SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2024
ORGANIZATION AND MANAGEMENT SERIES NO. 205

DEMAND FOR ELECTRIC CARS IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT – A MODEL APPROACH FOR SELECTED MARKETS

Ewa MAJEROWSKA[1*], Hanna JASIK[2]

[1] Department of Corporate Finance, Faculty of Management, University of Gdańsk; ewa.majerowska@ug.edu.pl, ORCID: 0000-0003-0991-3714
[2] hanna.j.jasik@gmail.com, ORCID: 0009-0002-9817-7308
* Correspondence author

Purpose: The purpose of the paper is to identify the factors shaping the sales volume of passenger electric cars in selected European countries that differ in the level of development and advancement of the electric car market.
Design/methodology/approach: The empirical analysis covers annual EV sales data from five countries annually, spanning 2012-2022. To achieve the aim of the study, a single-equation linear regression model was used, estimated using the classic least squares method. Appropriate fit measures and statistical tests were used to verify the estimated models.
Findings: The study showed that there are differences in the factors determining electric car sales in the countries surveyed. Driver preferences vary by region. However, due to the demands of climate change, interest in electric cars has increased dramatically in recent years.
Research limitations/implications: The study concerned the demand for electric cars in selected countries. It constitutes the basis for further research, covering a larger number of countries in Europe and beyond.
Practical implications: The obtained research results allowed us to indicate what elements constitute the main reasons for purchasing electric cars by European residents. They signal to decision-makers what elements should be paid attention to increase the ecological awareness of European residents, influencing decisions to purchase an electric vehicle.
Social implications: Research indicates the need to promote electromobility to increase the number of publicly available fast charging points and policies related to facilitating the purchase of electric vehicles due to the need to reduce greenhouse gas emissions.
Originality/value: The article is an attempt to identify the factors determining the demand for electric cars, indicate the causes of differences in demand in European countries, and recommendations for increasing interest in this type of car in the light of sustainable development goals.
Keywords: sustainable development, demand for cars, electric cars.
Category of the paper: Research paper.

1. Introduction

Ecology, technological progress, developed charging infrastructure and government subsidy programs are the key elements that make up a comprehensive picture of the electric car industry. The electric car market has significant development potential, making it a subject of particular interest in recent years. Additionally, it is strongly related to the growing ecological awareness of society. In the face of the growing problem of climate change, electric cars are becoming more and more attractive to consumers looking for environmentally friendly solutions.

The negative impact of traditional combustion vehicles on the environment has led to increasingly stringent emission standards around the world, which positively impacts the market for vehicles with alternative drives, such as electric drives (Śliwka, Łyko, Pomykała, 2015). Due to the limited amount of energy resources, there is a growing need to use alternative, environmentally friendly energy sources. Additionally, many energy resources are located in politically unstable areas, which encourages to take steps to become independent from this resource (Sienkowicz, Drzewosz, 2013). For example, in response to the energy crisis caused by Russia's invasion of Ukraine, the European Commission adopted the REPowerEU plan in May 2022, aimed at weakening the dependence of European Union member states on Russian fossil fuels. Electromobility implements the assumptions of sustainable development by:

- promoting renewable energy sources,
- reducing carbon dioxide emissions (Buberger, 2022),
- improving air quality,
- supporting technological innovation (Schill, 2020).

The fear of insufficient range of an electric vehicle is the main obstacle to the adoption of electric cars (Liao, Wolin, van Wee, 2017). Another factor discouraging the purchase of an electric car is the high price of an electric vehicle compared to a traditionally powered vehicle (Lebeau et al., 2013). Technological progress, focused on improving electric vehicles and their components, aims to eliminate these barriers. Innovations aimed at improving battery performance, extending vehicle range and improving energy management systems make electric cars increasingly competitive with traditional vehicles powered by combustion engines.

The purpose of the paper is to identify the factors shaping the sales volume of passenger electric cars in European regions that differ not only in geographical location but also in the level of advancement of the electric car market. The study is part of the sustainable development trend. The research hypothesis assumes that the sales of electric passenger cars in countries from different regions of Europe are not determined by the same factors.

To achieve the aim of the study, annual data covering the period 2012-2022 were used, coming from five European countries representing different levels of development in terms of both geography and the degree of implementation of sustainable development goals,

and therefore interest in electric cars. The Gretl program was used to estimate econometric models.

The paper is organized as follows. After the introduction, section two is devoted to the Sustainable Development Goals. The third concerns the electric car market. It describes the specificity of this market. Then its development in the world was characterized. The next subsection identifies potential factors determining the level of electric car sales resulting from a review of the literature and economic theories. The last subsection provides a justification for the selection of European countries for which the analyzes were carried out. The fourth section describes the research methodology, and the fifth section presents the results and discussions. The paper ends with a summary and references.

2. Importance of sustainable development goals

In 2015, all United Nations countries signed "The 2030 Agenda for Sustainable Development". This agenda was a common position of states on activities related to improving the lives of citizens, reducing poverty, and saving the planet. These activities were defined as The Sustainable Development Goals (SDGs), also known as the Global Goals. They encourage all countries to take action to eliminate poverty in the world and protect the planet by 2030 so that all can enjoy peace and prosperity.

There are seventeen of these goals, followed by 169 targets. Their integrated nature was assumed. It was assumed that activities in one area would influence results in other areas. Development, treated as sustainable, refers to three areas: social, economic, and environmental development (United Nations, 2024). The list of all goals is given in Table 1.

Table 1.
Sustainable Development Goals

SDG no	Goal	SDG no	Goal	SDG no	Goal
SDG 1	No poverty	SDG 7	Affordable and clean energy	SDG 13	Climate action
SDG 2	Zero hunger	SDG 8	Decent work and economic growth	SDG 14	Life below water
SDG 3	Good health and well-being	SDG 9	Industry, innovation and infrastructure	SDG 15	Life on land
SDG 4	Quality education	SDG 10	Reduced inequalities	SDG 16	Peace, justice, and strong institutions
SDG 5	Gender equality	SDG 11	Sustainable cities and communities	SDG 17	and Partnerships for the goals
SDG 6	Clean water and sanitation	SDG 12	Responsible consumption and production		

Source: own presentation based on https://sdgs.un.org/.

One of the SDG goals, marked as 13, is to prevent global warming. Many factors influence the climate. Pro-ecological activities can be carried out on many levels. The first step is to use secondary raw materials by recycling paper, plastic, glass, and metal. Another is the repeated use of packaging, another is the purchase of organic products or a reduction in the purchase of meat products. Goal 13 assumes reducing gas emissions by 43% by the end of 2023 and then to zero by 2050 (SDGS, 2024). The implementation of individual goals varies between countries. Research conducted by Chmielewski et al (2024) indicated that the leading country in Europe to achieve goal SDG13, concerning the climate changes, is Malta, while Hungary and Lithuania performed the worst. The goal can be achieved by changing ways of transport from passenger cars to bicycles or public transport. Another possibility, requiring significant financial outlays, is to choose electrically powered cars that emit smaller amounts of gases than traditional cars. This solution is becoming more and more common in the modern world due to the need to implement the SDG goals.

3. Electric cars market

3.1. Specificity of the electric car market

An electric vehicle is a motor vehicle whose functioning is based only on electricity accumulated by connecting the car to an external power source. A hybrid car combines both combustion and electric drive. In the case of hybrids, electricity is accumulated in the same way as in electric cars (Ustawa…, 2018). Passenger cars may differ in the share of electric drive in their design. Therefore, the following types of these vehicles can be distinguished (PSPA Report, 2020): battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), extended-range electric vehicles (EREV) and fuel cell electric vehicles (FCEV).

Technologies important for the electric car market are developing around the world, such as wireless charging, intelligent power grid, V2H (vehicle-to-home) function, V2G (vehicle-to-grid) function, connected vehicles (CVs) vehicles) and autonomous vehicles (AVs).

The electric car market is closely related to the available charging infrastructure. Investments in charging stations both in urban areas and along communication routes make the use of electric cars more and more convenient and accessible to users. The growing number of electric cars requires the expansion of charging station infrastructure. As the number of charging stations increases, concerns about the limited range of electric vehicles are starting to disappear, which causes increased consumer confidence in this type of solution. The methods of charging batteries in electric vehicles include methods such as (Piąstka, Jajczyk, Bednarek, 2020):

- Plug-In charging,
- charging via pantograph,
- wireless charging,
- charging by replacing batteries.

While making the decision to buy electric cars, consumers are guided by three key motivations. Firstly, reducing the carbon footprint is an important factor, with eco-conscious buyers opting for zero or low-emission vehicles, often willing to pay more for an eco-friendly choice. Secondly, the benefits of owning an electric car, such as free parking or the ability to use bus lanes, are an additional incentive for drivers. Another important factor is the desire to save money, especially thanks to various government subsidies that make electric vehicles an economical choice, especially in times of rising fuel prices (McKinsey, 2014).

3.2. Development of the electric car market

The electric vehicle market has a long history, dating back to the 19th century when the first electric vehicles were created. These included the Electrobat, a vehicle constructed by engineer Henry G. Morris and chemist Pedro G. Salom. Electric vehicles seemed to be a promising alternative to cars powered by combustion engines. However, their popularity did not last long (PSPA Report, 2020).

The next wave appeared in the 1990s. During this period, concerns about global warming increased and specific legislative actions were introduced, such as California's Zero Emissions Vehicle (ZEV) ordinance. This resulted in increased interest in electric passenger vehicles. In the 1990s, the first mass-produced hybrid vehicles, such as the Toyota Prius, appeared and gained mass market popularity. Their success accelerated the development of electric drive technologies, creating new opportunities and prospects for the future of road transport.

The third wave occurred in the early 21st century. At that time, the main factor driving the development of technology was the growing crisis related to oil dependence and concerns about its depletion. The increase in fossil fuel prices prompted the search for alternative energy sources, which in turn contributed to the further development of electric vehicles. In 2003, Tesla Motors was founded, the company known today as Tesla Inc. Their first product was the Roadster sports car, which revolutionized the perception of electric vehicles, showing that they could not only be ecological, but also fast and efficient. The roadster has become a symbol of the new era of electric mobility, attracting the attention of both consumers and car manufacturers.

In recent years, interest in the electric car market has increased. In 2022, record sales of BEVs were recorded, as shown in Figure 1.

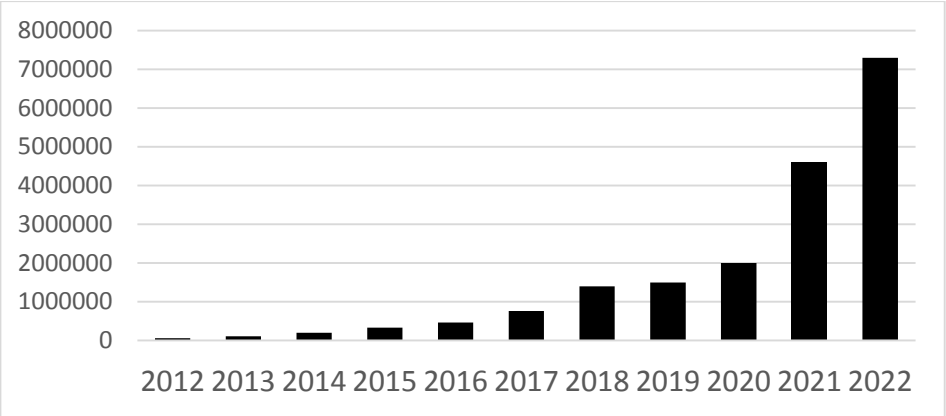


Figure 1. Number of BEVs sold worldwide in 2012-2022.

Source: own presentation based on data provided by the International Energy Agency (IEA) in Global EV Outlook 2023.

In the years 2012-2022, the number of BEVs sold increased from 58,000. in 2012 to 7.3 million. Above-average growth occurred between 2020 and 2022, when the number of BEVs sold increased by as much as 5.3 million, more than tripling in just two years. In the global car market, SUVs and larger models dominate both in the electric and combustion segments. In the United States, larger vehicles carry less stringent fuel economy standards, which encourages automakers to increase vehicle size to qualify as a light commercial vehicle. In 2022, approximately 16% of all SUVs sold were electric. Additionally, less than 40% of all available BEV models in 2022 are SUVs. In the same year, in China and Europe, SUVs and large models accounted for as much as 60% of available BEV models. However, the larger the vehicle, the more expensive the purchase price, and this creates significant affordability issues across the market, which may constitute a barrier to EV adoption, especially among lower-income households. For this reason, some countries make it easier for citizens to buy an electric car by pursuing policies supporting electromobility (IEA, 2023). For example, in 2022, Scotland introduced the possibility of obtaining an interest-free loan for used electric vehicles (Energy Saving Trust, 2024). Australia offers interest-free loans of up to AUD 15,000, with a repayment period of up to 10 years (Sustainable Household Scheme, 2024). In France, however, social leasing is offered, enabling low-income households to rent an electric car for a monthly fee of around EUR 100 (Ecologie, 2024).

In recent years, the EV market has undergone dynamic changes, influenced by factors such as economic growth and technological progress. The leaders in the BEV market are China, Europe, and the United States.

China maintains its position as the world leader in the electric car market. This country dominates both the production of batteries and vehicle components. In 2022, China's share in electric car exports was 35%. Additionally, China accounts for approximately 75% of global battery production capacity. The share of electric and plug-in hybrid cars in China's total vehicle sales rose to 29% in 2022, exceeding the country's 2025 target of 20% for new energy vehicles (NEVs). In comparison, in 2021 the share was 16%, which means a significant increase in one year (IEA, 2023).

In 2022, sales of fully electric vehicles increased by almost 63% compared to the previous year, reaching an impressive 4.4 million units, as shown in Figure 2.

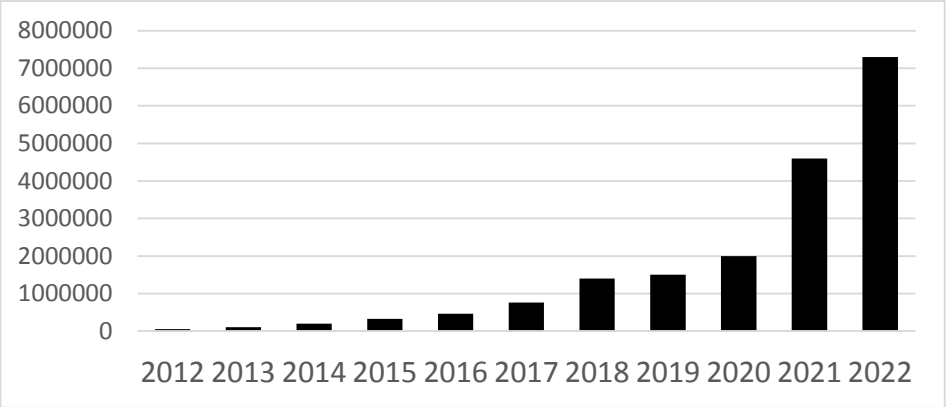


Figure 2. Number of BEVs sold in China in 2012-2022.

Source: own presentation based on data provided by the International Energy Agency (IEA) in Global EV Outlook 2023.

In 2012, the number of BEVs sold was only 9,600, in 2015 sales exceeded 150,000, and in 2017 already 470,000. The most popular models of fully electric vehicles in 2022 were Wuling Mini BEV, Tesla Model Y, and BYD Dolphin, as shown in Figure 3.

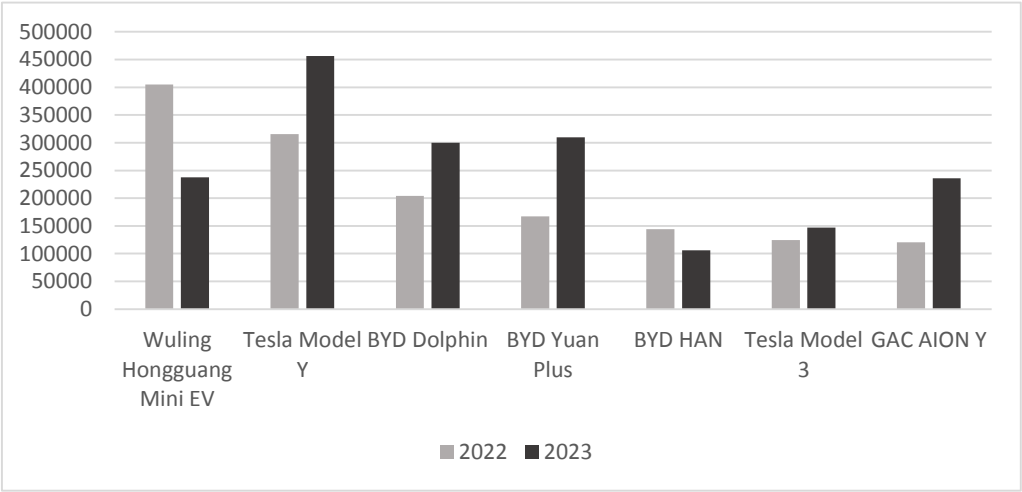


Figure 3. Most popular BEV models in China by number of vehicles sold in 2022 compared to 2023 sales.

Source: own presentation based on data provided by Yiche.

China has been supporting the development of electromobility for years through various measures on both the demand and supply sides. This policy includes, among others: subsidies for consumers and producers, as well as partnerships with international car manufacturers.

Recent years have seen rapid growth in electric vehicle sales in the United States, even as overall car sales in the country have declined. In 2022, sales of fully electric cars increased by as much as 70%. As a result, as seen in Figure 4, approximately 800,000 electric vehicles were sold in 2022.

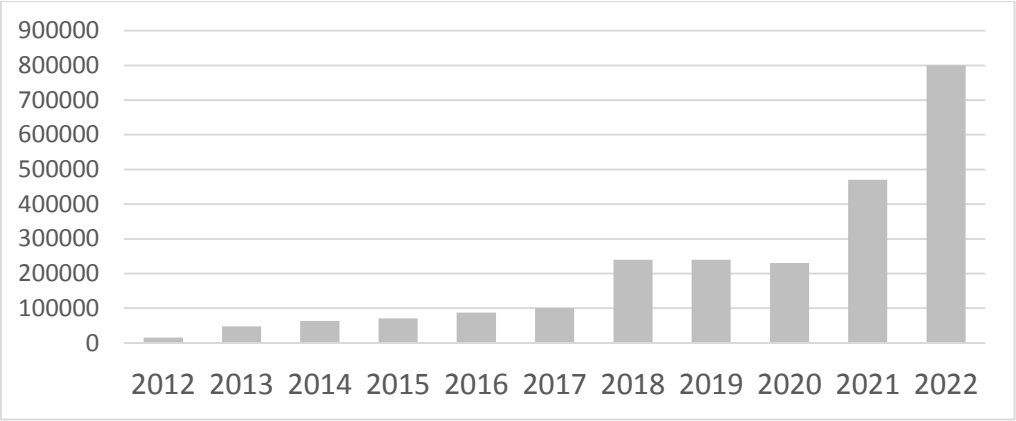


Figure 4. Number of BEVs sold in the US in 2012-2022.

Source: own presentation based on data provided by the International Energy Agency (IEA) in Global EV Outlook 2023.

Between 2012 and 2014, sales hovered around low levels, starting at 15,000 in 2012 and gradually increasing to around 63,000 in 2014. Then, between 2015 and 2017, sales increased, exceeding 100,000 vehicles in 2017. The most dynamic growth occurred in the years 2018-2022, where the number of BEVs sold increased from 240,000 in 2018 to as many as 800,000 in 2022, which was more than a threefold increase in just four years. Tesla dominates the market in the United States, as seen in Figure 5. Model Y and Model 3 took first and second place, respectively, with Model Y reporting sales of 251,974 units and Model 3 achieving 211,618 (PwC Strategy& Electric Vehicle Sales, 2022).

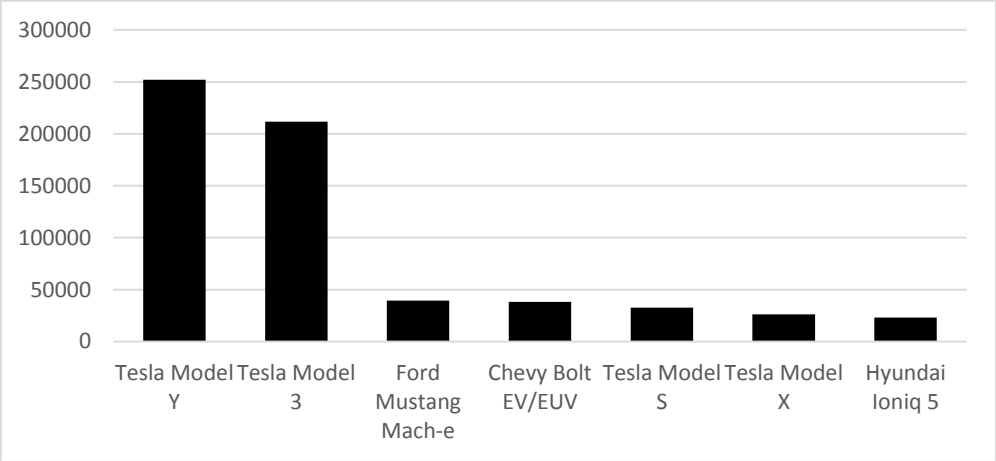


Figure 5. Most popular BEV models in the US by number of vehicles sold in 2022.

Source: own presentation based on the PwC Strategy& Electric Vehicle Sales Review Q4-2022 report.

According to the American Automobile Association (AAA), as many as a quarter of Americans are willing to buy an electric car as their next vehicle. The main concerns among respondents were the price of the vehicle and insufficiently developed charging infrastructure (AAA Research, 2024).

In Europe, the sales volume of electric cars continues to grow, as seen in Figure 6. In 2022, BEV sales increased by 30% compared to 2021. However, in 2021, these sales increased by 65% compared to the previous year.

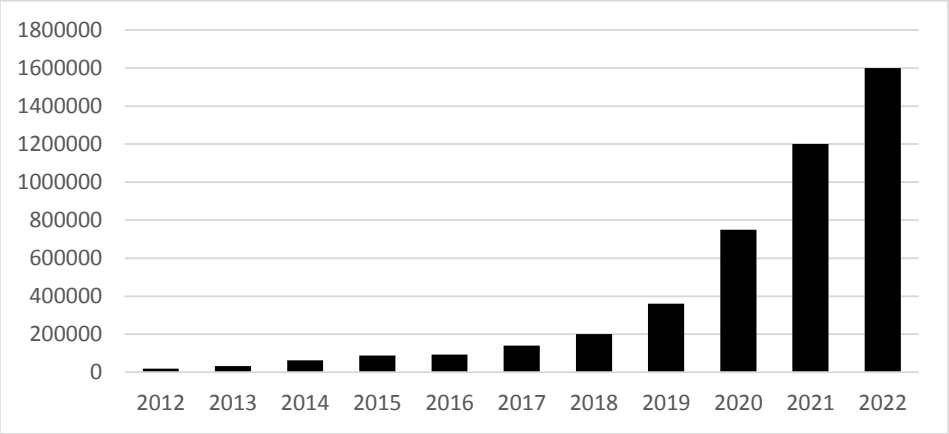


Figure 6. Number of BEVs sold in Europe in 2012-2022.

Source: own presentation based on data provided by the International Energy Agency (IEA) in Global EV Outlook 2023.

The slowdown in growth is noticeable in the context of exceptional growth in electric car sales in 2020 and 2021. During this time, car manufacturers were adapting their corporate strategies to meet the European Union's stricter CO2 emissions standards for passenger cars and commercial vehicles in 2019. The new regulations cover the period from 2020 to 2024, moreover, the European Union plans to tighten them further from 2025 (European Commission, 2023). In recent years, not only have the prices of gasoline and diesel oil for combustion vehicles increased, but in some cases, the price of electricity has also increased noticeably, which has meant higher production costs for both combustion and electric cars.

In recent years, there has been an increase in interest in electric vehicles from both producers and consumers. This is evidenced by the increase in the number of available BEV models in Europe. Particularly impressive growth occurred between 2020 and 2022, where the number of available models increased from 97 to 253 (European Alternative Fuels Observatory, 2024).

3.3. Determinants of electric car sales

Over recent years, many studies have been conducted to define the factors influencing the sales of all-electric cars. Particular attention was paid to factors such as:

- socio-economic factors,
- psychological and social factors,
- technological factors,
- government support,
- market and economic conditions.

Zhang, Yu and Zou (2011) showed that variables such as income and education influence Chinese citizens' EV purchasing decisions. In Sweden, Westin, Jansson and Nordlund (2018) also examined the factors influencing the decision to own an electric car using logistic regression analysis. The focus was on sociodemographic characteristics, geographical conditions and personal norms. Sociodemographic characteristics such as age and education level have been shown to increase the propensity to own an electric car. Results from a more recent study by Nazari et al. (2019) conducted on residents of the United States suggest that an increase in disposable income leads to the purchase of a car regardless of its type of drive. In recent years, it has also been examined whether owners of electric and traditional cars differ in socioeconomic factors. Simsekoglu (2018) showed that buyers of electric cars often have higher incomes and better education compared to buyers of conventional cars. High income allows you to cover the costs associated with purchasing an EV.

The relationship between ecological awareness and the expression of interest in purchasing an electric car was also examined. As a study by Egbue and Long (2012) suggests, consumers who are environmentally aware and committed to reducing their carbon footprint may not decide to purchase an electric vehicle if it is powered by electricity from coal or natural gas.

Additionally, Thøgersen and Ebsen (2019) suggest that people are more willing to purchase electric vehicles if they perceive their increasing acceptance and positive reception in their social circles. The limited range of electric vehicles and insufficiently developed charging infrastructure constitute barriers to electromobility. Alanazi (2023) proposed that to effectively encourage consumers to purchase electric cars, the focus should be on improving the performance of these vehicles and improving battery technology. Hall and Lutsey (2017) emphasize that a developed charging infrastructure is necessary for the transition to electromobility, as it reduces concerns about the vehicle's range among potential buyers of electric cars. Also, Illmann and Kluge (2019) showed that charging speed is more important to consumers than the number of available charging points. This research suggests that investing in fast-charging technology may be more effective than increasing the number of lower-power chargers.

Government support in the form of incentives such as tax breaks, privileges, and financial subsidies is one of the most frequently taken into account factors when examining the demand for electric cars. Jenn, Springel, and Gopal (2018) showed that every $1,000 in rebates or tax credits increases average BEV and PHEV sales by 2.6%. Xue et al. (2021) used a panel model with random effects and confirmed that tax breaks have a positive impact on the development of the EV market. Rietmann and Lieven (2019) found that a wide range of policy incentives in a given country leads to a higher market share of electric cars. A study conducted by Tang and Sun (2019) used a linear regression model to analyze the factors influencing the sales of electric vehicles. The price of crude oil has been shown to influence NEV sales. In a more recent study, Gong (2022) used a fixed-effects panel model to examine the relationship between NEV sales

and fuel prices and showed that there was a relationship between EV sales and gasoline prices, with gasoline price having a greater impact on EV sales than the price of crude oil.

To sum up, the review of research on the factors influencing the electric car market shows that consumer decisions in this area are complex and depend on many factors. Further research in this area is necessary to better understand these relationships and enable more effective promotion of sustainable mobility and support the development of this industry.

According to economic theories, the factors that influence the demand for cars may be education, income, the price of gasoline, the price of crude oil, and the availability of fast charging points. Education may influence the acceptance and purchase of new technologies, which is in line with the theory of diffusion of innovations. The higher the level of education, the greater the ecological awareness and willingness to adopt new, ecological technologies, such as electric cars (Rogers, 1983). According to Engel's law, the higher the income, the greater the share of spending on luxury goods in total expenditure. Due to their price, electric cars are still treated as luxury goods. High income may mean a greater ability to invest in more expensive but more innovative solutions, such as electric cars. The price of gasoline may influence the decision to purchase electric cars, according to rational choice theory. The relatively high increases in gasoline prices observed in recent years may encourage consumers to choose more economical alternatives to traditional passenger cars, such as BEVs. The price of oil can influence fuel prices and, consequently, consumer decisions, again in line with rational choice theory. Fluctuations in oil prices may encourage the purchase of electric cars. The availability of fast charging points for electric cars may reduce the risks associated with the use of electric cars. This is consistent with the perceived risk theory. Easy access to fast charging increases the convenience and practicality of using BEVs, which may increase their sales. The availability of fast charging infrastructure is crucial for potential BEV buyers, who are often afraid of problems with vehicle range and charging - its time and availability.

3.4. Electric car markets for empirical analysis

To examine the factors influencing the development of the electric passenger car market in Europe, it is worth focusing on the geographical and cultural diversity of the region. Therefore, the following countries were selected for the study: Germany, the United Kingdom, Norway, Spain and Poland. These countries differ not only in their geographical location but also in the dynamics of the development of the electric car market. According to EuroVoc, the European Union's official multilingual thesaurus, Europe can be divided into the following regions: Northern Europe, Southern Europe, Western Europe, and Central and Eastern Europe.

Germany, as the dominant country on the BEV market in Europe, represents the western region of Europe. This country has been distinguishing itself from other European countries for years in terms of the number of registrations and sales of electric cars. In 2023, as many as 524,219 new BEVs were registered (ACEA, 2023). Additionally, Germany is an important country for the European Union, both economically and politically (eu2020, 2020). The most

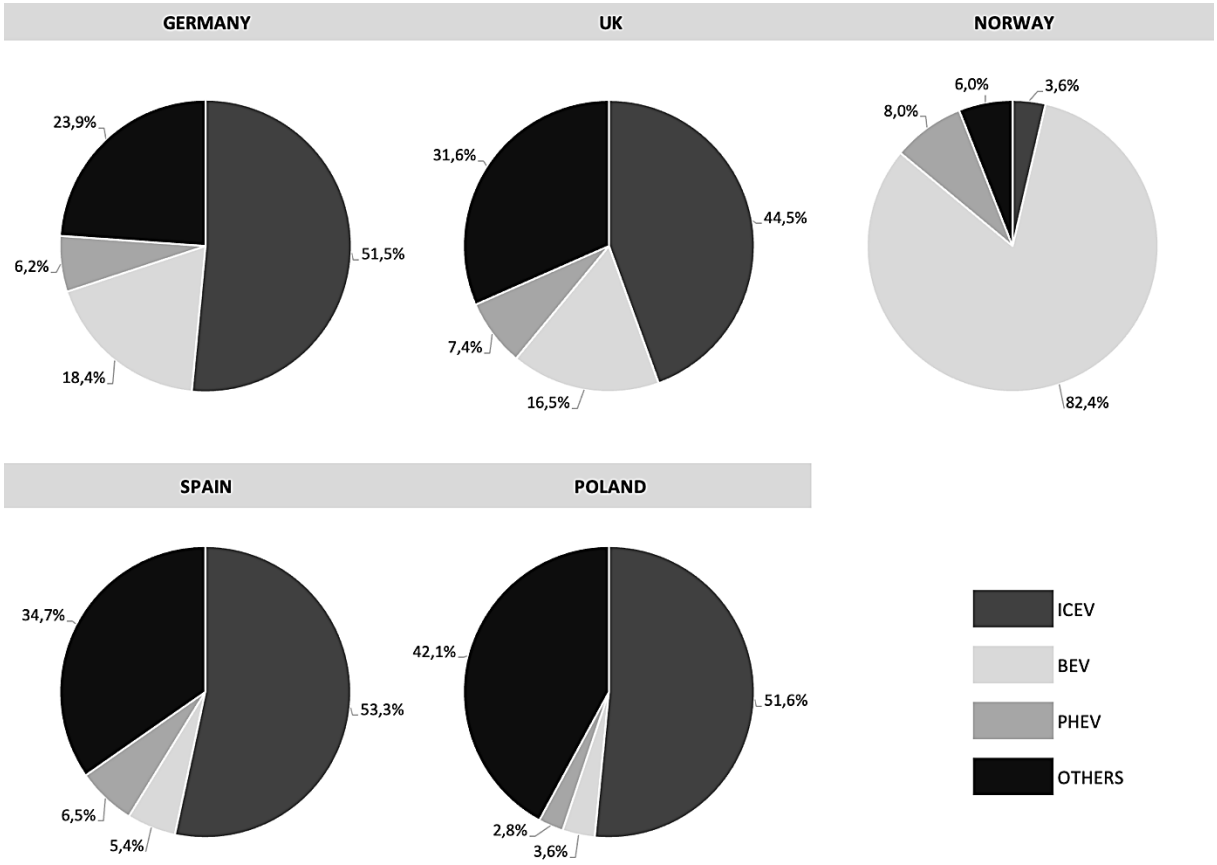
popular BEV models in 2023 were: Tesla Model Y, Volkswagen ID. 4, and Skoda Enyaq (EAFO, 2024). In the same year, the number of publicly available charging points was 108,000, of which 21,000 points were fast charging and 87,000 were slow charging (IEA, 2024). The national system of incentives and regulations supports the development of the electric vehicle market. The tax benefits include a 10-year tax exemption for electric-only vehicles registered until December 31, 2025. The tax exemption is valid until December 31, 2030 (Wappelhors, 2020). In December 2023, the Federal Office for Economic Affairs and Export Control (BAFA, germ: Bundesamt für Wirtschaft und Ausfuhrkontrolle) announced the sudden termination of the subsidy program for the purchase of electric cars (BAFA, 2024).

The United Kingdom, also part of Western Europe, left the European Union but nevertheless remained one of the largest electric car markets in Europe, making it an important representative of this region (SMMT, 2024). In 2023, the Tesla Model Y, MG4 EV and Audi Q4 e-tron were the most popular BEV models. In the same year, 314,688 electric cars were registered (EAFO, 2024). The government supports the development of charging infrastructure and offers subsidies for the installation of charging points through initiatives such as the Electric Vehicle Homecharge Scheme (EVHS) and the Workplace Charging Scheme (WCS), (Department for Transport, 2023).

Norway, as a representative of Northern Europe, has the largest share of electric cars in passenger vehicle registrations in the world. In 2023, the share of BEVs in new registered passenger cars was as high as 82.4%, making Norway a world leader in the adoption of electric vehicles (OFV, 2024). In 2023, the most popular car model was the Tesla Model Y, which reached 23,088 registrations. This was followed by the Volkswagen ID.4 and Skoda Enyaq models, with 6,614 and 5,906 registrations respectively. In 2022, the total number of newly registered BEV passenger cars amounted to 138,287 (EAFO, 2024). Norway continues to encourage the use of electric vehicles, including VAT exemption and tax breaks for companies. In addition, people using electric cars receive benefits in the form of reduced road tolls and the ability to use bus lanes (Norwegian EV policy, 2024).

Spain, representing Southern Europe, has seen a significant increase in BEV sales in recent years, with 33,000 units sold in 2022 and 57,000 units sold in 2023, demonstrating the growing interest in electric vehicles. In 2023, the number of publicly available charging points was 25,600, including 6,600 fast charging points and 19,000 slow charging points (IEA, 2024). In the same year, the most popular BEV models were Tesla Model Y, Tesla Model 3, and MG4 EV (EAFO, 2024). Spain supports the development of electromobility through initiatives such as the Moves program. The third edition of the program, known as Moves III, aims to make it easier for citizens to purchase electric cars through financial support and the development of charging infrastructure. The program budget is partially financed by the European Regional Development Fund (ERDF). The program includes subsidies, the amount of which depends on the vehicle category (Programa Moves III, 2024). Spain represents a relatively small but growing market in terms of electric car sales.

Poland, representing Central and Eastern Europe, is characterized by a slower pace of development of the BEV market compared to Western and Northern European countries. In 2023, the share of BEVs in newly registered passenger cars was 3.6%, slightly more than in the previous year (PZPM, 2023). In the same year, the number of newly registered electric cars was 17,083. The most frequently purchased models were Tesla Model Y, Tesla Model 3 and Audi Q4 e-tron (EAFO, 2024). The Polish government offers citizens support for the purchase of electric cars through the "My Electrician" program, which aims to minimize the emission of harmful substances into the environment by co-financing the purchase or leasing of zero-emission vehicles (National Fund, 2024). The countries mentioned above differ in the share of electric cars in newly registered vehicles, as can be seen below in Figure 7.



The category "others" includes full and mild hybrids, fuel-cell electric vehicles, natural gas vehicles, LPG, E85/ethanol, and other fuels.

Figure 7. New car registrations by power source in selected countries in 2023.

Source: own presentation based on data provided by the European Automobile Manufacturers Association (ACEA).

To identify the factors shaping the demand for electric cars in various regions of Europe, we focused on five countries: Germany, the United Kingdom, Norway, Spain and Poland. These countries differ in many aspects, including geographical location, but also the degree of development of the electric car market. The data used in the study are annual and cover the years 2012-2022.

Based on a review of the literature and economic theories, variables were selected that could potentially be factors influencing the level of electric car sales. The proposed linear model took the form:

$$BEV_t = \beta_0 + \beta_1 EDUC_t + \beta_2 INCM_t + \beta_3 PV_t + \beta_4 SFS_t + \beta_5 NFS_t + \beta_6 CRUDE_t + \varepsilon_t \quad (1)$$

where:

BEV – number of electric cars sold (units),

EDUC – share of people with higher education in the population (%),

INCM – median equivalent net income (national currency) for Germany, Norway, Spain and Poland; median gross income for the UK (£),

PV – price for 1,000 liters of 95-octane unleaded motor gasoline (national currency),

SFS – share of fast chargers in publicly available charging points (%),

NFS – number of fast chargers (units),

CRUDE – average crude oil price ($/bbl),

$\beta_0, \beta_1, \ldots, \beta_6$ – structural parameters,

ε – error term.

The model proposed was estimated in the gretl program. The ordinary least square estimation method (OLS) was in use. The first step of verification of the model was a qualitative assessment of the compliance of the signs and values of structural parameters with economic theory. The next step is quantitative evaluation using diagnostic tests and measures of goodness of fit to real data. The following tests for error terms are applied: for the normality of the distribution of the error terms the Doornik-Hansen test, for the heteroscedasticity the White test, and for the autocorrelation of error terms the Durbin-Watson test. For the correctness of the selection of the analytical form of the model by the Ramsey RESET test is appropriate. The individual significance of structural parameters is tested using the t-test. The goodness of fit measures used in this analysis are the coefficient determination R^2 and the standard deviation of the residuals *SE*.

In the case that the Ramsey RESET test statistic indicated an incorrectly selected form of the model, its exponential form was estimated:

$$lnBEV_t = \beta_0 + \beta_1 EDUC_t + \beta_2 INCM_t + \beta_3 PV_t + \beta_4 SFS_t + \beta_5 NFS_t + \beta_6 CRUDE_t + \varepsilon_t \quad (2)$$

or logarithmic form:

$$lnBEV_t = \beta_0 + \beta_1 lnEDUC_t + \beta_2 lnINCM_t + \beta_3 lnPV_t + \beta_4 lnSFS_t + \beta_5 lnNFS_t + \beta_6 lnCRUDE_t + \varepsilon_t \quad (3)$$

The model is considered correct if the signs of the estimated structural parameters are consistent with economic theory. Error terms should be normally distributed with constant variance and be uncorrelated with each other.

The data used for the analysis come from the websites of financial institutions. The exact sources of data broken down by variables and countries are included in Table 2.

Table 2.
Sources of data according to variables and countries

Country/variable	Germany	UK	Norway	Spain	Poland
BEV	IEA	IEA	IEA	IEA	IEA
EDUC	OECD	OECD	OECD	OECD	OECD
INCM	Eurostat	ONS	Eurostat	Eurostat	Eurostat
PV	Wirtschaftsverb Fuels und Energie	ONS	Statistisk Sentralbyrå	Ministerio para la Transición Ecológica y el Reto Demográfico	GUS
SFS	IEA	IEA	IEA	IEA	IEA
NFS	IEA	IEA	IEA	IEA	IEA
CRUDE	World Bank	World Bank	World Bank	World Bank	World Bank

Source: own presentation.

4. Results and discussion

The dependent variable in this study was the number of electric passenger cars sold during the year in each of the surveyed countries. Monitoring this variable can help assess the level of adoption of electric vehicle technology, geographically, culturally and economically. The development of this variable in the studied countries is presented in Figure 8.

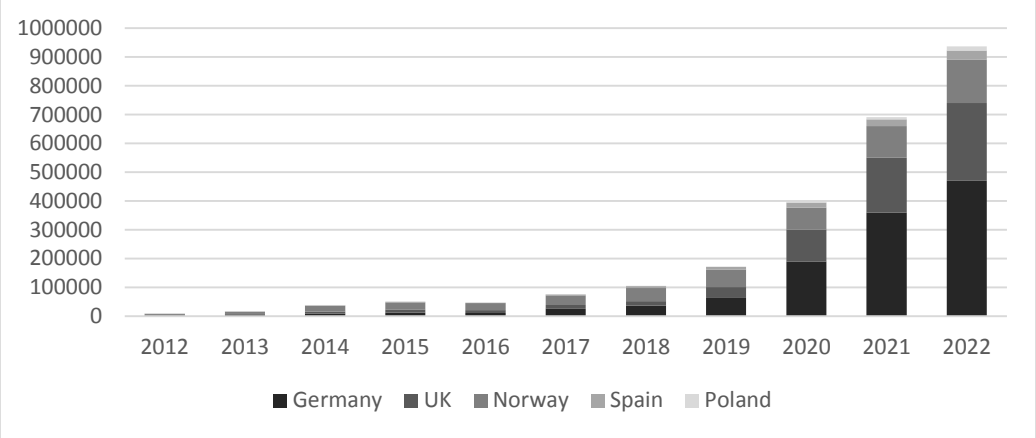


Figure 8. Sales of electric cars in selected countries, 2012-2022.

Source: Own presentation based on IEA (2024).

As already mentioned, the empirical analysis covered data from five European countries. The analytical form of the model for each country was selected using the Ramsey RESET test. The starting point was model (1). Then, during work on the model, variables that had a statistically insignificant impact on the number of electric cars sold were removed. The final estimation results are presented in Table 3.

Table 3.
Estimates of the model of electric car sales

Country/model form	Germany exponential	UK exponential	Norway logarithmic	Spain logarithmic	Poland exponential
const	-1.055	-9.047	-159.957	1.918	-2.486
EDUC		0.343***			
INCM	0.001***		13.318***		0.0003***
PV					
SFS		0.083**			
NFS	0.0001**			1.046***	
CRUDE					
Determ. coeff. R^2	0.954	0.964	0.958	0.954	0.953
Stand. dev. SE	0.423	0.351	0.234	0.286	0.485
Durbin-Watson test stat.	1.653	1.666	2.346	2.307	2.111
Doornik-Hansen test stat.	3.336	2.641	2.161	0.751	1.187
White test stat.	3.893	7.505	3.067	0.272	1.463
RESET Ramsey test stat.	0.682	1.992	1.181	1.309	2.121

*)**)***) statistically significant at 0.1; 0.05 and 0.01 significance levels. #) at 0.05 significance level, the null hypothesis should be rejected.

Source: own estimations.

As can be seen, all estimated models are well-fitted to the real data, as evidenced by the high value of the coefficient of determination (close to one) and the relatively low value of the standard deviation of the residuals. Moreover, stochastic assumptions were met for all of them, i.e. the error terms of the models are normally distributed with constant variance, and in each case there is no first-order autocorrelation. The analytical form of each model was selected correctly.

For each country, it was possible to identify factors influencing the level of electric car sales. However, they were not the same for sales in all analyzed countries. The factor of median equivalent net income has a statistically significant impact on BEV sales in Germany, Norway, and Poland, which is what these countries have in common. It turned out that it had no statistically significant impact on the sales of this type of junk in the United Kingdom and Spain. Another factor, the share of people with higher education in the population, has a statistically significant impact on sales only in the United Kingdom, which distinguishes this country from Germany, Norway, Poland, and Spain, for which no such impact was observed. The number of public fast charging points influences BEV sales in Germany and Spain but has no such effect in the UK, Norway, and Poland. In turn, the share of fast charging points in publicly available charging points is significant only in the United Kingdom, but not in Germany, Norway, Poland, and Spain. This result is not surprising due to the relationship between these two factors.

The occurrence of differences in the impact of individual factors on BEV sales confirms the hypothesis that these sales in different regions of Europe are not always determined by the same factors. The above results allow for suggestions on further actions to increase the popularity of electric cars. Activities to promote electromobility should focus primarily on increasing the

number of publicly available fast charging points. Additionally, state policies focused on subsidizing the purchase of an electric car may facilitate the purchase of such a vehicle among households with insufficient income.

5. Summary

In the face of global challenges related to the Sustainable Development Goals, the world is working to combat climate change. This is inextricably linked to environmental protection, including reducing CO2 emissions. The popularization of electric cars has become a key element of the strategy to reduce Europe's dependence on fossil fuels. This topic is very important in the context of current environmental, economic, and political challenges. It was addressed in this work to identify factors influencing the sales of electric cars, which may help create more effective strategies to promote electromobility. Moreover, the development of electromobility is an integral part of the pursuit of sustainable development, which assumes a harmonious combination of economic development, environmental protection and improvement of the quality of life of communities. The implementation of electromobility not only reduces greenhouse gas emissions but also supports technological innovation, which has a positive impact on economic growth.

Interest in electric cars has increased rapidly in recent years. However, different drivers' preferences are observed depending on the geographic region. In China, drivers prefer smaller vehicles with a shorter range but an affordable price, while people in Europe prefer larger vehicles with a long range. Many countries pursue policies supporting the purchase of electric cars and invest in charging infrastructure. Additionally, the European Union encourages Member States, through various regulations and provisions, to abandon combustion vehicles in favor of purely electric vehicles.

The conducted empirical analysis showed that there are differences in the factors determining the sale of electric cars in the surveyed countries. Therefore, the research hypothesis established in the introduction was confirmed. There are various reasons why residents of the analyzed countries decide to buy electric cars. An important aspect is the level of ecological awareness of European residents, which influences decisions about purchasing an electric vehicle. European governments should focus on increasing this awareness. A direction for further research would be to assess the impact of variables such as government support, subsidies, and the presence of environmental regulations on the sales of electric cars in Europe.

References

1. *AAA Research: 25% of Americans say They'd Buy an EV for their Next Auto Purchase*. Retrieved from: https://info.oregon.aaa.com/aaa-research-25-of-americans-say-theyd-buy-an-ev-for-their-next-auto-purchase/, 8.04.2024.
2. ACEA (2023). *New Car Registrations, European Union.* Retrieved from: https://www.acea.auto/files/Press_release_car_registrations_full_year_2023.pdf, 8.04.2024.
3. Alanazi, F. (2023). Electric Vehicles: Benefits, Challenges, and Potential Solutions for Widespread Adaptation. *Applied Sciences, Vol. 13, Iss. 10*, 6016, doi: 10.3390/app13106016.
4. BAFA (2024). *Die Förderung des Absatzes von elektrisch betriebenen Fahrzeugen (Umweltbonus) ist ausgelaufen*. Retrieved from: https://fms.bafa.de/BafaFrame/login?redirect=/fems, 8.04.2024.
5. Buberger, J., Kersten, A., Kuder, M., Eckerle, R., Weyh, T., Thiringer, T. (2022). Total CO2-equivalent life-cycle emissions from commercially available passenger cars. *Renewable and Sustainable Energy Reviews, Vol. 159*, 112158, doi: 10.1016/j.rser.2022.112158.
6. Chmielewski, M., Śledzik, K., Płoska, R., Malinowska, E., Pęksyk, M. (2024). Multivariate Sustainable Development Goals Analysis – Competitive Position Of European Countries in 2022. *Scientific Papers of Silesian University of Technology. Organization and Management Series, No. 192*, pp. 63-78, doi: 10.29119/1641-3466.2024.192.4.
7. Department for Transport (2023). *Electric vehicle charging device grant scheme statistics: April 2023*. Retrieved from: https://www.gov.uk/government/statistics/electric-vehicle-charging-device-grant-scheme-statistics-april-2023/electric-vehicle-charging-device-grant-scheme-statistics-april-2023, 8.04.2024.
8. EAFO (2024). *Germany*. Retrieved from: https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/germany, 28.04.2024.
9. EAFO (2024). *Norway*. Retrieved from: https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/norway, 28.04.2024.
10. EAFO (2024). *Poland*. Retrieved from: https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/poland, 28.04.2024.
11. EAFO (2024). *Spain*. Retrieved from: https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/spain, 28.04.2024.
12. EAFO (2024). *United Kingdom*. Retrieved from: https://alternative-fuels-observatory.ec.europa.eu/transport- mode/road/united-kingdom, 28.04.2024.

13. Ecologie (2023). *Changements et entrées en vigueur au 1er janvier 2023.* Retrieved from: https://www.ecologie.gouv.fr/changements-et-entrees-en-vigueur-au-1er-janvier-2023, 8.04.2024.
14. Egbue, O., Long, S. (2012). Barriers to Widespread Adoption of Electric Vehicles: An Analysis of Consumer Attitudes and Perceptions. *Energy Policy, Vol. 48*, pp. 717-729, doi: 10.1016/j.enpol.2012.06.009.
15. *Electric vehicle model statistics.* Retrieved from: https://alternative-fuels-observatory.ec.europa.eu/policymakers-and-public-authorities/electric-vehicle-model-statistics, 8.04.2024.
16. European Commission (2024). *CO2 emission performance standards for cars and vans.* Retrieved from: https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en, 22.04.2024.
17. *Germany, a country in the heart of Europe - EU2020 - EN.* Retrieved from: https://www.eu2020.de/eu2020-en/presidency/germany-history-background-eucouncilpresidency-laender/2361346, 8.04.2024.
18. Gong, C. (2022). *The impact of oil prices on the sales of new energy vehicles in China: Empirical study of different vehicle models.* 7th International Conference on Social Sciences and Economic Development (ICSSED 2022). Atlantis Press, pp. 273-280. doi: 10.2991/aebmr.k.220405.046.
19. Hall, D., Lutsey, N. (2017). *Emerging best practices for electric vehicle charging infrastructure.* Retrieved from: https://theicct.org/sites/default/files/publications/EV-charging-best-practices_ICCT-white-paper_04102017_vF.pdf, 28.04.2024.
20. IEA (2023). *Global EV Outlook 2023*. Retrieved from: https://iea.blob.core.windows.net/assets/dacf14d2-eabc-498a-8263-9f97fd5dc327/GEVO2023.pdf, 8.04.2024.
21. IEA (2024). *Global EV Outlook 2024 data.* Retrieved from: https://www.iea.org/data-and-statistics/data- product/global-ev-outlook-2024, 28.04.2024.
22. Illmann, U., Kluge, J. (2020). Public Charging Infrastructure and the Market Diffusion of Electric Vehicles. *Transportation Research Part D: Transport and Environment, Vol. 86*, 102413, doi: 10.1016/j.trd.2020.102413.
23. Jenn, A., Springel, K., Gopal, A.R. (2018). Effectiveness of electric vehicle incentives in the United States. *Energy Policy, Vol. 119, Iss. C*, pp. 349-356, doi: 10.1016/j.enpol.2018.04.065.
24. Lebeau, K., Van Mierlo, J., Lebeau, P., Mairesse, O., Macharis, C. (2013). Consumer attitudes towards battery electric vehicles: A large-scale survey. *International Journal of Electric and Hybrid Vehicles, Vol. 5, Iss. 1*, pp. 28-41, doi: 10.1504/IJEHV.2013.053466.
25. McKinsey, A.R.F. (2014). EVolution Electric Vehicles in Europe: Gearing up for a New Phase? *Amsterdam Round Table: Amsterdam, The Netherland*. Retrieved from: https://www.mckinsey.com/~/media/McKinsey/Locations/Europe%20and%20Middle%20

East/Netherlands/Our%20Insights/Electric%20vehicles%20in%20Europe%20Gearing%20up%20for%20a%20new%20phase/Electric%20vehicles%20in%20Europe%20Gearing%20up%20for%20a%20new%20phase.pdf, 8.04.2024.

26. National Fund for Environmental Protection and Water Management (2024). *O programie – Elektromobilność*. Retrieved from: https://www.gov.pl/web/elektromobilnosc/o-programie, 28.04.2024.
27. Nazari, F., Noruzoliaee, M., Mohammadian, A. (2023). Electric Vehicle Adoption Behavior and Vehicle Transaction Decision: Estimating an Integrated Choice Model with Latent Variables on a Retrospective Vehicle Survey. *Transportation Research Record: Journal of the Transportation Research Board, Vol. 2678, Iss. 4*, pp. 378-397, doi: 10.1177/03611981231184875.
28. *Norwegian EV policy*. Retrieved from: https://elbil.no/english/norwegian-ev-policy/, 28.04.2024.
29. OFV (2024). *Usikkerhet og stram økonomi bremset nybilsalget i 2023*. Retrieved from: https://ofv.no/aktuelt/2024/usikkerhet-og-stram-økonomi-bremset-nybilsalget-i-2023, 8.04.2024.
30. Piąstka, R., Jajczyk, J., Bednarek, K. (2020). Charakterystyka procesu komunikacji podczas ładowania baterii pojazdu elektrycznego. *Poznan University of Technology Academic Journals. Electrical Engineering, No. 105*, pp. 37-47, doi: 10.21008/j.1897-0737.2020.105.0004.
31. *Programa Moves III.* Retrieved from: https://www.idae.es/ayudas-y-financiacion/para-movilidad-y-vehiculos/programa-moves-iii, 28.04.2024.
32. PSPA (2020). *Kompendium Elektromobilności, Infografiki. Wydanie II.* Retrieved from: https://pspa.com.pl/wp-content/uploads/2020/08/kompendium_elektromobilnosci_raport_2020_S.pdf, 8.04.2024.
33. PwC (2022). *Strategy & Electric Vehicle Sales Review Q4-2022*. Retrieved from: https://www.strategyand.pwc.com/tr/tr/pdf/electric-vehicle-sales-review-q4-2022.pdf, 8.04.2024.
34. PZPM (2023). *Registrations of PC and LCV in December 2023.* Retrieved from: https://www.pzpm.org.pl/en/Automotive-market/FIRST-REGISTRATIONS-PZPM-CEP/Passenger-Cars-Light-Commercial-Vehicles/Year-20232, 8.04.2024.
35. Rietmann, N., Lieven, T. (2019). A Comparison of Policy Measures Promoting Electric Vehicles in 20 Countries: Towards New Organizational Structures for the Development of Shared, Automated, Electric and Integrated Mobility. In: M. Finger, M. Audouin (Eds.), *The Governance of Smart Transportation Systems. The Urban Book Series* (pp. 125-145). Cham: Springer, doi: 10.1007/978-3-319-96526-0_7.
36. Rogers, E.M. (1983). *Diffusion of Innovations*. Canada: Free Press, pp. 1-453.
37. Schill, W.P. (2020). Electricity Storage and the Renewable Energy Transition. *Joule, Vol. 4, Iss. 10*, pp. 2059-2064, doi: 10.1016/j.joule.2020.07.022.

38. Sienkowicz, K., Drzewosz, A. (2013). Możliwości zmniejszenia negatywnego wpływu transportu samochodowego na środowisko przez zastosowanie alternatywnych paliw i układów napędowych. *Zeszyty Naukowe Politechniki Poznańskiej seria Organizacja i Zarządzanie, No. 60*, pp. 97-110.
39. Şimşekoğlu, Ö. (2018). Socio-demographic characteristics, psychological factors and knowledge related to electric car use: A comparison between electric and conventional car drivers. *Transport Policy, Vol. 72*, pp. 180-186, doi: 10.1016/j.tranpol.2018.03.009.
40. Śliwka, M., Łyko, P., Pomykała, R. (2015). Aspekty ekonomiczne i ekologiczne wybranych alternatywnych źródeł zasilania samochodów osobowych. *Logistyka, Logistyka – nauka, No. 4, CD 3*, pp. 9865-9870.
41. SMMT (2024). *UK reaches million EV milestone as new car market grows.* Retrieved from: https://www.smmt.co.uk/2024/02/uk-reaches-million-ev-milestone-as-new-car-market-grows/, 8.04.2024.
42. *Sustainable Development.* Retrieved from: https://sdgs.un.org, 17.07.2024.
43. Tang, L., Sun, J. (2019). Predict the sales of New-energy Vehicle using linear regression analysis. *E3S Web of Conferences, Vol. 118*, 02076, doi: 10.1051/e3sconf/201911802076.
44. Thøgersen, J., Ebsen, J.V. (2019). Perceptual and motivational reasons for the low adoption of electric cars in Denmark. *Transportation Research Part F: Traffic Psychology and Behaviour, Vol. 65*, pp. 89-106, doi: 10.1016/j.trf.2019.07.017.
45. *Used Electric Vehicle Loan - Energy Saving Trust.* Retrieved from: https://energysavingtrust.org.uk/grants-and-loans/used-electric-vehicle-loan/, 08.04.2024.
46. Ustawa z dnia 11 lipca 2018 r. o elektromobilności i paliwach alternatywnych. Dz.U. 2023, poz. 875, ISAP (2023).
47. Westin, K., Jansson, J., Nordlund, A. (2018). The importance of socio-demographic characteristics, geographic setting, and attitudes for adoption of electric vehicles in Sweden. *Travel Behaviour and Society, Vol. 13*, pp. 118-127, doi: 10.1016/j.tbs.2018.07.004.
48. Xue, C., Zhou, H., Wu, Q., Wu, X., Xu, X. (2021). Impact of Incentive Policies and Other Socio- Economic Factors on Electric Vehicle Market Share: A Panel Data Analysis from the 20 Countries. *Sustainability, Vol. 13, No. 5*, 2928, doi: 10.3390/su13052928.
49. *Yiche Top Ranking*. Retrieved from: https://car.yiche.com/salesrank/?energy=2&flag=2023, 8.04.2024.
50. Zhang, Y., Yu, Y., Zou, B. (2011). Analyzing public awareness and acceptance of alternative fuel vehicles in China: The case of EV. *Energy Policy, Vol. 39, Iss. 11*, pp. 7015-7024, doi: 10.1016/j.enpol.2011.07.055.