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Post-COVID-19 Electric Vehicle Market in Poland: Economic-Based Determinants

Keywords: automotive industry; electric vehicles; electrification of transportation; car market; Poland

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Abstract

Theoretical background: The theory of rational consumer choice significantly impacts the shape of the contemporary car market, which constitutes an essential part of the automotive industry and the national economy and has a considerable influence on the behavior of individuals. In the context of the car market, consumers' decision-making process is subject to several factors, particularly in light of the EU's initiative to transition the automotive industry towards zero-emission solutions. Furthermore, this implies potential changes in the degree of impact on the course of transformation, adoption rate, and economic growth through network effects. Recent years have witnessed changes in various critical factors, alongside the emergence of new factors, which could significantly impact the competitiveness of electric vehicles in relation to internal combustion vehicles.
Purpose of the article: The article aims to examine the current condition of the Polish car market in the post-COVID-19 period with particular emphasis on the electric vehicle market and indicate its present shape in comparison to the market of conventional vehicles from the supply perspective. Also, it attempts to identify and define the most critical factors that influenced the development of the market and their role in the coming years. Identifying and categorizing the most critical factors will allow us to indicate the current weaknesses of the zero-emission vehicle market. This may allow for more efficient identification and solving of problems standing in the way of its development.

Research methods: In order to realize the goals of the research, several methods were used: a critical analysis of the literature on the subject; a quantitative analysis of statistical data was used along with qualitative research to examine the factors that impacted the car market in Poland. As a result, a network of categories describing the associations between factors and their effects on the researched topic was identified and studied.
Main findings: Examination of Poland's electric vehicle market reveals a complex interplay of variables across market. The identified combined factors impede mass adoption of battery electric vehicles, resulting in dynamic yet relatively insignificant annual percentage changes in market growth within the overall passenger vehicle market. The problems focus on governmental, economic and social factors, but also on very important technological and ecological factors, questioning in some cases the current form of electromobility on the Polish market.

Introduction

The automotive industry constitutes a pivotal economic sector within the European Union, underpinning a host of ancillary industries and serving as an economic cornerstone for several member states, including Poland. Emanating from its extensive network effects, the industry's influence transcends its immediate sphere, substantially affecting macroeconomic indicators such as GDP, employment rates, and R&D investments.

From a macroeconomic perspective, the automotive sector's contribution to the aggregate value of goods and services within the EU is non-trivial, accounting for about 7–8% of the European Union's GDP in 2021, according to estimates from both the European Commission (2022) and (ACEA, 2022b) The sector is equally salient in its capacity for job creation. In Poland, for instance, it directly employed approximately 224,496 individuals, comprising 7.7% of manufacturing employment in 2019, albeit slightly below the EU average of 8.5% (ACEA, 2022a). The automotive industry is the largest R&D sector in the European Union, and in 2020 it had a 33.6% share in research and development investments (Grassano et al., 2021). In addition, a role in exports, foreign direct investments, and participation in technology transfer should be underlined. Among the benefits for the state treasury, attention should also be paid to the income generated from taxes, customs, and excise duties. Due to the network effects within the automotive industry, its contributions to the GDP, employment, R&D, exports, and tax revenue have far-reaching consequences beyond the industry itself, affecting various sectors and stakeholders within the economy.

Between 2015 and 2021, there was a significant uptick in the registration of electric vehicles in key European countries. Germany, as a market leader within the EU, showcased the most impressive growth in demand for battery electric vehicles, especially in the years 2020–2021. France and Italy also displayed positive trends. The Netherlands, after a surge in 2019, experienced some stabilization, while Sweden maintained a steady increase in registrations. Poland has been slower in transitioning towards electric vehicles, falling behind these trends and to rival with leaders. This overarching growth in electric vehicle registrations across Europe indicates a rising

interest in eco-friendly transportation alternatives, especially post the COVID-19 pandemic (Eurostat, 2023b). Distinct growth rates separate countries actively promoting electric vehicles, with Poland being an example of slower progress. Challenges like rising prices and new emission standards further complicate this landscape. Any mismanagement could result in significant economic implications.

Considering rational choice theory, the automotive sector provides insights into microeconomic decisions by businesses and households. While companies, especially SMEs, rely on this sector for optimal operations, households tend to seek cost-effective choices in the secondary market. Despite its importance, the sector faces vulnerabilities, emphasized by challenges like the COVID-19 pandemic and disruptions in the semiconductor sector, highlighting the need for a sustainable and resilient industry.

This study addresses the shift to zero-emission vehicles in Europe, emphasizing Poland. Aiming to highlight factors influencing the Polish market's transition, especially concerning battery electric vehicles. Existing research post-2017 scarcely addresses Poland's automotive market, leaving gaps in understanding the evolution of electromobility.

In discussions on sustainable transport, the category of "electric vehicles" (EVs) comprises "battery electric vehicles" (BEVs) and "fuel cell electric vehicles" (FCEVs). Poland has notably leaned towards BEVs due to the limited presence of FCEVs and the scarcity of hydrogen refueling infrastructure. Jałowiec et al. (2022) emphasize that despite potential uses of hydrogen in sectors like industry and transport, the country lags behind others, notably Germany, in green hydrogen infrastructure and capacity. This underscores the current irrelevance of FCEVs in Poland, validating a stronger focus on BEVs.

The main aim of the study is to examine what factors influence the current state of BEV adaptation on the Polish market from an economic perspective. To encapsulate, while the automotive sector remains instrumental for Polish economy, it stands at a crossroads laden with challenges, especially in its quest towards sustainable mobility. By employing a comprehensive analytical approach, this study aims to explicate the nuances of these challenges, with a particular focus on Poland's transition towards zero-emission vehicles.

Literature review

Changes on the electric vehicle market in Poland are significant due to events like COVID-19 pandemic, the war in Ukraine and semiconductor supply issues. These issues have worsened existing challenges such as energy and fuel crisis and supply chain disruptions for European auto plants. Comprehensive research on car market, industry, and BEV penetration in Poland is essential to grasp underlying causality and economic implications. Tracking progress and transition potential from internal combustion engine vehicles (ICEVs) to BEVs in the Polish car sector is also critical.

Stojczew (2021) explores COVID-19's impact on Poland's auto industry, revealing its sensitivity to crises like economic slowdown, Brexit, and emission standards. The sector shifts towards pricier but profitable vehicles, like SUVs, amid scarce affordable electric cars. Micek et al. (2021) study on Polish automotive manufacturers indirectly offers valuable context by underscoring key themes like technological competencies and government policies, which help identify directions for research on factors that are potentially related and important from market perspective. Drożdż et al. (2020) identify barriers to enterprises linked to infrastructure construction. Burchart-Korol et al. (2020) underline Poland's reliance on external fuel providers, suggesting a challenging market for BEVs and less infrastructure than neighbors. Majchrzak et al. (2021) assessed the economic and environmental factors influencing electric car adoption in Poland, emphasizing the need for financial incentives and improved charging infrastructure to promote electromobility transition.

Sendek-Matysiak and Łosiewicz (2021) find Poland's electric car incentive system ineffective due to low subsidies and high vehicle costs. They propose enhancements like increased purchase funding, tax relief, and public charging station support, particularly for fast chargers. Sobiech-Grabka et al. (2022) emphasize long-term campaigns and reduced Russian fuel dependence in consumer behavior research. Bienias et al. (2020) reveal a preference for the secondary market, implying low demand for new battery and hybrid vehicles. Surveys show positive consumer views on electric vehicles and subsidy impact on buying decisions, suggesting ineffective Polish solutions. Zioło (2022) examines company behavior in industrial sectors, noting pandemic, political challenges, and semiconductor market impacts. Though not auto-focused, his work considers the sector's role in shaping consumer preferences. Hoffmann (2023) studies Poland's electromobility state, highlighting shared mobility growth but electric vehicle cost and charging infrastructure issues. He stresses addressing these problems urgently.

In examining ecological elements, Zimakowska-Laskowska and Laskowski (2022) explore CO_2 and other emissions from ICEVs and BEVs, considering engine type, electricity consumption, and energy sources. They find that Poland's varied energy mix causes mixed BEV emission results. Even with fossil fuel dependence, BEVs could cut CO_2 by 24%, but 2019's fuel blend might raise emissions by 14%. Some pollutants decrease, while NOx and SOx increase. Adamczyk et al. (2023) contend that solely promoting EVs without updating energy infrastructure will not yield desired environmental benefits due to Poland's coal reliance. They stress the need for upgrades amid geopolitical energy price shifts and potential public transport growth from economic contexts. Martin et al. (2022) examine vehicular photovoltaic roofs, suggesting that electric vehicle owners relying on solar power could increase coverage from 15% to 56%, emphasizing transportation decarbonization potential.

An intriguing source informing about potential significant factors for consumers is found in the article where Stachowicz (2023) analyses consumer considerations in the social dimension, examining future cars through the lens of the "Californian

ideology", a belief in digital tech, algorithms, and economic liberalism. While technology promises progress, it also ushers in challenges like surveillance capitalism. The evolving car transforms from a freedom symbol to a "Software as a Service" entity, where software shapes functionality and users trade off some privacy. Stachowicz also sheds light on latent inequalities in autonomous driving tech. He ultimately portrays the car as a media device, underscoring the expanding digital influence on automotive culture and its broader cultural implications.

Discussions on electric vehicle fires warrant examining various viewpoints. Dorsz and Lewandowski (2022) link fire risks to BEVs, citing rising incidents and predicting surges. They analyze fire impacts on evacuation, rescue, and structures using Computational Fluid Dynamics (CFD). Brzezinska and Bryant (2022) detail battery fires in electric vehicles, addressing safety concerns and protection strategies. Acknowledging the lack of full-scale EV fire tests, they recommend accepted heat release rates for car park design. Water remains crucial to extinguishing EV fires despite access issues and re-ignition risks. Sun et al. (2020) focus on BEV battery fire hazards, highlighting lithium-ion battery risks and water as the main solution. Sturm et al. (2022) investigate EV safety in tunnels, emphasizing unique Li-Ion battery fire characteristics. Austrian research reveals higher heat release in EV fires compared to traditional vehicles but verifies the adequacy of tunnel safety standards as EV presence increases.

The literature review highlights the complex and dynamic nature of Poland's BEV market, shaped by various factors. Studies have explored car market trends, technological competencies, infrastructure barriers, consumer preferences, environmental impacts, and safety concerns related to the transition from ICEVs to BEVs.

Research methods

In light of the extant but nascent body of literature, particularly under the transformative conditions of the current era, the investigation undertaken in this paper posits the following research questions:

RQ1. What variables serve as pivotal drivers in the evolution of Poland's zero-emission vehicle market?

RQ2. To what degree has the market penetration of BEVs materialized in the Polish automotive sector, and what are its attendant economic ramifications?

Corresponding to these research questions, the study advances the following hypothesis:

H1. The growth of the battery electric vehicle market in Poland is negatively influenced by economically intertwined factors related to the financial viability of owning a BEV.

To substantiate hypothesis and research questions empirically, the study employs a qualitative methodology, incorporating an eclectic blend of statistical and economic data. The analytical scope spans from 2017 to the most recent data avail-

able, capturing market dynamics both antecedent and subsequent to the onset of the COVID-19 pandemic. Employed as a methodological tool, the Ishikawa diagram adeptly facilitates the systematic examination of multifaceted determinants. Its structured categorization enables a granular analysis of variables across multiple dimensions, thereby enhancing empirical rigor. Furthermore, the diagram's visual representation serves as an efficient tool for identifying causal pathways and policy levers. Its adaptability to temporal shifts and compatibility with authoritative data sources amplifies its utility, thereby fortifying both the analytical depth and policy relevance of the study.

In order to maintain ethical standards, it is imperative to note that this study was conducted in adherence to the principles of neutrality and impartiality. The topic of electromobility has become a ground for misinformation and biased opinions due to the vested interests of various parties attempting to validate their respective viewpoints. To ensure an objective identification and characterization of the factors at play, must be clearly indicated that the author's empirical experience and personal opinions were disregarded in favor of a comprehensive and meticulous analysis. This approach was taken to avoid duplicating biased content and provide an unbiased assessment of the topic under research.

Data for the study are sourced from credible and trustworthy repositories, such as Statistics Poland, the National Bank of Poland, and Eurostat. Ancillary information is culled from the official portals of the Polish government and the European Commission, as well as from reports disseminated by reputable non-governmental organizations, including the European Automobile Manufacturers Association. Given the qualitative nature of the study, the results are substantiated through methodological triangulation and are not subject to statistical validation.

Among the limitations of the article, it should be noted that there is limited availability of statistical data and potential flaws in using qualitative research. The article, along with its format, is also limited in terms of volume, which may affect the conveyance of certain content.

Results

The European automotive sector has been significantly affected by the dual effects of reduced consumer demand and disruptions in manufacturers supply due to the COVID-19 pandemic, which resulted in many consequences for the car industry. Numerous factors can be listed, such as lockdowns imposed by national governments, disruptions in supply chains (especially transnational ones), and the deterioration of the economic situation resulting in decreased consumer demand. The semiconductor crisis, compounded by COVID-19 and the reliance of many companies on sub-suppliers for these components, led to production stoppages, reduced output, and equipment shortages for numerous carmakers, especially those in Europe.

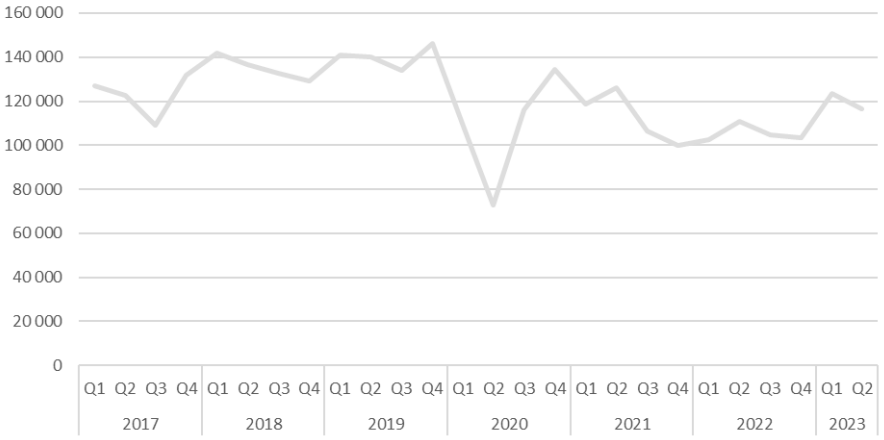

Figure 1. Brand new motor vehicles registered for the first time in Poland (quarterly data in units, 1Q2017–2Q2023)

Source: (Statistics Poland, 2023).

As seen in Figure 1, in the years preceding the COVID-19 pandemic, according to Statistics Poland (2023), 490,651 vehicles were sold in Poland in 2017 and 540,396 in 2018. In 2019, sales amounted to 561,153 vehicles. The year 2020 brought a decrease in sales of approximately 129,000 units compared to the previous year, with a particular decrease in Q1 and Q2. In Q4, however, sales returned to a level similar to previous years (134,423 registrations), surpassing Q4 quarterly sales from 2017–2018 (131,922 and 129,371 registrations, respectively). However, it is unknown whether this is due to increased demand or order shifts (delayed order fulfillment) resulting from delays in previous quarters, e.g. logistical or production problems.

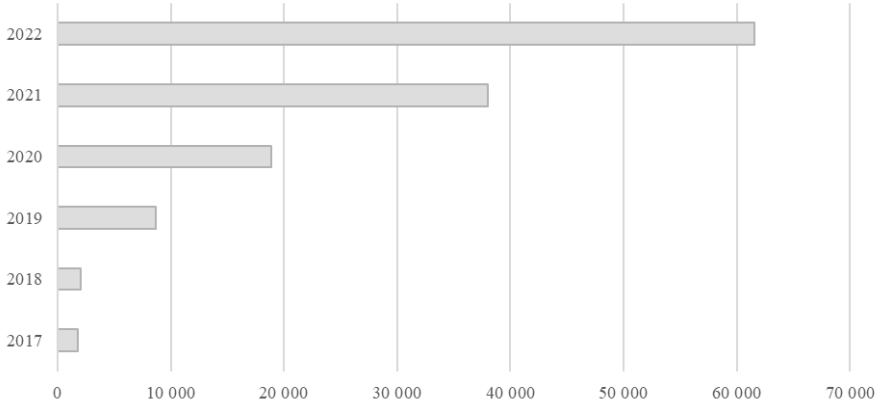

Figure 2. Number of electric passenger vehicles in Poland, 2017–2022

Source: (IBRM Samar et al., 2023).

The year 2021 resulted in a slight annual increase in sales of just 18,437 vehicles. Sales results in the first and second quarters improved y/y, but Q3 and, above all, Q4 resulted in a significant decrease in new vehicle registrations. The data was worrying as Q4 is usually characterized by relatively stable demand for new vehicles. The year 2022 was challenging due to the economic situation in Poland, which was reflected in the sales of new vehicles due to a decrease in demand, especially from enterprises. The registration results for the first three quarters of 2022 suggest that sales of new vehicles will remain at a similar level as in the previous year or will result in a downward trend.

In the case of electric vehicles charged from the socket (including both plug-in hybrid and battery electric vehicles), there is an undisputed upward trend, but the total volume of registrations of this type of vehicle remains marginal compared to the total number. In 2017–2018, 1,770 and 2,033 (+263 y/y) EVs were registered in Poland, as indicated by the data in Figure 2. In 2019, the increase in sales was 425%, and in the following years, 219% (2020), 201% (2021), and 162% (2022). The volume remains low compared to conventional vehicles; however, the growing scale and the continuing trend prove good forecasts for the sale of plug-in hybrid electric vehicles (PHEVs) and BEVs (IBRM Samar et al., 2023).

Subtracting PHEVs from the EV pool in Figure 2 for the registration of BEVs, only 7,092 vehicles were registered in 2021 and 11,293 vehicles in 2022, representing an increase of 159% y/y (Polish Automotive Industry Association, 2023). Based on the total number of new vehicle registrations in 2021 provided by Statistics Poland, it can be estimated that BEVs accounted for about 2.5%.

Factors for developing the electric car market can be identified in several areas. Due to the purpose and focus of work, the most critical areas have been identified as depicted in Figure 3: governmental, economic, social, technological, and ecological. The Ishikawa diagram describing the current state of the electric vehicle market in Poland focuses on these categories and their causes.

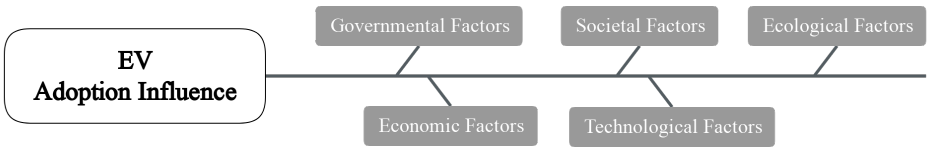

Figure 3. Framework factors influencing the current situation of the electric car market in Poland

Source: Author's own study.

Governmental factors

The government plays a crucial role in shaping the trajectory of the automotive industry, suggesting its potential to significantly influence the BEVs market's evolution. In European Union countries, the shift toward zero-emission vehicles is often spearheaded by policies at the supranational level, complemented by national government initiatives. A significant challenge for the development of the electric vehicle market in Poland is the excessive fragmentation in terms of entities responsible for implementing various policies and programs aimed at promoting electromobility to stimulate demand. This dispersion of responsibility leads to inefficiency, a lack of transparency, and complicates the decision-making process. Among the involved entities are the Ministry of Climate and Environment, Ministry of Infrastructure, Ministry of Energy, National Fund for Environmental Protection and Water Management (NFOŚiGW), and the Polish Agency for Enterprise Development (PARP). Furthermore, local governments, including various cities and municipalities, are initiating efforts to promote electromobility. It is also noteworthy to mention organizations such as the Polish Association of Alternative Fuels (PSPA) and e-Mobility Association (eMobi). There is a pressing need for improved coordination and integrated actions among these entities to achieve effective and sustainable outcomes for the development of the electric vehicle market in Poland.

In terms of causes from the governmental category, it is necessary to point out the geopolitical situation influencing rising energy carrier prices as a factor, as well as earlier neglect and lack of consistency, alongside the absence of a comprehensive long-term governmental strategy in the energy sector. Efforts towards the development of more ecological nuclear energy were taken too late, and their implementation is a long-term task. The stated number of nuclear power plants is likely to constitute too small a portion within the perspective of the entire energy mix. More research is needed on these issues and their potential impact in the context of electric vehicles.

In the context of Poland, the government has launched specific actions to bolster the growth of electromobility. One such strategic move involves the advancement of EV infrastructure, encompassing charging facilities for plug-in vehicles and FCEVs. The National Fund for Environmental Protection and Water Management earmarked PLN 1.87 billion to foster this development, aiming to establish 17,000 EV charging stations and 20 hydrogen refueling points (Gov.pl, 2021). This fund is split between infrastructure development (PLN 870 million) and grid enhancement (PLN 1 billion) to accommodate the growing demand for chargers. A notable collaboration in this endeavor is with TAURON, which secured PLN 26 million to augment the power grid, integrate renewable energy sources, and support the bus depot in Wrocław (TAURON, 2022).

In a bid to reduce transport-related emissions, the European Commission (2021) approved an allocation of EUR 173 million (PLN 800 million) for Poland under the European Green Deal for the period 2021–2025. This budget encompasses EUR 151 million (PLN 700 million) dedicated to EV charging stations, prioritizing non-urban

regions, and an additional EUR 22 million (PLN 100 million) for hydrogen charging infrastructure. The EU's actions are a contrast to the independent policy of the Polish government, showing the difference in consistent actions regarding supporting activities for the development of electromobility.

Furthermore, the government introduced the "My EV" ("Mój elektryk") program, offering subsidies for electric vehicles, with a focus on BEVs and FCEVs. According to the official website of the Republic of Poland (Gov.pl, 2023), the maximum price of the vehicle to be subsidized was also defined. Three maximum vehicle price limits are set depending on the VAT costs for the applicant. If the taxpayer can legally deduct the entire VAT amount, the limit is PLN 225,000 net and PLN 276,750 gross. If half of the VAT is deducted, the gross price limit drops to PLN 248,205. If it is impossible to deduct VAT, the vehicle price limit is fixed at PLN 225,000. In previous application rounds, the maximum price of the vehicle was lower and amounted to PLN 125,000 gross (Gov.pl, 2023). The limit, especially in the third case, eliminates most cars from subsidies, leaving only the smallest and poorly equipped vehicles to choose from. While the program was initially available for households only, it expanded its reach to enterprises. However, challenges persist, particularly regarding subsidy eligibility criteria. According to official sources, the maximum vehicle price for obtaining a subsidy remains based on the applicant's VAT deduction eligibility, which, especially in certain cases, restricts the range of vehicles available for subsidies (Gov.pl, 2023).

Economic factors

The automotive market in Poland relies on imported passenger cars, predominantly imported from abroad, with a notable emphasis on inflow from the EU. In addition to the significant role of domestic economic factors, the car market is burdened with the influence of external factors due to its internationalization and the impact of globalization of production (global value chain). This affects, among others, the final prices of products sold on the Polish market and their stability. In recent years, several economic factors significantly affect the domestic market of passenger cars, particularly electric cars.

Energy policy and energy management vary between countries of the European Union. Energy structure in the context of electricity production is a problem for countries like Poland, which is more disadvantaged since its energy industry is based on fossil fuels. Plans to build nuclear energy have existed for many years and have been delayed. As a result of the war in Ukraine and the deteriorating economic situation due to the COVID-19 pandemic, the import of energy resources, which essentially were coming from Russia, was disrupted. As a result of the trade factors, there was a need to import from other sources, affecting the availability, price, and delivery time. The government's energy shields, which were based on freezing energy prices for households and, to some extent, enterprises, did not help either. According to the Eurostat (2023a), in 2021, HICP energy prices increased by 114.2 index points. The

year 2022 resulted in a significant deepening of the problems, as depicted in Figure 4, due to the above-mentioned factors and the upward trend to 147.9 index points. From the perspective of the car market, this significantly affects EV operating costs, encouraging households and enterprises to invest in renewable energy sources. Given the fluctuations in energy prices and the evolving energy landscape, consumer rational choice plays a crucial role in driving the adoption of electric vehicles and renewable energy sources, as individuals and businesses weigh the long-term benefits of reduced operating costs and environmental impact against the upfront costs and perceived limitations of such technologies.

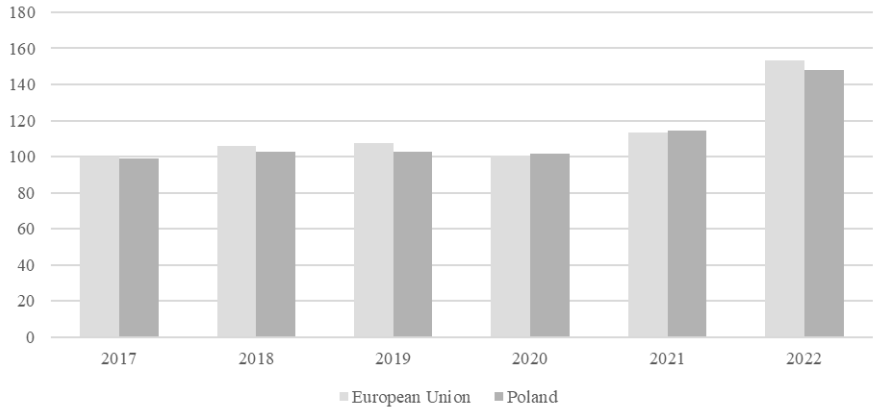

Figure 4. Harmonized indices of consumer prices (HICP) of energy (ENRG) prices in the EU and Poland, 2017–2022 (index points)

Source: (Eurostat, 2023a).

Another crucial factor impacting the vehicle market in Poland is the fluctuation in exchange rates. These rates are pivotal in international trade, influencing the production of goods that often comprise components from various countries. Consequently, they affect the final product's price and indirectly the trade of that product. Exchange rate fluctuations can sway consumer decisions in the vehicle market, especially in the context of more expensive electric vehicles. Both entrepreneurs and households weigh the cost of new vehicles against the residual value of second-hand ones, choosing based on perceived cost-effectiveness.

In the context of the Polish car market, exchange rates for the euro and dollar hold significant weight since both currencies serve as primary invoicing standards. Fluctuations in these rates can affect production costs, including research and development expenses, potentially influencing product prices more in markets with lower purchasing power parity, like Poland compared to Germany or France. The ramifications largely hinge on the specific company, as well as the geography of its production and supply chains. For end consumers, a sharp appreciation in the currency of the exporting country (or conversely, a devaluation of the importing na-

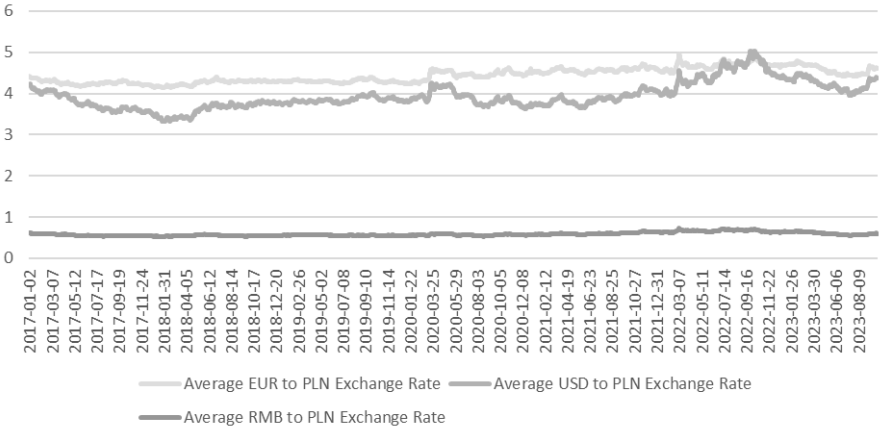

Figure 5. Average exchange rates of EUR, USD, and RMB compared to PLN, 2017–2023

Source: (Money.pl, 2023).

tion's currency) might precipitate a notable spike in product prices. This is contingent on the manufacturer's capacity and inclination to buffer these effects, perhaps by slashing its margins to uphold competitive pricing. With regard to Poland, the PLN experienced depreciation against the EUR and USD starting from 2Q2018 (National Bank of Poland, 2023), as illustrated by the data in Figure 5. This trend was particularly evident against the USD in 2022. The onset of the 2022 war in Ukraine further aggravated the economic landscape, amplifying inflation and eroding the business environment, notably for SMEs. The RMB's exchange rate stability is of interest, potentially becoming a factor that influences the import of electric vehicles from China in the future. Understanding the impact of currency exchange rate fluctuations on the Polish car market is crucial for evaluating the availability and pricing of electric vehicles, emphasizing the need to address these factors to improve market competitiveness and product accessibility, thereby influencing demand.

Since mid-2021, the Polish economy has struggled with high inflation, as demonstrated by Figure 6, which remains one of the highest in the European Union and is higher than in the Eurozone (National Bank of Poland, 2023). This affects the automotive production costs and operating costs of carmakers, along with the purchasing power of consumers. Cars are expensive products, so inflation significantly impacts the increase in the prices of new and used vehicles. The combination of high inflation with the increase of interest rates by the National Bank of Poland has consequences for enterprises due to the higher financing costs. As inflation affects the overall cost of vehicle ownership, consumers may reevaluate their choices based on the changing value proposition, potentially shifting their preferences towards more affordable or cost-effective alternatives in line with the principles of consumer rational choice theory.

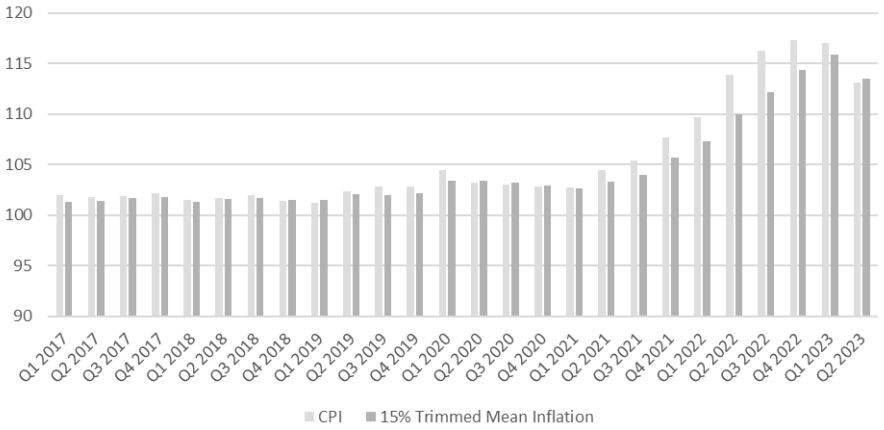

Figure 6. Inflation (CPI and 15% Trimmed Mean) in Poland, 2017–2022 (percentage change)

Source: (National Bank of Poland, 2023).

Societal factors

A significant social factor influencing the adoption of electric vehicles is consumer awareness regarding battery replacement. Many believe that replacing batteries in EVs is often challenging and not cost-effective (CR Survey Research Department, 2022). Some instances make replacement almost unattainable due to a lack of appropriate service infrastructure. For numerous manufacturers, the only option is to replace the battery at an official dealership, reducing consumer choices and compromising market competitiveness. This could elevate prices. Instead of replacing entire battery packs, which might involve changing functioning cells, manufacturers should allow for the replacement of only the faulty cells, reducing costs and having a positive environmental impact. Current practices might deter potential consumers, affecting the vehicle's resale value and influencing other costs, like insurance.

Among the commonly cited drawbacks of BEVs is their range compared to traditional ICEVs (Franke et al., 2012; Pevec et al., 2020). While some new BEVs can travel up to 600 km on a full charge, real-world distances often fall short due to factors such as the European WLTP (Worldwide Harmonized Light Vehicles Test Procedure) standard. These discrepancies in range can cause concerns, especially in regions like Poland where expressway and highway speeds are between 120 and 140 km/h. Moreover, even if consumers do not embark on long journeys, frequent charging of smaller NMC (nickel-manganese-cobalt) batteries can accelerate battery degradation, and to a lesser extent, this is also observed with LFP (lithium-ferrophosphate) batteries.

Safety concerns also loom large. A segment of the public views BEVs as potential fire hazards, possibly due to media coverage of isolated incidents. This fear is multifaceted, encompassing worries about personal safety and the potential loss of

a valuable asset like a car. These perceived risks may also affect insurance premiums and coverage availability for EVs, adding financial concerns to safety worries. External societal pressures, such as parking restrictions specifically targeting BEVs due to their perceived fire risks, further shape consumer attitudes. The role of social media in shaping opinions on BEVs is undeniable. Platforms like X and Facebook have sometimes exaggerated the risks associated with EV fires, potentially skewing public perception. Educational programs and campaigns are vital to counteract this misinformation. While both advocates and critics of BEVs present their cases, the truth is likely more nuanced. Many challenges can be addressed in the future, but they often become subjects of exaggerated media content.

Technological factors

Electric cars necessitate a distinct infrastructure and operate differently from traditional combustion vehicles. A key divergence lies in the method of powering the vehicle, particularly in BEVs, where the on-board battery pack is charged. Numerous BEVs boast batteries exceeding 70 kWh, with some models surpassing 100 kWh in capacity. Currently, BEV passenger vehicles primarily employ two types of lithium-ion cells: NMC cells, predominant in European cars, and LFP batteries, popular in China.

NMC batteries offer high power, energy efficiency, and a balance between battery capacity and weight. However, concerns arise due to production issues (cobalt), safety risks (higher fire risk in case of mechanical damage), and limited lifespan. Recent studies indicate a notable rise in electric vehicle fires, particularly with BEVs experiencing severe consequences. Many reported fires in Poland, while widely publicized, were not directly linked to the ignition of the traction battery but rather to electrical short circuits and other failures common in ICEVs. The primary challenge, excluding extreme cases, revolves around the limited lifespan of NMC batteries, dictated by factors like charging cycles, usage conditions (temperature, deep discharge, regular full charging), and age. These technological and operational challenges significantly impact electromobility in terms of consumer perspective and ecological considerations. Conversely, alternative LFP batteries provide an extended lifespan and enhanced safety with trade-offs in capacity, weight, and lower low-temperature resistance.

For BEVs to compete effectively, the country's public charging infrastructure should realistically deliver a minimum of 150 kW charging power currently, with a forward-looking goal to incrementally increase it to at least 300 kW by 2030–2035. Infrastructure development should not only prioritize charging speed but also emphasize safety standards, particularly considering recent research highlighting fire risks associated with BEVs. Existing chargers in Poland rarely exceed 50 kW, and even a 100 kW charger is considered relatively slow. Assuming an 800-volt NMC BEV with charging capability of 250–300 kW and access to a suitable charger, an 80% charge could be achieved in 20–30 minutes, however, posing a challenge to

infrastructure and vehicles. However, this poses a challenge to both infrastructure and vehicles (Aghabali et al., 2021; Tomaszewska et al., 2019).

Establishing a network of high-power charging stations, each offering a minimum of 150 kW, necessitates a corresponding national infrastructure. This stands as a critical factor hindering the development of electromobility in Poland. The underdeveloped domestic infrastructure fails to meet the demands of superchargers, impacting both charging density and the low power provided by many chargers (often limited to 50 or 100 kW, even divided among multiple ports). The challenge lies in the potential for electric car numbers to outpace charger installations, creating imbalances. Demand can stimulate private charging infrastructure development, reliant on the domestic energy sector, but limited infrastructure adversely affects electric vehicle sales. Recognizing consumer rational choices and network effects, charging infrastructure development is pivotal for widespread electric vehicle adoption.

As the charging station network expands, consumer choices may pivot towards BEVs due to increased convenience and reduced range anxiety. Additionally, network effects come into play, creating a positive feedback loop that accelerates BEVs adoption and infrastructure development. These trends are also observable in Poland, where the growing charging infrastructure is similarly enhancing convenience and alleviating range anxiety for consumers. Beyond convenience and reduced range anxiety, consumer decisions may also be influenced by technology-driven socio-cultural implications, such as privacy concerns and the broader role of vehicles in a digitized society.

Ecological factors

An essential environmental consideration is the recycling of worn-out and damaged BEVs and their batteries or electric motors. Unlike traditional combustion engine counterparts, processing EVs is more intricate, resulting in increased costs and complications (European Parliament, 2022). The European Union is actively developing legal regulations pertaining to various batteries including those used in electric vehicles, with a focus on carbon footprint and raw materials like lithium, cobalt, nickel, and manganese. If well-designed and enforceable, these regulations could address significant objections to electromobility. Discussions also touch on battery replaceability in EVs, yet refurbishing battery packs, specifically the replacement of damaged cells, remains an understated aspect.

However, overcoming barriers and negative factors affecting the European electric vehicle market, particularly in Poland, requires addressing a crucial determinant: the source of electricity used to charge EVs. Poland currently relies heavily on fossil fuels for energy generation, resulting in a high CO_2 impact for vehicles charged through the national power grid (Zimakowska-Laskowska & Laskowski, 2022). Studies indicate that the introduction of BEVs in Poland may not be the pro-environmental solution it appears to be, due to the nation's dependence on a primarily

fossil fuel-based energy mix, which influences the potential decisions of consumers guided by ecology and sustainability. While some vehicles use renewable sources, the majority rely on the non-renewable national power grid, undermining the environmental benefits of electric vehicles. Until the integration of renewable energy sources and the reduction of fossil fuel dependency, the Polish electric vehicle market cannot be considered ecologically sound. Conclusively, this argument presents justification for governmental bodies and consumers alike to abstain from endorsing or purchasing electric vehicles.

An avenue to alleviate the impact of Poland's conventional energy industry is the adoption of available technological solutions. For instance, installing photovoltaic panels on the roofs of both BEVs and PHEVs can generate small amounts of energy to offset the negative impact of conventional energy sources (Martin et al., 2022). Slow charging with low current should not accelerate battery degradation (Zimakowska-Laskowska & Laskowski, 2022). However, transitioning to BEVs might not unequivocally reduce CO_2 emissions; an analysis shows a nuanced landscape, with certain emissions decreasing while others increase. Incorporating available technological solutions, such as photovoltaic panels on vehicle roofs, can contribute to offsetting emissions. Some manufacturers, like Hyundai and Toyota, already offer solutions that harness generated energy for auxiliary systems when the vehicle is stationary or offset battery discharge. This approach complements stationary infrastructure solutions like photovoltaic panels and wind turbines, eliminating the need for additional infrastructure and reducing consumer exclusion.

Discussion

The study results reveal numerous significant factors within selected categories that influence the electric vehicle market in Poland. In many cases, these factors are comprehensive and multifaceted, depending on the approach and analysis. Identified crucial factors that are pivotal for the average consumer, yet may be perceived differently by early adopters due to their greater inclination towards accepting risk and experimentation. A good example of this are the factors related to infrastructure and energy. Moving forward with the interpretation of the results, we thereby address the questions posed in earlier research assumptions.

The Polish BEV market's adopting trends are influenced by five interconnected factors, namely governmental, economic, societal, technological, and ecological. Governmental factors consist of four components shaping the market dynamics; skepticism surrounds existing government initiatives for sector transformation. Educational campaigns addressing misinformation from both pro-BEV and anti-BEV factions are crucial to counteract this skepticism. Inefficient subsidies on electric car purchases, due to numerous exclusions and consumer challenges, hinder market growth. Infrastructure development shows positive effects with new charging stations;

however, lack of government action to improve density and charger absence in some regions remain issues. Lastly, government policy towards the energy sector increases the country's dependency on external suppliers, affecting consumer market risks.

Economic factors are primarily driven by inflation resulting in price increases for new vehicles, a general increase in vehicle operating costs, and a decline in consumer purchasing power. Exchange rates show periodic depreciation of the Polish zloty affecting vehicle imports and prices set by importers. The cost of electricity, which is low but steadily rising, significantly influences BEV operating costs, impacting investment profitability, especially for businesses.

Societal factors include safety apprehension with BEVs perceived as potential fire hazards, impacting consumer decisions due to concerns about purchase loss, home damage, and insurance stress. Limited options for repairing and replacing electric vehicle batteries exacerbate consumer concerns and impede the growth of specialized BEV service firms. Range anxiety influences consumer choices but can be alleviated through research and technology advancements.

Technological factors play a pivotal role in shaping the market, with two primary determinants: battery dominance (NMC) affecting repair costs and fire risk compared to LFP batteries, and energy infrastructure's condition and efficiency impacting charger availability and power restrictions. To enhance BEV competitiveness against ICEVs, an efficient charger network is required to reduce charging times.

Ecological factors consist of two main reasons affecting the market in Poland: the energy mix creating a kind of ecological paradox, with CO_2 emissions from vehicles charged from the power grid and insufficient recycling processes for end-of-life electric vehicles. These ecological aspects need improvement to ensure a sustainable BEV market in Poland.

In summary, addressing governmental, economic, societal, technological, and ecological factors is vital for the Polish BEV market's sustainable growth. Each of these components interacts with and influences one another, necessitating a comprehensive understanding and approach when analyzing adopting trends.

Moving on to the final assessment of the hypothesis:

H1. The growth of the battery electric vehicle market in Poland is negatively influenced by economically intertwined factors related to the financial viability of owning a BEV.

Upon examining of the collected data, the hypothesis is validated. The growth of the BEV market in Poland is indeed hindered by a complex mix of interconnected factors whose direct or indirect impact is of an economic nature. Quantitative data indicate relatively insignificant annual percentage changes in market growth within the overall passenger vehicle market. Qualitative results based on a multidimensional analysis of variables indicate the impact of factors identified in this study, such as government programs and subsidies, economic factors, economic social factors, technological and ecological factors. These results are consistent with the framework recognized by rational consumer choice theory and network effects.

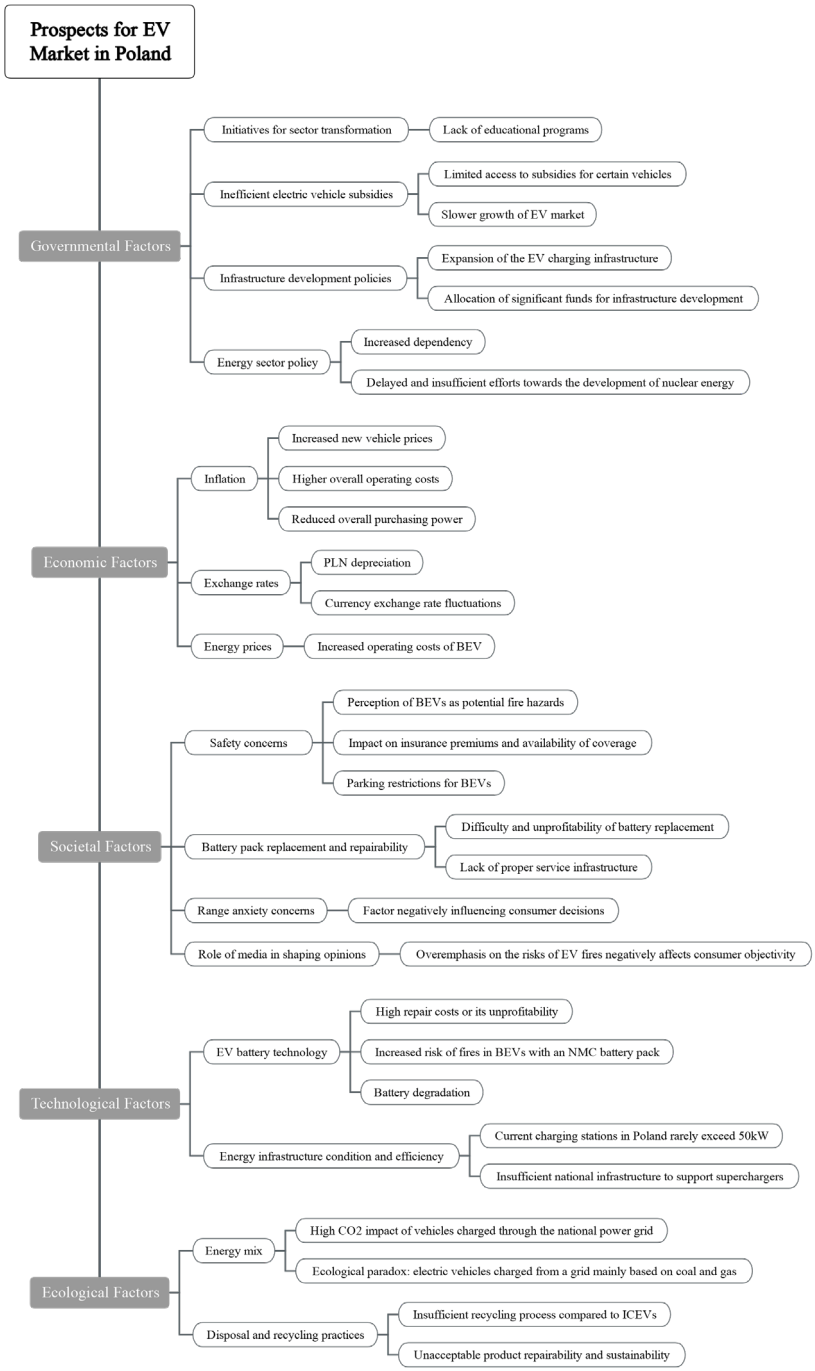

Figure 7. Cause-and-effect diagram for the prospects of the electric vehicle market in Poland

Source: Author's own study based on research results.

Conclusions

In conclusion, as seen in Figure 7, the examination of the post-COVID-19 electric vehicle market in Poland has uncovered a complex interplay of factors across various categories, each exerting its influence on market dynamics. While the discussions elucidated the nuanced landscape, the conclusions distill the key insights and their broader implications.

1. Governmental factors: The effectiveness of governmental initiatives remains a point of contention, particularly in the transformation of the sector. Educational campaigns are imperative to counteract misinformation. Subsidies, though present, face challenges in execution, hindering market development. Infrastructure improvements, while commendable, grapple with regional disparities. Government energy policies and delayed nuclear power plant construction pose risks to market stability.

2. Economic factors: Inflation emerges as a formidable challenge, impacting vehicle costs and consumer purchasing power. Exchange rate fluctuations affect vehicle imports, influencing showroom prices. The cost of electricity, a critical consideration, significantly shapes the operating costs of electric vehicles, impacting their overall profitability.

3. Societal factors: Safety concerns, battery repairability, range anxiety, and media influence collectively shape consumer perceptions. Addressing safety apprehensions, improving battery repair options, and mitigating range anxiety are pivotal for fostering broader acceptance. Media influence, especially in the context of fire-related incidents, necessitates a balanced approach to information dissemination.

4. Technological factors: Battery technology, with a prevalence of NMC batteries, introduces economic and social implications, notably in repair costs and fire risks. Energy infrastructure limitations underscore the need for an efficient charging network to enhance the competitiveness of electric vehicles against traditional counterparts.

5. Ecological factors: The energy mix paradox questions the environmental benefits of electric vehicles if powered by non-renewable sources. Recycling and disposal challenges highlight the need for advanced processes. The ecological dimension of electric vehicles extends beyond their operation, emphasizing the importance of a holistic approach.

Assessment of Hypothesis:

H1: The hypothesis holds true, as various analyzed challenges hinder mass adoption of BEVs over ICEVs in Poland, making BEV investment less attractive for regular consumers and businesses compared to early adopters, despite ongoing infrastructure development efforts and dynamic but relatively insignificant yearly percentage changes in Polish BEV market growth within the overall passenger vehicle market.

In light of the presented findings, a holistic approach involving targeted policy reforms, consumer education, and technological advancements is imperative for the sustainable development of the electric vehicle market in Poland. Policymakers, industry stakeholders, and consumers must collaborate to navigate the intricate challenges and propel the nation towards a greener automotive future.

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