https://doi.org/10.14669/AM/196877

ANALYSIS OF ELECTRIC VEHICLES IN THE CONTEXT OF THE WORLD'S LARGEST ECONOMIES

ANNA BORUCKA[1], ONDREJ STOPKA[2], EDWARD KOZŁOWSKI[3]

Abstract

The global electric vehicle (EV) market is dominated by three global powers: China, the USA, and the European Union. Each of these three regions has adopted unique strategies and differs in terms of regulations, government policies, and market structure. The growth of the EV market in these countries is driven by both climate policies and economic and technological ambitions. Discussing these three markets illustrates the directions of development for the global EV market, as well as its future challenges and potential. This article provides a detailed characterization of the policies pursued by these three economies based on a literature review and its synthesis. It then conducts a quantitative analysis of the electric vehicle markets using a trend development study and calculates the sales elasticity index. The future of the global electric vehicle market will largely be shaped by the development of policies, infrastructure, and innovations in these three regions, each of which has a unique approach to EV development. On one hand, these differences may lead to increased competition among the three powers in the coming decades, fostering further innovation and the development of technologies that support the sustainable growth of the EV market. On the other hand, the analysis of strategies implemented thus far may serve as an excellent benchmark for other countries.

Keywords: electric vehicles; electrification policy; sales elasticity index

[1] Faculty of Security, Logistics and Management, Military University of Technology, Warsaw, Poland e-mail: anna.borucka@wat.edu.pl, ORCID: 0000-0002-7892-9640

[2] Department of Transport and Logistics, Institute of Technology and Business in České Budějovice, Czech Republic, e-mail: stopka@mail.vstecb.cz, ORCID: 0000-0002-0932-4381

[3] Faculty of Management, Lublin University of Technology, Poland, e-mail: e.kozlovski@pollub.pl, ORCID: 0000-0002-7147-4903

https://doi.org/10.14669/AM/196877

1. Introduction

Road accidents are a major social and health problem worldwide. Despite technological progress and the introduction of numerous safety measures, reducing the number of fatalities in road accidents faces numerous challenges. One of the key problems is human error, which is responsible for a significant proportion of road accidents [14, 32]. Even with advanced driver assistance systems, such as lane departure warning systems and automatic braking, the risk of human error cannot be completely eliminated. Another challenge is the integration of new technologies into the existing road infrastructure [33, 42]. The introduction of autonomous vehicles and vehicle-to-vehicle communication systems requires the modernization of roads and the creation of appropriate regulations, which is a time-consuming and expensive process. In addition, the variety of vehicles on the road, from bicycles to trucks, makes it difficult to develop universal solutions to increase safety. Each group of road users has specific needs and risks, which require an individual approach in the design of safety measures. Finally, the effectiveness of safety measures depends on their acceptance and correct application by road users. Even the most advanced technologies will not bring the expected results if drivers do not use them or ignore them even at low travel speeds [12, 13]. It should be noted, however, that the development of the automotive industry, especially in the field of active systems, significantly reduces the risk of road accidents. Systems such as automatic emergency braking, lane keeping assistant and adaptive cruise control contribute to increased road safety by reducing the number of collisions and their consequences. To sum up, reducing the number of fatalities in road accidents requires a comprehensive approach, taking into account human, technological, infrastructural and educational factors [11, 24].

The global electric vehicle (EV) market is currently one of the fastest-growing segments of the automotive industry. Driven by ambitious climate goals, increasing social pressure, and dynamic technological advancements, it has become a key element of the energy transition worldwide [23]. Major powers such as China, the United States, and the European Union have played a significant role in establishing the foundations of this market through various regulatory approaches, subsidies, and the expansion of charging infrastructure, making them the subjects of this study. Electric vehicles can play a crucial role in creating a more sustainable future for transportation; however, this market is largely dependent on the stability of raw material supplies for battery production, advancements in energy storage technology, and the expansion of charging networks [10, 28]. At the same time, increasing competition among regions and their unique approaches to EV market development may accelerate technological progress and enhance the global availability of electric vehicles, contributing to their growing popularity worldwide [28]. The expansion of the EV market results from both climate policies and economic and technological ambitions. Analyzing these three areas provides insight into global trends in the EV sector, while also revealing future challenges and opportunities. Therefore, a detailed characterization of the electrification policies of the three most important global markets has become the foundation of this article. Its goal is to present the key actions of these regions at a strategic level and to analyze the electric vehicle market,

https://doi.org/10.14669/AM/196877

taking into account the BEV and PHEV segments. To this end, a trend development study of sales in individual economies was conducted, and the elasticity indices were calculated in both nominal and logarithmic terms, reflecting the relative growth rates of sales over time.

The development of the electric vehicle market, both globally and in the context of individual countries, will primarily depend on government policy, the expansion and accessibility of infrastructure, and innovative solutions [5]. The strategies presented in this article from three key global economies serve, on one hand, as a showcase of solutions that can be an excellent benchmark for other countries and, on the other hand, as a presentation of differences that may enhance competition, support innovation, and promote the development of technologies that favor sustainable growth.

2. Analysis of the current state and literature review

2.1 China: The Largest Electric Vehicle Market in the World

When analyzing the electric vehicle (EV) market, China undoubtedly takes the lead. In 2017, Shenzhen became the first city in the world where all buses operated on batteries, and a year later, the government announced plans for a similar policy regarding taxis [20]. China's policy concerning electric vehicles over the past decade (2013–2023) has played a crucial role in the global development of this sector, transforming China into the largest EV market in the world. The primary aim was to support the development of this technology to establish China as a global leader in low-emission transport. Numerous programs were introduced to promote the adoption of electric vehicles [18]. One of the most notable initiatives was the subsidies for purchasing electric vehicles, which China implemented as early as the 2010s. These subsidies represented one of the most direct ways to encourage consumers to choose EVs and were provided at several levels [19, 22, 25]. At the central level, the government offered direct financial support to buyers of electric vehicles, covering a significant portion of the purchase costs (in some cases up to 50% of the total cost). The amount of the subsidy depended on the vehicle's range and type of powertrain (electric, plug-in hybrid) [8]. Local subsidies were initiated by local authorities, which implemented their own programs, meaning that buyers in certain regions could receive additional financial support (the largest subsidies were available in cities like Beijing, Shanghai, and Shenzhen) [18]. The level of subsidies also varied with technological advancements and was gradually reduced as the market matured and production costs for EVs declined. At the same time, the requirements for vehicle range and energy efficiency were increased, resulting in subsidies being available only for more technologically advanced models [39]. The programs made electric vehicles more affordable for consumers, significantly accelerating their sales. Between 2015 and 2020, EV sales in China skyrocketed, reaching over 1 million vehicles sold annually by 2018 (Figure1 and Figure 2).

https://doi.org/10.14669/AM/196877

Among other government measures promoting electric vehicle sales, China introduced numerous tax incentives and financial mechanisms that reduced the costs of owning electric vehicles, such as exemptions from VAT, which lowered their prices, and reduced or completely waived registration fees [38]. In addition to consumers, these actions were also directed at manufacturers, aiming to encourage investment in electric vehicle technology and the development of zero-emission model offerings. EV manufacturers and suppliers of essential components could benefit from income tax reductions, which promoted local production development and investment in technology. Furthermore, manufacturers unable to produce a sufficient number of electric vehicles faced additional costs, which effectively served as an incentive for advancing EV technology. This had a tremendous impact, leading to such dynamic growth in electric vehicle production in China that by 2023, it accounted for nearly 70% of global electric vehicle sales, with 9.5 million vehicles produced [16, 30].

A carbon credit and ZEV (Zero Emission Vehicle) policy was also developed in relation to manufacturers. The carbon credit policy required manufacturers to achieve a certain percentage of sales of electric or plug-in hybrid vehicles to meet state requirements. If they failed to reach the mandated level, companies had to purchase "credits" from other manufacturers that had exceeded the required EV sales thresholds, incurring additional costs. This created a secondary market for credits, where EV manufacturers like BYD and NIO could sell their surplus credits to companies producing traditional gasoline vehicles, thereby generating additional revenue for themselves [40]. It is also worth noting that China's enormous production potential in the automotive industry has attracted the interest of Western companies, which have chosen to invest in the Chinese market. In 2017, Volkswagen invested $12 billion to develop electric vehicles in China [34], and later allocated an additional $2.7 billion to expand its operations in the country. A key element of China's policy to support the development of electric vehicles was its substantial investment in building a nationwide network of charging stations. Both the public and private sectors received subsidies, and by the end of 2023, China had more than 5 million public and private charging points, making it the largest market in the world in terms of infrastructure availability [16]. Standardized charging technology and regulations made it easier for consumers to access charging stations. Policies also affected the use of combustion-engine vehicles. Cities like Beijing and Shanghai implemented restrictions on new registrations of gasoline-powered vehicles, making it more challenging to obtain the right to use traditional cars, while EV owners were exempt from these limitations. Many cities introduced low-emission zones, where the movement of combustion-engine vehicles was restricted or completely prohibited.

It is also worth emphasizing that China, as a leader in global production of electric vehicles, is also leading in terms of exports. In 2023, Chinese companies such as BYD, NIO, and Geely significantly increased EV exports, targeting European and South American markets [29]. Exports are supported by competitive prices and a developed production infrastructure. In terms of imports, China imports a limited number of EVs, mainly luxury vehicles from brands such as Tesla and Porsche [41]. Imports of these cars are relatively small compared to

https://doi.org/10.14669/AM/196877

exports. Exports drive technological development and allow for scaling production, reducing unit costs. Growing exports strengthen China's position as the leader in the global EV market.

2.2 United States: Innovation and the Premium Market

The electric vehicle market in the United States has also developed rapidly and, like China's, has undergone many changes in recent years. Initially dominated by niche models and brands, the market now includes a wide range of EV offerings from major automakers across various segments. Similar to China, government policies and regulations play a key role in the U.S. through a comprehensive set of incentives, regulations, financial plans, and infrastructure investments. Both the federal government and individual states have adopted approaches to accelerate the automotive transition toward climate neutrality, increase EV production, and encourage consumer adoption. The U.S. offers tax credits through the Federal Tax Credit program to incentivize consumers to purchase electric vehicles, including both fully electric and plug-in hybrid models [21]. In 2022, the Inflation Reduction Act (IRA) was passed, significantly boosting support for the EV market. The act provides tax credits for manufacturers that localize vehicle and battery production in the U.S. and for consumers purchasing vehicles within specific price thresholds [35]. This legislation also aims to reduce dependence on imports from China and support American manufacturers. To qualify for full tax credits, vehicles must be assembled in North America, and a significant portion of battery components must be sourced from local suppliers or from countries with trade agreements with the U.S. In addition to support for electric vehicle manufacturers, the U.S. has also prioritized the development of facilities for battery recycling and production. Companies can apply for grants and low-interest loans to support research, development, and modernization of production facilities. To encourage domestic battery manufacturing, the government offers additional tax benefits and invests in technologies related to lithium-ion cell materials. The Inflation Reduction Act (IRA) introduced a requirement that 50% of the value of battery materials must originate from the U.S. or countries with trade agreements with the U.S. for a vehicle to qualify for tax credits. By 2027, this requirement is expected to increase to 80%, which will significantly boost local investments and reduce imports [27]. Programs supporting the establishment of so-called "gigafactories" in the U.S., like those of Tesla and LG Chem, are examples of this initiative [4].

At the same time, similar to China, investments are being made in charging infrastructure. Of particular note is the "Bipartisan Infrastructure Law," under which the U.S. will invest approximately $7.5 billion to expand its EV charging network. The goal is to establish 500,000 charging points by 2030, including chargers along highways, in urban areas, and in rural regions [44]. Additionally, the EV Charging Action Plan has been implemented to support the expansion and standardization of charging networks and to establish uniform consumer rates [1].

https://doi.org/10.14669/AM/196877

Beyond federal programs, state-level initiatives are also being introduced to bolster the EV infrastructure. California leads the U.S. in promoting electric vehicles, offering additional tax credits and rebates for EV purchases, the most popular of which is the "Clean Vehicle Rebate Project" [26]. The California Air Resources Board (CARB) enforces emission standards that effectively push manufacturers to meet higher environmental benchmarks, strengthening EV production and sales. Other states, such as New York, Colorado, and Washington, have adopted similar financial incentives for EV purchases and residential charging stations, building on California's model. U.S. climate policy is shaped by the Environmental Protection Agency (EPA), which establishes emission standards to reduce the automotive industry's environmental impact. The Clean Air Act governs permissible pollution levels, directly affecting vehicle emissions. California imposes even stricter emission standards than the federal government and has announced plans to ban new gasoline vehicle sales by 2035 [31].

Tesla has been instrumental in transforming the U.S. EV market, pioneering advancements in battery technology, range, and autonomous driving systems. The company's influence has elevated EVs to a prominent role in U.S. climate policy and public discourse, making the U.S. a global leader in the EV market and intensifying competition with an expanded model lineup. As a result, Tesla has become an icon in the electric vehicle industry. It is also important to emphasize Tesla's role in scaling global production and reducing its costs. This was achieved through substantial investments in battery and electric vehicle factories both in the U.S. and worldwide (e.g., Nevada, Texas, Shanghai), in line with the gigafactory concept massive production facilities that enable large-scale battery and vehicle manufacturing, reaching a production scale previously unseen in the EV industry [31]. Tesla exports EVs mainly to Europe, China and other regions. US EV exports are concentrated in premium vehicles such as Tesla Model 3 and Model Y. The US also imports EVs, mainly from Europe (Volkswagen, BMW) and Asia (Hyundai, Kia). These imports cover the demand for a variety of models that are not yet available in the local market. International trade allows complementing the local product range, which increases the dynamics of EV adoption. Exports strengthen the global reach of US brands and support the development of the technology sector.

2.3 European Union: A Leader in Climate Policy and Environmental Standards

The policies and regulations of the European Union concerning electric vehicles are a cornerstone of the EU's strategy for decarbonizing transportation and are implemented within the framework of the European Green Deal. The EU promotes automotive transformation through comprehensive legal and financial actions aimed at increasing the number of electric vehicles on the market, developing charging infrastructure, and supporting research and technological development in the area of electromobility [6].

The European Green Deal, adopted in 2019, serves as the EU's main strategic document with the objective of achieving climate neutrality by 2050. As part of this strategy, the "Fit for

https://doi.org/10.14669/AM/196877

55" climate package sets a goal of reducing CO_2 emissions by 55% by 2030, compared to 1990 levels. To meet this target, the EU has established stringent emission standards for new vehicles, requiring manufacturers to reduce emissions from new cars by 55% by 2030 and by 100% by 2035 (relative to 2021 levels). In practice, this means a ban on the sale of new combustion-engine vehicles from 2035 onward [9]. Manufacturers that do not meet the established CO_2 emission limits are subject to financial penalties, aimed at encouraging a higher share of electric vehicles in their offerings and investments in greener technologies. The compilation also considers heavy-duty vehicles and buses, with a gradual increase in the number of zero-emission vehicles in this sector and the development of high-power charging infrastructure [36].

Similar to the initiatives seen in China and the USA, investments in charging infrastructure are being intensified, along with regulations concerning charging stations. To support this, the Alternative Fuels Infrastructure Regulation (AFIR) was adopted in 2022, setting targets for alternative fuel infrastructure in EU member states [2]. It mandates the availability of charging stations every 60 km on major European routes, along with the development of high-power chargers for trucks and buses. Member states can receive funding for this program, including resources for building charging stations and hydrogen refueling infrastructure (e.g., through the Connecting Europe Facility [37]). To ensure interoperability across the EU, technical standards are also being implemented, similar to those in China and the USA. These standards cover unified payment methods, charging point accessibility, and uniform tariffs and signage.

The EU's electromobility policy includes various funds, such as the European Electromobility Fund, designed to finance research on advanced battery technologies and promote national and regional EV initiatives. Additionally, as part of the Recovery and Resilience Facility (RRF) launched post-COVID-19, member states can access EU funds for electromobility programs [17]. The program includes financial support for the development of charging infrastructure, electric vehicle production and technological innovation. The EU is also involving the private sector in the development of electromobility through partnerships with technology and automotive companies, such as the European Battery Alliance, to establish local battery manufacturing facilities and secure raw materials for production [7]. Individual EU member states offer various grants and tax incentives for purchasing EVs, along with fiscal benefits in the form of tax relief, exemptions from registration fees, and reduced insurance costs. Programs are also in place to provide privileges for EV users, such as free parking, access to low-emission zones in cities, and the ability to use carpool lanes.

Examining EU exports, it can be seen that Europe exports a significant number of EVs, mainly to the US and China. Leading manufacturers such as Volkswagen, BMW, and Mercedes-Benz are developing their global markets. In terms of imports, the EU imports a significant number of EVs from China (mainly cheaper models such as those produced by BYD and MG) and the US (Tesla). Imports of Chinese EVs are constantly growing due to their competitive prices

https://doi.org/10.14669/AM/196877

and rapid technological development. Exports allow European manufacturers to compete in the global market and diversify revenues. Imports of Chinese EVs exert price pressure on European manufacturers, accelerating their innovation. International trade undoubtedly favors the exchange of technologies between regions. China, thanks to exports, can invest in R&D, while the US and EU benefit from cheaper components and finished vehicles. Chinese EVs, offered at lower prices, force production costs in the EU and the US, while American and European premium brands raise their quality and technology standards to maintain their position in the global market. Imports allow consumers to access a wider range of products, which drives EV adoption in various markets. Growing international trade allows for larger production volumes, which leads to reduced unit costs. China has achieved dominance precisely through mass production and global distribution.

Additionally, the EU has introduced comprehensive regulations governing the production and recycling of batteries to ensure environmentally friendly sourcing, production processes, and recycling capabilities. These regulations require manufacturers to achieve a minimum recycling percentage for essential materials like lithium, cobalt, and nickel. Batteries manufactured in the EU must meet specific quality and environmental standards, promoting sustainable development and reducing dependence on imported raw materials. Under these regulations, EV manufacturers are responsible for the proper collection and processing of used batteries [7].

3. Results and Discussion

The least squares method [3], or machine learning methods can be used to analyze the EV market including BEV and PHEV segments and identify trends related to EV sales. However, in this approach, the development trend of sales across specific economies was examined using elasticity indicators in both nominal and logarithmic scales, which allowed for assessing the relative growth rate of sales over time [3, 15, 43].

We analyze the series $\{v_{t_j}\}_{1\le j\le n}$, where v_{t_j} denotes the number of electric vehicles sold in the year t_j.

Definition 1: Elasticity of sales over time is defined as the ratio of the relative change in sales to the relative change in the time interval and is estimated using the formula:

$$\gamma_{t_j} = \frac{v_{t_{j+1}} - v_{t_j}}{v_{t_j}} : \frac{t_{j+1} - t_j}{t_j}$$

Where $\frac{v_{t_{j+1}} - v_{t_j}}{v_{t_j}}$ denotes the relative change in sales, and $\frac{t_{j+1} - t_j}{t_j}$ the relative change in the time interval for $1 \le j \le n-1$.

https://doi.org/10.14669/AM/196877

Definition 2: Elasticity of sales in the logarithmic scale is the ratio of the relative change in sales on a logarithmic scale to the relative change in the time interval, estimated by the formula:

$$\gamma_{t_j}^{log} = \frac{\log\left(v_{t_{j+1}}\right) - \log\left(v_{t_j}\right)}{\log\left(v_{t_j}\right)} : \frac{t_{j+1} - t_j}{t_j}$$

Elasticity indicators correspond to the relative rate of sales growth, thus reflecting the EV development policy of a given country.

The average sales elasticity is calculated as:

$$\bar{\gamma} = \frac{1}{n-1} \sum_{j}^{n-1} \gamma_{t_j}$$

and for logarithmic scale measurements:

$$\bar{\gamma}_{log} = \frac{1}{n-1} \sum_{j}^{n-1} \gamma_{t_j}^{log}$$

Standard deviation of sales elasticity over time is determined using the following formulas:

$$\sigma_\gamma = \sqrt{\frac{1}{n-1} \sum_{j}^{n-1} \left(\gamma_{t_j} - \bar{\gamma}\right)^2}, \qquad \sigma_{v_{log}} = \sqrt{\frac{1}{n-1} \sum_{j}^{n-1} \left(\gamma_{t_j}^{log} - \bar{\gamma}_{log}\right)^2}$$

on a nominal and logarithmic scale, respectively.

The coefficient of variation of sales elasticity indicates the proportion of the average demand elasticity represented by the standard deviation:

$$H_\gamma = \frac{\sigma_\gamma}{\bar{\gamma}} 100\%, \qquad H_{\gamma_{log}} = \frac{\sigma_{\gamma_{log}}}{\bar{\gamma}_{log}} 100\%$$

In the following figures, the sales volume is presented in years, while calculations were conducted assuming $t_j = j$ for $1 \le j \le n$. Electric vehicle sales on a nominal scale of the BEV and PHEV segment for the economies studied are shown in Figure 1 and Figure 2 respectively.

https://doi.org/10.14669/AM/196877

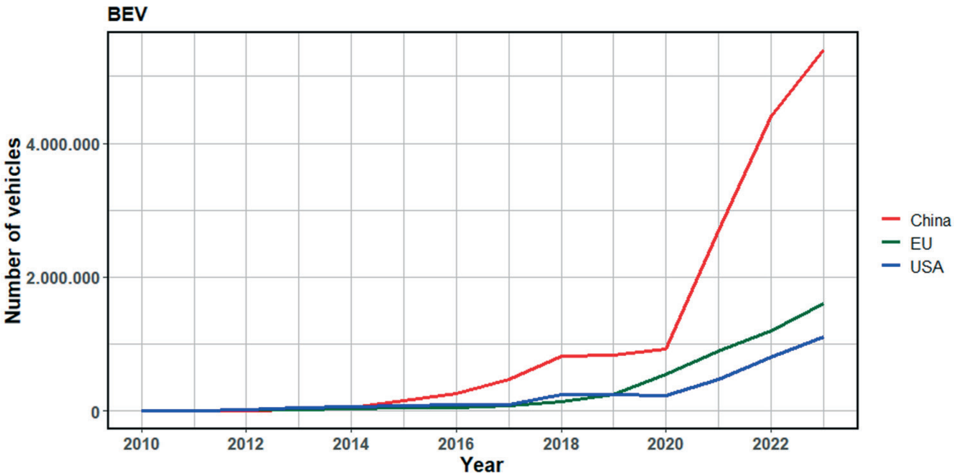

Fig. 1. BEV segment electric vehicle sales from 2010 to 2023

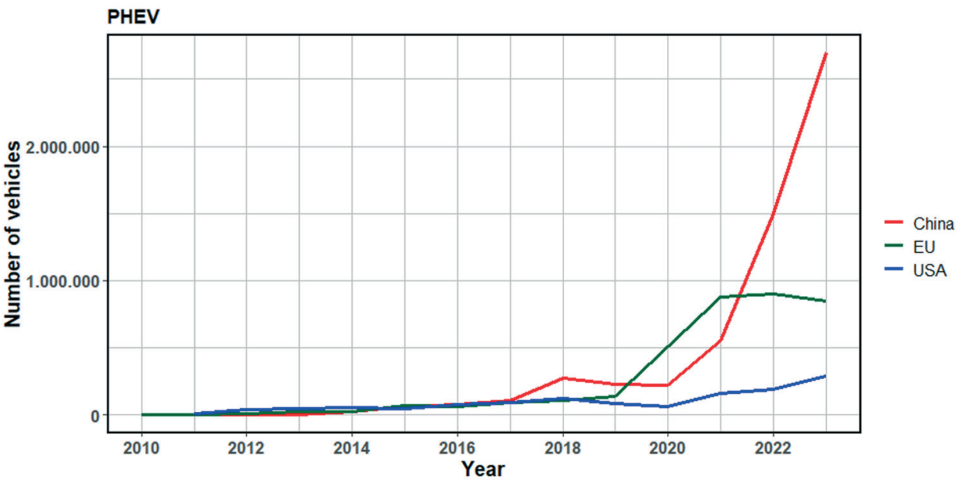

Fig. 2. PHEV segment electric vehicle sales from 2010 to 2023

The figures reveal exponential dependencies, indicating that EV sales are escalating over time. This trend likely reflects the effects of government-implemented programs and policies. An analysis of sales on a logarithmic scale for both BEVs and PHEVs is presented in Figure 3 and Figure 4.

https://doi.org/10.14669/AM/196877

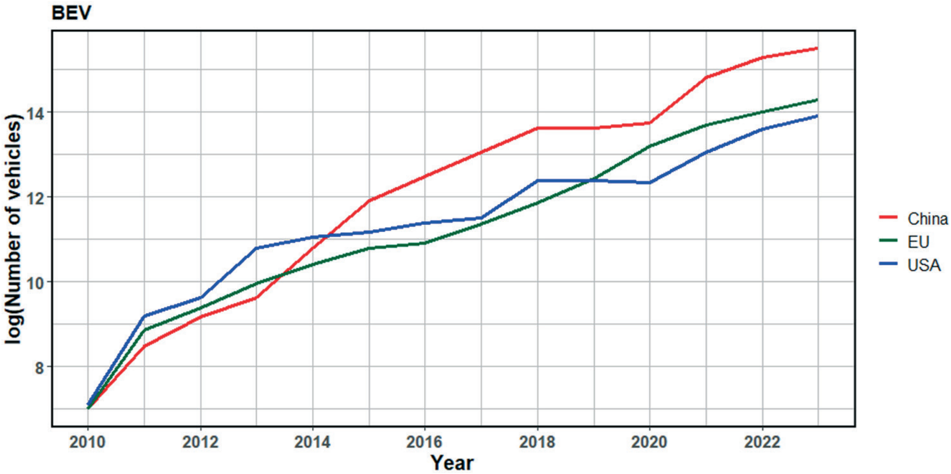

Fig. 3. BEV segment electric vehicle sales from 2010 to 2023 on a logarithmic scale

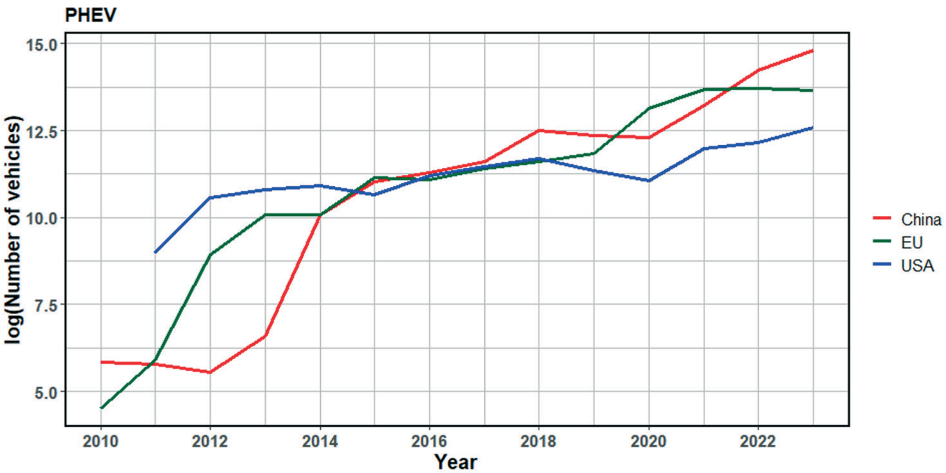

Fig. 4. PHEV segment electric vehicle sales from 2010 to 2023 on a logarithmic scale

The logarithmic scale shows linear trends with varying degrees of slope. To evaluate the dynamics for sales values on a logarithmic scale, the mean value of elasticity, standard deviation and coefficient of variation were determined. The results obtained for BEVs are shown in Table 1 while for the PHEV segment vehicles in Table 2

Tab. 1. The value of the elasticity index for the sales of BEV segment vehicles on a logarithmic scale, the standard deviations of elasticity, and the coefficient of variation

Country	Type	$\bar{\gamma}_{log}$	$\sigma_{v_{log}}$	$H_{\gamma_{log}}$
China	BEV sales	0.307	0.226	73.610
EU	BEV sales	0.280	0.150	53.693
USA	BEV sales	0.239	0.229	95.667

Tab. 2. The value of the elasticity index for the sales of PHEV segment vehicles on a logarithmic scale, the standard deviations of elasticity, and the coefficient of variation

Country	Type	$\bar{\gamma}_{log}$	$\sigma_{v_{log}}$	$H_{\gamma_{log}}$
China	PHEV sales	0.472	0.604	127.849
EU	PHEV sales	0.328	0.376	114.447
USA	PHEV sales	0.136	0.288	211.156

The values of the calculated indexes for the BEV segment are presented in Figure 5.

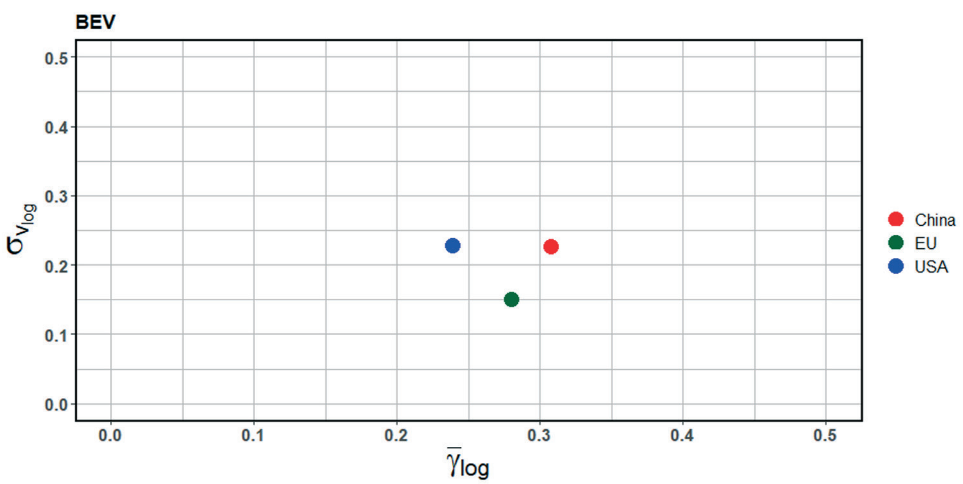

Fig. 5. Elasticity of BEV sales for specific regions

The average sales elasticity (mean relative sales growth to relative changes over the time interval) corresponds to rate (speed) of growth dynamics in sales, but the standard deviation of sales elasticity indicates stability (resistance to external market disturbances) of this sales growth. Countries with higher average sales elasticity and lower standard deviation show faster and more stable development of the electric vehicle market. Analyzing the results

https://doi.org/10.14669/AM/196877

in the coordinate system, the position of the point in relation to expected elasticity and standard deviation further to the right and lowest indicates greater demand elasticity with a smaller standard deviation, which can be interpreted as a faster and more stable growth in sales. For BEV vehicles (see Figure 5 and Table 1), the highest value of elasticity over time (relative sales increase) pertains to China, while the lowest value of elasticity over time is observed in the USA. On a logarithmic scale, the lowest value of the standard deviation of the elasticity index over time was obtained for EU countries, indicating greater stability in sales growth. Based on Table 1, it can also be noted that the coefficient of variation of elasticity for EU countries is the smallest.

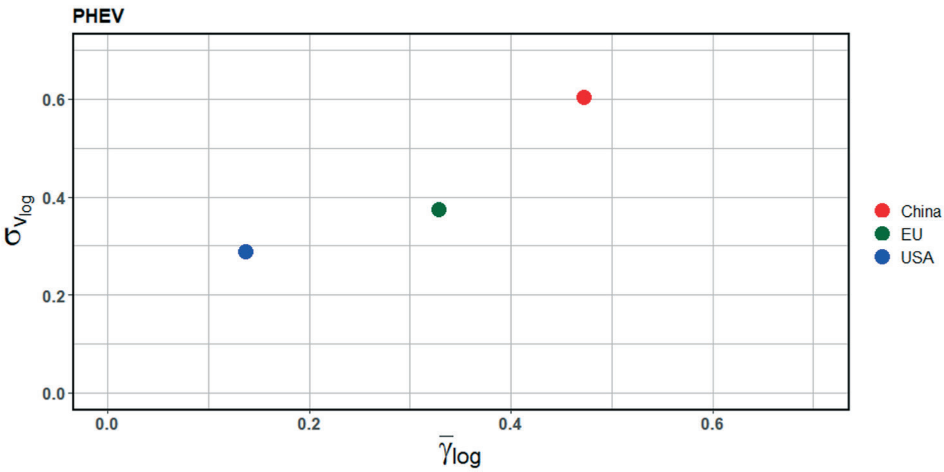

Fig. 6. Elasticity of PHEV sales for specific regions

For PHEV vehicles (see Figure 6 and Table 1), again, the highest value of elasticity over time pertains to China (indicating a faster growth in sales), while the lowest value of elasticity over time is observed in the USA. The standard deviation of elasticity over time for China is also greater than that for the USA, indicating that the growth dynamics in logarithmic scale (see Figure 4) for the Middle Kingdom is less stable. For EU countries (see Table 2), the coefficient of variation of elasticity over time is the smallest; however, it still exceeds 100%.

When comparing the standard deviations of elasticity over time and the coefficients of variation for BEV and PHEV vehicles, it is evident that significantly higher values of variability and standard deviation apply to PHEV vehicles, which indicates a less stable growth dynamic for PHEV vehicles compared to BEV vehicles.

The analysis above shows that economies such as the EU or the USA do not achieve the same sales dynamics for electric vehicles as China. While this growth is stable, it is not as expensive

https://doi.org/10.14669/AM/196877

as that in the case of the Middle Kingdom. This is likely influenced by the economic situation in these regions and the still high costs of purchasing electric vehicles, leading consumers to often choose cheaper alternatives. Additionally, the lack of sufficient infrastructure, especially in less urbanized regions, and its slow development serves as a barrier. It is also important to highlight the recent supply and production issues resulting from supply chain disruptions following the COVID-19 pandemic and the global chip shortage, which caused significant interruptions in electric vehicle production. Automotive companies faced difficulties in fulfilling orders, which slowed sales growth. Concerns about the technology itself, particularly regarding battery life, charging times, and efficiency, especially in cold climates, remain pertinent. For many individuals, this risk continues to be a key barrier to purchasing an electric vehicle. In light of economic challenges, there has also been a noticeable reduction or phasing out of tax incentives that were primarily available during the initial period.

4. Conclusion

In China, over the past few years, the number of electric vehicle manufacturers has reached more than 400 companies. China has become the world's largest EV producer, surpassing the U.S., while European car manufacturers are now establishing production in China. China is undoubtedly a global leader in promoting electric vehicles, offering some of the world's strongest purchase support programs, as demonstrated by this study. This support is diverse, and its form and scope stand out compared to other regions. China implements highly comprehensive solutions for the entire EV market, benefiting both consumers and manufacturers, and expanding infrastructure with targeted tools and dedicated subsidies. The U.S. and the EU are also investing in the development of this sector, though in a more limited or decentralized manner. By far, the most significant government support is found in China, driven not only by the global need for electrification but also by China's goal of building a robust and dynamic economy and aspiring to become a leader in global markets. China's policy of aggressively advancing EV technology as part of its energy development strategy could serve as an excellent benchmark for many countries.

Regarding further research in the fields of electromobility, emphasis should be placed on the following issues:

- Investigation of new materials and technologies to enhance energy density, charging speed, and battery lifespan.
- An analysis of the optimal placement and technology of charging stations to enhance accessibility and convenience for users.
- Exploration of the question of how electromobility can be integrated with renewable energy sources to create a sustainable energy ecosystem.
- Conduction of comprehensive studies on the environmental impact of EVs throughout their lifecycle, starting with production, ending with disposal.

https://doi.org/10.14669/AM/196877

- Research of factors affecting consumer adoption of EVs, including incentives, awareness, and perceived barriers.
- Examination of the question of how electromobility can interact with smart grid systems for better energy management and grid stability.
- Investigation of the effectiveness of different policies and regulations in promoting electromobility, including subsidies, tax incentives, and emission standards.
- Research of the potential of Vehicle-to-Grid (V2G) technologies that allow EVs to return energy to the grid, enhancing energy storage and stability.
- Exploration of the implications of integrating autonomous driving technology with electric vehicles, including safety, efficiency, and regulatory challenges.
- Research of the benefits and challenges of electrifying public transport systems and their impact on urban mobility.

The development of electric vehicle markets in the US, China and the EU is key to the global transformation of the automotive sector. Each of these regions has unique characteristics and challenges that could affect future changes. China will undoubtedly seek to deepen its dominance in the global market. Chinese manufacturers such as BYD, NIO and Xpeng will continue to expand exports, especially to Europe and emerging markets such as Latin America and Africa. It is also possible that the share of Chinese EVs in the US will increase, despite current trade barriers. The development of cheap and technologically advanced batteries (e.g. sodium-ion batteries) can reduce the cost of EV production and increase their global availability. Government subsidy programs and the development of charging infrastructure in smaller cities can drive demand in the local market, especially for cheap EVs. The challenge for the Chinese market is undoubtedly the customs and political barriers in Europe and the US, which may limit the expansion of Chinese manufacturers. High competition in the domestic market may reduce the margins of Chinese companies. In the US, we can expect the development of Tesla, GM, and Ford factories and investments by foreign companies such as Panasonic and LG Energy Solution. The undoubted direction of action will be to minimize dependence on the import of components, especially from Asia, and to increase the availability of EVs in the medium and lower price range. Growing competition from manufacturers such as Hyundai and Kia and Chinese brands introducing cheaper models may force American companies to expand their offer. The biggest challenge for the US economy is the shortage of raw materials, such as lithium, which may delay production plans and pose a significant problem. Competition from China in the battery and component sector may put pressure on production costs. The EU, on the other hand, faces the challenge of protecting local producers from cheap competition from China, while striving to maintain its position as a leader in technological innovation. Regulatory policy will be a key factor in accelerating the transformation of the market. The considered introduction of protective tariffs on Chinese EVs may reduce imports and protect local producers. The increase in imports of Chinese electric vehicles forces European producers to reduce costs and introduce innovative models in order to compete on price. Undoubtedly, the desired direction should be the intensification of investment in local factories and increase in exports, espe-

https://doi.org/10.14669/AM/196877

cially towards developing markets, especially in South America and Africa, to balance competition with China. Undoubtedly, all three regions will strive to dominate the EV market, but the dynamics of change will vary depending on politics, technological capabilities and global trade relations.

5. References

[1] Bauer G, Hsu CW, Nicholas M, Lutsey N. Charging up America: Assessing the growing need for US charging infrastructure through 2030. White Paper ICCT. International Council on Clean Transportation. 2021.

[2] Bernard MR. European Union Alternative Fuel Infrastructure Regulation (AFIR). POLICY. International Council on Clean Transportation. 2023

[3] Borucka A. Seasonal Methods of Demand Forecasting in the Supply Chain as Support for the Company's Sustainable Growth. Sustainability. 2023;15(9):7399. https://doi.org/10.3390/su15097399.

[4] Bridge G, Faigen E. Towards the lithium-ion battery production network: Thinking beyond mineral supply chains. Energy Research & Social Science. 2022;89:102659. https://doi.org/10.1016/j.erss.2022.102659.

[5] Burdzik R, Celiński I, Ragulskis M, Ranjan V, Matijošius J. Estimation of Vehicle Traffic Parameters Using an Optical Distance Sensor for Use in Smart City Road Infrastructure. Journal of Sensor and Actuator Networks. 2024;13(4):35. https://doi.org/10.3390/jsan13040035.

[6] Cempírek V, Rybicka I, Ljubaj I. Development of Electromobility in Terms of Freight Transport. LOGI – Scientific Journal on Transport and Logistics. 2019;10(2):23–32. https://doi.org/10.2478/logi-2019-0012.

[7] Church R, Kempf O, Aaron J. The European Battery Alliance: Paving the Way for a Sustainable and Competitive Battery Ecosystem. Battery Energy. 2024;5(3):450–462.

[8] Dong Y. Analysis of consumers' willingness to accept of government subsidies for electric vehicles. Transportation Research Procedia. 2022;61:90-97. https://doi.org/10.1016/j.trpro.2022.01.016.

[9] Erbach G, Jensen L. Fit for 55 package. EPRS, European Parliament. 2022.

[10] Fang P, Sui X, Zhang A, Wang D, Yin L. Fusion model based RUL prediction method of lithium-ion battery under working conditions. Eksploatacja i Niezawodność – Maintenance and Reliability. 2024;26(3):186537. https://doi.org/10.17531/ein/186537.

[11] Frej D, Jaśkiewicz M. Behavior of pedestrians when using a pedestrian crossing with traffic lights. Transportation Research Procedia. 2023;74:34–41. https://doi.org/10.1016/j.trpro.2023.11.109.

[12] Frej D, Jaśkiewicz M. Comparison of volunteers' head displacement with computer simulation—crash test with low speed of 20 km/h. Sensors. 2022;22(24):9720. https://doi.org/10.3390/s22249720.

[13] Frej D, Jaśkiewicz M. Head motion analysis of the KPSIT C50 dummy in simulated low-speed collisions. Transport Problems. 2024;19(3):59–70. https://doi.org/10.20858/tp.2023.19.3.05.

[14] Frej D. The effect of changing the angle of the passenger car seat backrest on the head trajectories of the 50th percentile male dummy. Sensors. 2024;24(12):3868. https://doi.org/10.3390/s24123868.

[15] Grzelak M, Borucka A, Guzanek P. Application of Linear Regression for Evaluation of Production Processes Effectiveness. Lecture Notes in Mechanical Engineering. Springer, Cham. 2022:36–47. https://doi.org/10.1007/978-3-030-78170-5_4.

[16] Khaleel M, Nassar Y, El-Khozondar HJ, Elmnifi M, Rajab Z, Yaghoubi E, et al. Electric Vehicles in China, Europe, and the United States: Current Trend and Market Comparison. International Journal of Electrical Engineering and Sustainability. 2024;2(1):1–20.

[17] Lascu CE. The recovery and resilience facility: investments in the energy sector. XI International Conference of Management and Industrial Engineering. 2023;11:323–330. https://doi.org/10.56177/11icmie2023.11.

[18] Li W, Yang M, Sandu S. Electric vehicles in China: A review of current policies. Energy & Environment. 2018;29(8):1512–1524. https://doi.org/10.1177/0958305X18781898.

[19] Liao Y. Intention of consumers to adopt electric vehicle in the post-subsidy era: Evidence from China. International Journal of Sustainable Transportation. 2022;16(7):647–659. https://doi.org/10.1080/15568318.2021.1918297.

[20] Lin Y, Zhang K, Shen Z-JM, Miao L. Charging Network Planning for Electric Bus Cities: A Case Study of Shenzhen, China. Sustainability. 2019;11(17):4713. https://doi.org/10.3390/su11174713.

[21] Liu H, Dai Z, Rodgers MO, Guensler R. Equity issues associated with US plug-in electric vehicle income tax credits. Transportation Research Part D: Transport and Environment. 2022;102:103159. https://doi.org/10.1016/j.trd.2021.103159.

[22] Liu X, Sun X, Zheng H, Huang D. Do policy incentives drive electric vehicle adoption? Evidence from China. Transportation Research Part A: Policy and Practice. 2021;150:49–62. https://doi.org/10.1016/j.tra.2021.05.013.

[23] Lučić M, Lukić J, Grujić I. Statistical analysis of trends in Battery Electric Vehicles: Special reference to vehicle weight reduction, electric motor, battery, and interior space dimensions. The Archives of Automotive Engineering – Archiwum Motoryzacji. 2024;104(2):63–96. https://doi.org/10.14669/AM/189962.

[24] Ludwinek K, Jurecki R, Jaśkiewicz M, Szumska E, Sulowicz M. A test stand for the experimental analysis of physical quantities during crash test at low speeds. XI International Science-Technical Conference Automotive Safety. Slovakia. IEEE. 2018:1–7. https://doi.org/10.1109/AUTOSAFE.2018.8373306.

[25] Masiero G, Ogasavara MH, Jussani AC, Risso ML. Electric vehicles in China: BYD strategies and government subsidies. RAI Revista de Administração e Inovação. 2016;13(1):3–11. https://doi.org/10.1016/j.rai.2016.01.001.

[26] Mejía-Duwan J, Hino M, Mach KJ. Emissions redistribution and environmental justice implications of California's clean vehicle rebate project. PLOS climate. 2023;2(5):e0000183. https://doi.org/10.1371/journal.pclm.0000183.

[27] Moors C, Keen K. Biden administration releases electric vehicle tax credit rule. S&P Global. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/050324-biden-administration-releases-electric-vehicle-tax-credit-rule (accessed on 22 Oct 2024).

[28] Nasri E, Jarou T, Benchikh S, El Koudia Y. Reliable energy supply and voltage control for hybrid microgrid by pid controlled with integrating of an EV charging station. Diagnostyka. 2023;24(4):2023409. https://doi.org/10.29354/diag/174145.

[29] NG LK. Internationalization of Firms: Assessing Liability of Foreignness in China's Electric Vehicle Industry. Asian Journal of Business Environment. 2024;14(4):1–11.

[30] Oxford Economics. The China electric vehicle boom promises much. https://www.oxfordeconomics.com/resource/the-china-electric-vehicle-boom-promises-much/ (accessed on 22 Oct 2024).

[31] Plumer B, Cowan J. California Plans to Ban Sales of New Gas-Powered Cars in 15 Years. New York Times. https://www.nytimes.com/2020/09/23/climate/california-ban-gas-cars.html (accessed on 22 Oct 2024).

[32] Poliak M, Frej D, Jaśkiewicz M, Caban J, Górniak A, Gidlewski M, et al. Analysis of head movement in KPSIT dummies and the impact of seats and seat belts during low-speed collisions 20 km/h. Sensors. 2024;24(17):5714. https://doi.org/10.3390/s24175714.

[33] Sang T, Zhu K, Shen J, Yang L. An uncertain programming model for fixed charge transportation problem with item sampling rates. Eksploatacja i Niezawodność – Maintenance and Reliability. 2025;27(1). https://doi.org/10.17531/ein/192165.

[34] Shane D. CNN Business. VW has a $12 billion plan for electric cars in China https://money.cnn.

https://doi.org/10.14669/AM/196877

com/2017/11/16/investing/volkswagen-electric-vehicles-china/index.html (accessed on 22 Oct 2024).

[35] Slowik P, Searle S, Basma H, Miller J, Zhou Y, Rodríguez F, et al. Analyzing the impact of the Inflation Reduction Act on electric vehicle uptake in the United States. White paper. International Council on Clean Transportation. Washington, 2023.

[36] Szumska EM, Pawełczyk M, Jurecki R. Total Cost of Ownership analysis and energy efficiency of electric, hybrid and conventional urban buses. Eksploatacja i Niezawodność – Maintenance and Reliability. 2022;24(1):7–14. https://doi.org/10.17531/ein.2022.1.2.

[37] Vettorazzi S. Establishing the Connecting Europe Facility 2021-2027. EPRS: European Parliamentary Research Service. Belgium. 2018.

[38] Wang J, Wang R, Li L, Dong J. The market for electric vehicles in China: modelling the abolition of policy incentives. Climate Policy. 2022;22(7):865–881. https://doi.org/10.1080/14693062.2022.2063246.

[39] Wu L, Hu K, Lyulyov O, Pimonenko T, Hamid I. The impact of government subsidies on technological innovation in agribusiness: The case for China. Sustainability. 2022;14(21):14003. https://doi.org/10.3390/su142114003.

[40] Xie Y, Rodríguez F. Zero-emission integration in heavy-duty vehicle regulations: A global review and lessons for China. The international council on clean transportation. 2021.

[41] Xu J. Strategic Emerging Industry: Analysis of Development of New Energy Vehicles. Doctoral dissertation. Politecnico di Torino. 2024.

[42] Yadav S, Rishi R. An Optimal Security Framework Based on Driver Authentication for Intelligent Transportation Systems. LOGI – Scientific Journal on Transport and Logistics. 2023;14(1):24–34. https://doi.org/10.2478/logi-2023-0003.

[43] Zhan X, Liu Z, Yan H, Wu Z, Guo C, Jia X. A novel method of health indicator construction and remaining useful life prediction based on deep learning. Eksploatacja i Niezawodność – Maintenance and Reliability. 2023;25(4):171374. https://doi.org/10.17531/ein/171374.

[44] Zhang Z, Chen Z, Xing Q, Ji Z, Zhang, T. Evaluation of the multi-dimensional growth potential of China's public charging facilities for electric vehicles through 2030. Utilities Policy. 2022;75:101344. https://doi.org/10.1016/j.jup.2022.101344.