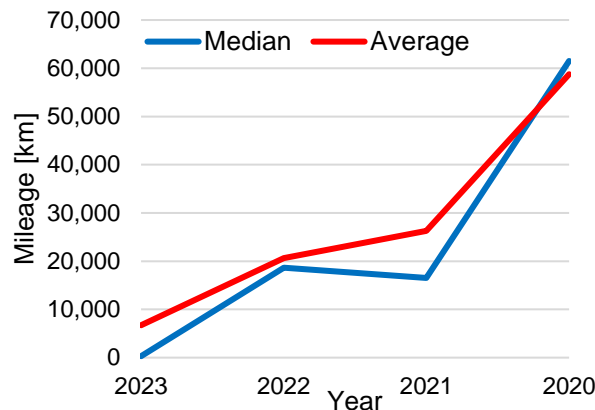


Fig. 10: Hyundai Nexo Mileage by Production Year

The graph in Fig. 9 shows that vehicles from 2022 are selling for less than half the value from 2023. The reason is that half of the cars from 2023 are practically new, having traveled less than 100 km. However, even vehicles that have traveled around 20,000 km are sold at the same price. The offerings from previous years are richer, and the prices of those vehicles seem more realistic. In terms of mileage, as shown in Fig. 10, Nexo vehicles have traveled significantly more kilometers than the previously analyzed Renault vehicles, which was expected given the size and purpose of the car. There is a noticeable difference between the median and average values, as the offerings included vehicles that significantly deviated from the others.

specificities of hydrogen technology, and the number of authorized service centers is smaller, which can affect the price. Unlike internal combustion engines, hydrogen fuel cells require not only hydrogen of >99.9% purity but also immaculate air. Specifically, the air should have very low levels of contaminants such as sulfur compounds (H₂S), carbon dioxide (CO₂), ethylene, and ammonia (NH₃) (Uribe, et al., 2005). To prevent damage, hydrogen fuel cell vehicles have specialized air purification systems that include filters to remove dust and other particles. (Martensson, 2020)

To analyze the impact of vehicle price depreciation on the cost per kilometer, we will compare 2023 with 2020. Based on the research data, we see that the median price value for this period decreased by 44,700 EUR. For the median value difference in kilometers traveled of 52,044 km, we find that the cost per kilometer based on vehicle depreciation is 0.859 EUR. The price of hydrogen in Germany for automotive use is approximately €12.85 per kilogram (Biogradlija, 2022). Hyundai (2018a), states that with a consumption rate of approximately 0.95 kg of hydrogen per 100 km, the fuel cost per kilometer is 12.2-euro cents.

Due to contamination of electrocatalysts, membrane degradation, and operating conditions (temperature and pressure), fuel cells can gradually lose efficiency. (James, 2022)

When we analyze hydrogen propulsion from the perspective of vehicle owners, we see that the main risks are the high purchase price of a new vehicle, its rapid depreciation immediately after purchase, and the availability of hydrogen stations along the planned route. Slightly higher fuel consumption costs may not be decisive for vehicle purchase in this case.

Regarding vehicle maintenance, the owner can count on lower costs because there are fewer moving parts. However, there are several

3.3 Economic Risks for Society as a Whole

The automotive industry is significant for any society because it employs many people, increases mobility, facilitates the transport of people and goods, and accelerates the country's

economic development. Various external factors impact these benefits and often cause significant changes in further development. The accelerated industrialization and rapid increase in the number of vehicles have brought numerous crises directly related to the production and use of fuels. Mass production of cars combined with low-quality fuels has contributed to enormous air pollution. This necessitated the creation of new regulations. Stricter standards forced manufacturers to produce higher quality power units, which required higher quality fuel, leading refineries to start to make better fuel. The first EURO standard for exhaust gas quality, EURO 1, was set in 1992 and came into force in 1993. In 2025, the EURO 6 standards are in effect (RAC, 2025). The EURO 7 standard has recently been adopted and is planned to come into force in 2026. These European standards have enabled technological progress. However, everything has its optimum. Further tightening of standards can lead to unrealistic demands and the opposite effect, to the stifling of the automotive industry, while the benefits may become negligible. A major risk is that the EURO standards are proposed by the European Commission and reviewed and adopted by the European Parliament and the Council of the European Union. These bodies are objectively incompetent in this area, and decisions are made politically based on lobbying, even if they are perhaps based on the best intentions. The consequences of poorly created standards are felt throughout the EU and beyond. In the following, we will attempt to systematize the risks different types of power units may pose to society.

3.3.1 Gasoline Engines

Gasoline engines are currently well-established and economically stable. They successfully meet current environmental standards. In the past, they have gone through several crises:

- In 1973 and 1979, OPEC increased oil prices, causing energy crises. Demand for gasoline vehicles has declined, while demand for more fuel-efficient diesel vehicles has increased.
- In the 1980s, car manufacturers began developing hybrid and electric vehicles as alternatives to gasoline vehicles.
- In the 1990s, increased environmental awareness and greenhouse gas emission

regulations led to the development of lower-emission vehicles.

- In the 2000s, climate change became a major concern, and the automotive sector intensified its shift to alternative fuels and drives.
- In the 2020s, the COVID-19 pandemic led to a global economic crisis that affected vehicle production, purchase, and use. High fuel prices became a new reality.
- From 2023 to 2025, the European auto industry faced numerous challenges, including high production costs, competition from China, and political and economic hurdles. The transition to electric vehicles became a priority. It was accompanied by numerous restructurings and layoffs. The announcement of EURO 7 standards further complicated the situation, threatening to stifle the gasoline engine and vehicle industry.

By 2035, the EU planned to phase out the production of internal combustion engine (ICE) vehicles, which includes gasoline and diesel, as well as vehicles powered by methane (CNG), LPG (propane-butane), and hydrogen. There will be no room for hybrid technology (MHEV, HEV, and PHEV) (Grozdanovic, 2023) However, there is an exception for vehicles that use renewable or climate-neutral fuels. This means that cars powered by methane, LPG, or hydrogen can continue to be produced and sold after 2035 if they use environmentally friendly fuels. (Visnic, 2023). These measures and restrictions will not contribute to the further development of gasoline engines.

The automotive industry is unevenly distributed across EU countries. EURO 7 standards, which are stricter and more complex than previous standards, may have different impacts on gasoline engine manufacturers depending on their technological readiness and capacity to invest in new technology. Some manufacturers, especially those already investing in green technologies and renewable energy sources, will be better prepared for the EURO 7 standards. However, smaller manufacturers or those already facing economic challenges may have more difficulty adapting to these new standards. This could lead to a situation where only certain countries and manufacturers can meet EURO 7 standards, while others struggle with adaptation and survival. (CanGO, 2023) The potential shutdown of manufacturers

could affect the overall state and stability of the affected country.

One of the risks for society is the variability in the cost of gasoline. The fuel price fluctuates depending on the price of oil on the market. However, it must be noted that the state also participates in the gasoline price through taxes in the broadest sense. For example, in Serbia, the retail price of gasoline is burdened by an energy tax (excise duty of about 0.53 euros per liter), value-added tax (VAT) of 20%, and local governments may also have additional taxes that contribute to the overall fuel price. The refinery price of gasoline in this case represents 43.4% of the retail price. (Nova.rs, 2024). This shows that the state has the tools to maintain the price of gasoline stable if it desires.

3.3.2 Electric Drive

Electric cars have become a reality and a common sight on the streets. That would not have been possible without economic incentives from states to support electric car purchases. Electric cars are often significantly more expensive than gasoline vehicles. Due to the spread of ideas about the need to switch to green technologies, various countries have introduced different solutions. Some examples are:

- *Norway* has VAT exemption (25%) for cars priced up to 500,000 Norwegian kroner (about 44,000 euros). For more expensive vehicles, the buyer pays VAT on the price difference. (Partridge, 2024)
- *Denmark*: Tax relief for electric vehicles will be also in effect in 2025. Municipalities also introduce zero-emission zones (Partridge, 2024).
- *Belgium*: Regional bonuses for registering electric vehicles that cost less than 40,000 euros (Partridge, 2024).
- *Austria*: Complete VAT exemption for vehicles up to 40,000 euros and additional bonuses for the new vehicle purchase (n.d., 2024).
- *Croatia*: Owners of purely electric vehicles are exempt from paying the special pollution tax. They pay other taxes. When purchasing an electric vehicle, they receive a subsidy of 9,000 euros, and for a plug-in hybrid, 5,000 euros. The car must cost less than 50,000 euros, and the owner cannot sell it for at least two years. (n.d., 2024)

- *Serbia*: Subsidies up to 5,000 euros for electric cars purchase with the announcements that authorities will introduce other forms of stimulation. (n.d., 2024)

Martins, Lepine, & Corbett (2024) studied the effectiveness of these incentives. They found that purchase incentives, i.e., direct subsidies or discounts that lower the vehicle price at the time of purchase, motivate people to buy electric vehicles. Another type is ownership incentives, which refer to benefits vehicle owners receive after purchase. These benefits include lower registration fees, free parking, or reduced tolls, but these alone are inadequate to increase the number of electric vehicle registrations to a greater extent.

However, the question is whether these incentives are justified. Why should the state pay anyone to buy an expensive electric car? That way, a state takes money from those who might have old cars or none, and allocates funds to small, privileged groups. The appearance of one new “green” car will not automatically remove an old car from the street. Investing money in public city transportation would be a much more favorable solution. Also, experience has shown that upon the cessation of financial incentives, the number of newly registered electric vehicles plummets because cars become too expensive for buyers. That proves examples from Germany, Sweden, Ireland, and the Netherlands (Partridge, 2024). Finally, if the goal was to reduce environmental pollution, it would have been more beneficial for governments to help buy back registered old cars and remove them from the streets. Otherwise, money was spent, and the polluters remained on the streets.

We also must note that states generate significant revenue from fuel sales. At the beginning of the promotion of electric vehicles, many provided chargers for free vehicle charging. It is easy to understand that this is not sustainable. Currently, in Germany, the price for charging at charging stations can be around 0.64 euros per kWh for fast charging (DC), while for the households, it is about 0.40 euros per kWh. That means, electricity for charging at stations is approximately 1.6 times more expensive than household pay. One of the risks for society is the possible use of household electricity for vehicle charging. In this case, the

state loses revenue, which in the example of Germany, with the current charging price at stations and VAT of 19%, for 15kWh consumed amounts to 1.824€. In the case of a gasoline car with a consumption of 5.4 liters per 100 km and a tax of 0.45 € per liter, the state takes 2.42 €. Even if it charges all drivers the highest price for consumed energy, the state will lose 0.596 € per 100 km traveled by the car or 23% of fuel sales revenue. A particular challenge will be to ensure that all drivers pay full price for electricity.

Another problem that may arise during electric vehicle use is the average age of vehicles in different countries. In Luxembourg, it is 7.6 years, and in Greece and Estonia, 17 years. In Germany, the average age of cars is 9.5 years. (acea, 2023) Modern batteries for electric vehicles have an average lifespan of 8 to 10 years, which means that electric vehicle owners are at risk of needing to replace the battery after the eighth year of use. For the state, there will be an increased need for battery recycling, which can be expensive. Recycling Li-ion batteries is currently economically inefficient, mainly due to the high energy and costs associated with the process. However, a significant reason for recycling is the extraction of rare metals such as lithium, cobalt, and nickel, which are environmentally and economically valuable (Tawonezvi, Nomnqa, Petrik, & Bladergroen, 2023)

Recycling is crucial for sustainability because it reduces the need for new raw materials and decreases negative environmental impacts. However, one should not overlook the energy required for recycling. With technological advancements, the economics of recycling may improve in the future.

3.3.3 Hybrid Drive

From an economic point of view, the operation of hybrid vehicles requires infrastructure for fuel supply and maintenance of hybrid vehicles. Such infrastructure already exists, so such risks are minimal if the fuel supply is stable. Just as it has adopted the best characteristics of gasoline and electric drives, hybrid drives also carry the risks associated with them. Additionally, hybrid drives, like gasoline engines, face the risk of sales bans, which can have far-reaching negative consequences.

3.3.4 Hydrogen Drive

It is essential to conduct detailed risk analyses to ensure safety in all stages of hydrogen production, storage, transport, and use. These analyses help identify potential hazards, assess the likelihood and consequences of accidents, and implement preventive and protective measures. For example, a Hazard and Operability (HAZOP) analysis can identify hazardous scenarios and evaluate the effectiveness of safety barriers.

Hydrogen poses several physical hazards, including high pressure, which risks explosion or tank rupture during storage and transport, and low temperature, which can cause severe burns or frostbite when hydrogen is in liquid form. Hydrogen leaks are dangerous as the gas can accumulate in confined spaces, increasing the risk of ignition and explosion. Hydrogen's high diffusivity means it spreads quickly through various materials and spaces, potentially leading to accumulation in confined areas where it may ignite.

The chemical reaction hazards of hydrogen include its:

- High explosiveness when mixed with air or oxygen. Hydrogen is highly explosive and can pose a risk in the event of a traffic accident, making safety a significant concern.
- flammability, and
- reactivity with various chemical substances such as halogens and oxidizers. Hydrogen can react with metals to form metal hydrides, which are very reactive. It can also penetrate many materials, leading to chemical reactions that degrade them, a process known as hydrogen embrittlement. A specific form of this is the high-temperature hydrogen attack (HTHA), which occurs when hydrogen at high temperatures reacts with carbon in steel, forming methane and weakening the structure (Ali, Ul-Hamid, Alhems, & Saeed, 2020).

Using hydrogen to power vehicles offers numerous advantages but also brings certain risks and dangers for users and the broader community. Developing a refueling infrastructure, which can be costly and time-consuming, is essential for making hydrogen widely accepted as a fuel. Internal combustion engines can use any hydrogen without significant risks. That is not the case with fuel cells. Suppliers must provide pure

hydrogen for fuel cells, as even electrolytic hydrogen can be contaminated during production or storage, negatively impacting fuel cell performance.

Although hydrogen as a fuel produces only water as a byproduct, it must come from renewable energy sources or methods that minimize CO₂ emissions to be environmentally friendly. The production, storage, and transport of hydrogen can be more expensive than with conventional fuels. If governments aim to promote hydrogen as a fuel for motor vehicles, they must reduce these costs. That involves technological advancements, policy support, and economic incentives to make hydrogen a viable and competitive option in the energy market.

Recognizing these hazards is essential for the safe handling, storage, and transportation of hydrogen. Addressing and mitigating these risks is vital for the broad acceptance of hydrogen as a sustainable energy source for vehicles. This requires a collaborative effort in research, development, and implementation of safety protocols to ensure that the advantages of hydrogen can be fully realized without compromising safety and reliability.

4 CONCLUSIONS

Modern motor vehicles currently use various types and sizes of power units. However, the number of engine manufacturers has decreased due to the introduction of increasingly stringent environmental pollution measures compared to the time before these standards. Many vehicle manufacturers collaborate or use the same engines in different body styles. The structure of vehicle drives varies depending on the region, technological opportunities, and political and economic factors. According to estimates on the shares of different types of power units:

1. In most parts of the world, gasoline and diesel engines are still dominant due to existing infrastructure and low costs. It is estimated that they make up about 85-90% of all vehicles.
2. LPG, CNG, and methanol as fuels are less present but are becoming increasingly popular due to their environmental advantages. They are used in gasoline engines, and their total

share within internal combustion engines is around 10%, with a tendency to grow.

3. The share of electric vehicles (BEV) is increasing, especially in developed countries. It is estimated they make up about 5-10% of all vehicles.
4. Hybrid gasoline-electric vehicles (HEV) have a share of about 5-10%.
5. Hydrogen-powered vehicles (FCEV), whether using internal combustion engines or fuel cells, are rare and make up a negligible part of the market, but their number is growing due to the need for cleaner drives. They are currently most present in Japan and South Korea.

We expect that as technologies and infrastructure develop, the share of electric- and hydrogen-powered vehicles will continue to increase.

Each of the applied technologies has its advantages and disadvantages. Internal combustion engines already have a fully developed infrastructure. That is not the case for electric and hydrogen drives. Significant research and investments are needed. The transition to more environmentally friendly options such as electric and hydrogen cars can significantly reduce pollution and contribute to sustainable development, but this is only valid if success is achieved in obtaining electricity from renewable energy sources. Additionally, focusing on just one pollutant component is insufficient. It's essential to consider the entire process from the environmental impact of mining to the consequences of vehicle use. Therefore, it is necessary to encourage research and development of new technologies to reduce the ecological footprint of transport.

Many current claims and predictions of green technologies depend on technological advancements, economies of scale, and changes in political and economic policies. In summary:

- The environmental risks for all types of propulsion are relatively evident. Economic risks often rely on expectations and predictions that may vary depending on the current state of technology and market.
- Gasoline propulsion still presents significant environmental and health challenges. It is economically stable and well-established.
- Electric and hybrid propulsion systems have the potential to reduce harmful emissions, but

face challenges related to production, infrastructure, and costs.

- Hydrogen propulsion is a promising option but depends on technological advancements and investments in infrastructure.

To better understand and accurately assess risks and benefits for society, continuous monitoring of developments and research in this area is crucial. Current research is still narrowly segmented, often focusing on solving narrow problems like air pollution in large cities. Successful solutions to these problems do not guarantee the success of the entire endeavor, as the problem often shifts from one place to another. All technical solutions have a limited scope.

Significant changes in the organization of transportation and the use of vehicles are necessary. The energy consumption of an 18-meter bus, which can transport 150 to 200 passengers at once (Ebusco, 2024), is 1.65 to 1.84 kWh per kilometer (Sustainable BUS, 2023). In the case of the Renault ZOE analyzed here, the consumption is 0.15 kWh/km, which means that the observed bus uses the same energy as 11 ZOE cars. In small passenger cars, more than two people are rarely transported, which would mean that these cars transport a maximum of 44, but realistically less than 22 people. More importantly, the bus continues with another journey while the car remains parked, unused. In addition, eleven cars need parking spaces, which is very expensive in cities. According to our analyses from this study, electric vehicles have traveled an average of 2,000 to 9,000 km annually, which is extremely low compared to their planned lifespan. That means

they were mostly used for short distances. Research shows that an average vehicle spends about 95% of its time parked and only about 5% of the time in motion. That highlights the underutilization of the vehicle fleet. If we look at just cars, using a vehicle 50% of the time would mean the total number of cars could be ten times smaller without compromising the number of passengers transported. The number of cars could be reduced by another 20 to 50 times if buses of different sizes were used instead of cars for transportation.

That would not only reduce harmful exhaust emissions but also reduce all pollution from mining to vehicle exploitation. Additionally in large cities, there would be no need for millions of parking spaces, streets would be less congested, and traffic would flow smoothly. Current production capacities would be sufficient to meet all needs, including transportation. Vehicle use could be more efficient and renewed with resources.

5 RECOMMENDATIONS

Based on this analysis, the sharing economy and the reorganization of public city transportation are the only solutions to city traffic problems. Given the current level of technological development, electric buses are most suitable for longer distances. For specific individual rides, rental car services are the most favorable option.

States should not subsidize the purchase of new electric cars. It would be more useful to help buy back registered old cars and remove them from the streets.

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