PRACE NAUKOWE
Uniwersytetu Ekonomicznego we Wrocławiu
RESEARCH PAPERS
of Wroclaw University of Economics and Business

Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu
Research Papers of Wroclaw University of Economics and Business
Year 2024, Vol. 68, No. 1
ISSN 2392-0041

Electromobility in Poland Compared to the European Union – Results of Preliminary Analysis

Paulina Bełch

Rzeszow University of Technology

e-mail: pbelch@prz.edu.pl

ORCID: 0000-0002-6877-2870

Elżbieta Szczygieł

University of the National Education Commission, Krakow

e-mail: elzbieta.szczygiel@up.krakow.pl

ORCID: 0000-0002-8804-1071

Marzena Hajduk-Stelmachowicz

Rzeszow University of Technology

e-mail: marzenah@prz.edu.pl

ORCID: 0000-0003-4945-7207

Qote as: Bełch, P., Szczygieł, E., and Hajduk-Stelmachowicz, M. (2024). Electromobility in Poland Compared to the European Union – Results of Preliminary Analysis. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, *68*(1), 1-13.

DOI: 10.15611/pn.2024.1.01

JEL Classification: M29, R40, Q50, N74

Abstract: The article analyses the trends in the growth of electric vehicles (EVs) in Poland compared to the EU. Verification of the assumed objective required the application of research methods such as analysis of domestic and foreign literature, analysis of statistical data, and statistical inference. This article commences a series of publications on sustainable transport management and electromobility in Poland and selected European countries. The number of electric vehicles (BEV and PHEV) is still increasing in Europe, including Poland. In 2010, there were 591 registered EVs only which was only 0.005% of the whole number of cars registered in Europe. For the first time, the share of EVs exceeded 1% in 2015 (130,900 electric vehicles), and in 2020 more than 10% of EVs were in Europe (in 2021, 17.8%). The largest share of EVs in the total number of cars was recorded in 2021 in Norway (86%), in Iceland (64%), and in Sweden (46%). At the same time, the countries with the highest number of EVs include Germany (more than 2.5 million), France (1.7 m.), and Italy (1.4 m.).

Keywords: electromobility, Poland, EU, analysis, transport, sustainable transport management

1. Introduction

Transport research focuses on different aspects of transport (see Belch et al., 2021; Belch and Rogaczewski, 2020; De Moraes et al., 2022; Dobrzanski et al., 2020; Hajduk-Stelmachowicz and Makowiecki, 2021; Hecht et al., 2022; Huber, Klauenberg, and Thaller, 2015, pp. 1-14; Šafrová, Hejduková 2021; Xu et al., 2020).

Recent research responding to the problems arising from the energy crisis and the spectre of the climate crisis refers specifically to improving the efficiency of energy use (Hajduk-Stelmachowicz, 2018). An energy audit is not only important in the context of optimising the energy consumption of means of transport. It is also important with regard to the diversification of energy sources and their use throughout the life cycle. It is becoming increasingly important to gradually move away from fossil fuels towards the use of, for example, hydrogen fuel or other sources of so-called green energy.

In the United States, there are currently over 275,000 plug-in electric vehicles (PEVs) on the roads, marking a significant increase since 2011 (Egbue et al., 2017). Since the introduction of electric vehicles to the market in 2010, their sales in Europe have been growing fourfold annually, reaching around 60,000 PEVs sold by 2013. As of September 2021, over 2 million electric vehicles were sold in Europe [Trends in Electric Light-Duty Vehicles]. China, as the fastest-growing market for electric vehicles (EVs), is implementing a strategy where, by 2025, electric vehicles are expected to constitute 20% of the total sales of new cars. The government of China has also set a goal that by 2035, all new cars will be sold as 'new energy vehicles' (NEVs). This category will include both fully electric vehicles and plug-in hybrid vehicles [*China Considers*…]. In recent research conducted in Germany, the sales of electric vehicles have shown an annual doubling trend over the past two years, as reported by Hecht et al. in 2022 and documented on www.mobility-chaarts.de. Notably, the battery capacity and charging power per vehicle have been on the rise. An encouraging aspect is the potential reduction in battery prices, applicable to both conventional nickel-manganese-cobalt chemistry and alternative chemistries based on iron phosphate or sodium. As of 1 August 2022, the cumulative battery energy stored in electric vehicles in Germany amounted to 50.5 GWh, with plug-in hybrids contributing 9.5 GWh to this total. The combined charging system has emerged as the predominant fast-charge technology in Germany, with only 2% of the vehicle fleet utilising the competing CHAdeMO standard (Hecht et al., 2022). In Poland, electromobility is concentrated in the largest urban centers. Nearly 22% of the entire Polish electric vehicle (EV) fleet is registered in Warsaw, where over 21% of new battery electric vehicle (BEV) registrations in Poland took place in 2022. Approximately 26% of the Polish fully electric vehicle fleet is registered in cities with populations ranging from 300,000 to 1 million, including Krakow, Lodz, Wroclaw, Poznan, Gdansk, Szczecin, Bydgoszcz, and Lublin. The fleet in smaller urban centers, with populations between 150,000 and 300,000, constitutes 12% of the total number of BEVs in Poland (for cities with populations ranging from 50,000 to 150,000, this figure is approximately 5%) (see: *Raport Polish EV Outlook 2023 już dostępny*!, n.d.; Wiśniewski and Witkowski, 2023).

The main goal of the article was to answer the question, of whether and how the share of electric vehicles (EV) changes (mainly cars) in the Polish market in comparison with the European Union. In this context, it is particularly important to establish whether the charging infrastructure for electric cars is being expanded at a sufficient rate. Attaining the required goals in the area of electromobility is connected not only with the production of the appropriate number and quality of electric vehicles, but also with the preparation of key components of the modern infrastructure, ensuring their proper and effective working/use in their entire lifecycle. In preparing this study, the authors sought to establish how the current economic situation, i.e. the general market trends (being, among others, the effect of the pandemic, global chip crisis, and supply-chain disruptions as a consequence of the Russian invasion of Ukraine and the global coronavirus pandemic, and rising inflation/economic slowdown) has affected the development of electromobility in Poland and the EU in general. The question was therefore posed relating to the extent to which the development of electric cars is linked to economic growth.

The verification of the stated objective requires the use of qualitative and quantitative research methods. Among those an analysis of national and foreign literature (a case study), and the use of quantitative methods (analysis of statistical data) was justified. The methods used are described in detail in the methods of research section. The article commences a series of publications on sustainable transport management and electromobility in Poland and selected countries.

2. Subject literature review

The global transport sector is the third-largest contributor to CO2 emissions after electricity generation and industry. An area for continuous improvement is the issue of pollutant reduction/elimination (including greenhouse gases and smog conditions due to increased PM emissions) along the value chain in low-carbon innovation, among others (Deqiang Shi et al., 2021; Fatima et al., 2022; Wu et al., 2022). The wide range of pollutants that transport generates (including those based on traditional fuels) negatively affects: mental well-being (mood) and amplifies behavioural biases, and cognitive ability. Research is being conducted on the relation between air quality and the financial markets (Guo et al., 2023). In the face of increasing global economic, environmental, social, engineering, and geopolitical challenges, the emphasis is on ensuring a systemic approach to energy management (Mentel and Hajduk-Stelmachowicz, 2020; Moriarty et al., 2012; Van Dender, 2009). Following the PESTLE approach, the motivators and barriers affecting electric vehicle adoption by consumers are being categorised (Anastasiadou and Gavanas, 2022), and the main policy challenges, implementations, and recommendations are being discussed. According to Chinoracký, Stalmašeková, Corejova (2022), further research directions should involve the mapping of electromobility from the point of view of market characteristics and value-added services.

The problem of ever-increasing fuel prices applies to the entire world. Petroleum reserves are running out, so it is necessary to have an alternative to be used before the complete depletion of stocks (Straka et al., 2015). In addition, various evolutionary and sometimes even revolutionary solutions are also being introduced by the EU and national governments in the area of transport as a response to climate change and pollution (Ministry of Energy Electromobility Development Plan in Poland “Energy into the Future”). The answer to the increasingly actual environmental challenges of atmospheric emissions, and the depletion of fossil fuels, is the introduction of electric and hybrid cars (Ziółko, 2021).

Therefore, it is becoming crucial to develop electromobility not only in the context of environmentally-friendly solutions, but also because of the positive impact of such solutions on the automotive industry and the economy as a whole (Tucki et al., 2022). It can be stated that electromobility is a complex field that includes many aspects, not just electric cars. National policies and strategies clearly indicate that transport must use cleaner energy for its operations, make better use of modern infrastructure, and above all, reduce its negative impact on the environment, including natural resources such as water, land, and ecosystems (Hájnika et al., 2021). Nevertheless European countries have not been among the world’s leading countries in this aspect. In addition, there has been different speed in the implementation of electromobility in individual countries (Rokicki et al., 2022).

Several types of electric vehicles with different technologies can be distinguished in the literature and practice, including plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), extended-range battery electric vehicles (E-REVs), and hybrid electric vehicles (HEVs) (Adnan et al., 2016). Since a fully hybrid vehicle can run on electric power, it only needs a plug-in and a larger battery so that it can be charged like a BEV. Thus, the category of plug-in hybrid vehicles (PHEV) was created. Over the past 10 years, various concepts for drive systems based on electric motors have been developed and will soon enter mass production. A distinction must be made between all-electric drives and hybrid electric drives (Helmers and Marx, 2012, pp. 1-15).

3. Methods of research

The primary purpose of this study is to analyse the trends in growth of Electric Vehicles (EV) in Poland compared to the EU. The following hypotheses were adopted for testing:

H_1: the share of electric cars is increasing in Poland and the European Union;
H_2: the charging infrastructure for electric cars is not expanding as fast as the number of electric cars is increasing;
H_3: the growth of electric cars is strongly linked to economic growth.

The U Mann-Whitney test ($\alpha = 0.05$, $p < \alpha$), Ccuster analysis and Pearson's linear correlation coefficient as well as linear regression modelling were used to verify these hypotheses. The following terms for statistical significance were adopted: $p < 0.05$ – existing (*), $p < 0.01$ – high (**), and $p < 0.001$ – very high (***). The data used in the article came from the European Environment Agency (EEA), Polish Alternative Fuels Association (PSPA), Polish Association Of Automotive Industry (PZPM) as well as Eurostat. The data covered the following periods: 1) 1990-2021 and 2010-2021 for EEA data, 2) 2019-2022 for PSPA and PZPM data, 3) 1995-2021 for Eurostat data. Statistical analysis was performed using STATISTICA 13.3.

4. Results and discussion

The number of electric vehicles (BEV and PHEV) is still increasing in Europe, including Poland (Figure 1). In 2010, there were 591 registered EVs only which was only 0.005% of the entire number of cars registered in Europe. For the first time, the share of EVs exceeded 1% in 2015 (130,900 electric vehicles), and in 2020 more than 10% of EVs were in Europe (in 2021, 17.8%). The largest share of EVs in the total number of cars was recorded in 2021 in Norway (86%), in Iceland (64%), and in Sweden (46%). At the same time, the countries with the highest number of EVs include Germany (more than 2.5 million), France (1,7 m.), and Italy (1.4 million). The countries where the number of electric cars is above the EU average are Germany, France, Italy and Sweden, however it is worth noting that the increasing number of electric cars places some countries in the 'below average' group from one year to the next, e.g. Spain, where the number of EVs was still above the EU average in 2020, but fell below the EU average in 2021 (Figure 2). It can be assumed that these changes were caused by a number of factors of an economic and social nature and have a variety of consequences. When analysing the situation in detail for these countries, especially those with EV numbers above the EU average, a steady increase in the popularity of this type of car can be seen. In three countries (Germany, France and Italy), over the past four years the number of newly registered electric vehicles increased from 38,000 to 311,000 per year in France,

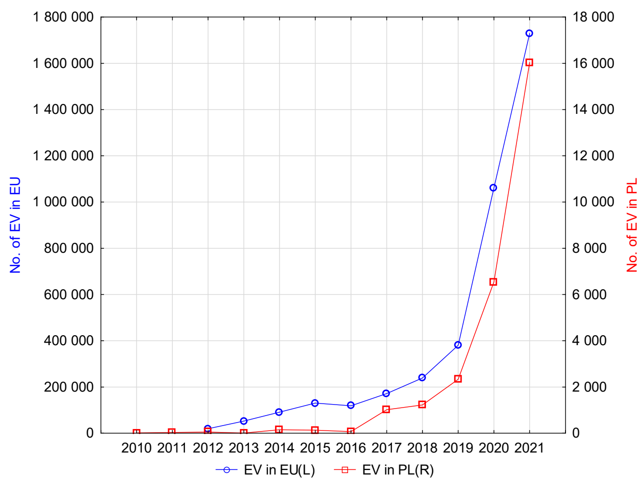

Fig. 1. Number of EVs in the European Union and in Poland

Source: own elaboration based on (EEA, 2022).

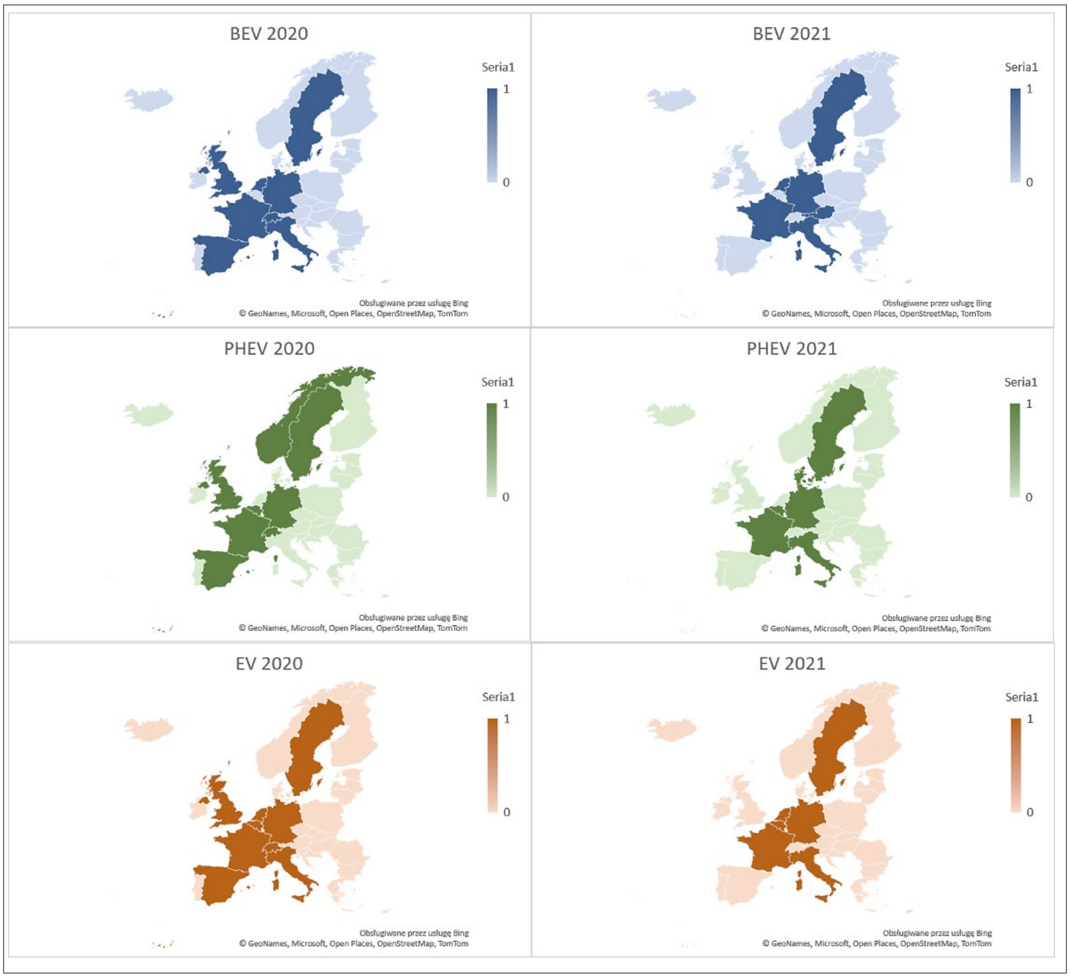

Fig. 2. Number of EVs in EU countries divided into above (1) and below (0) EU average

Source: own elaboration based on (EEA, 2022).

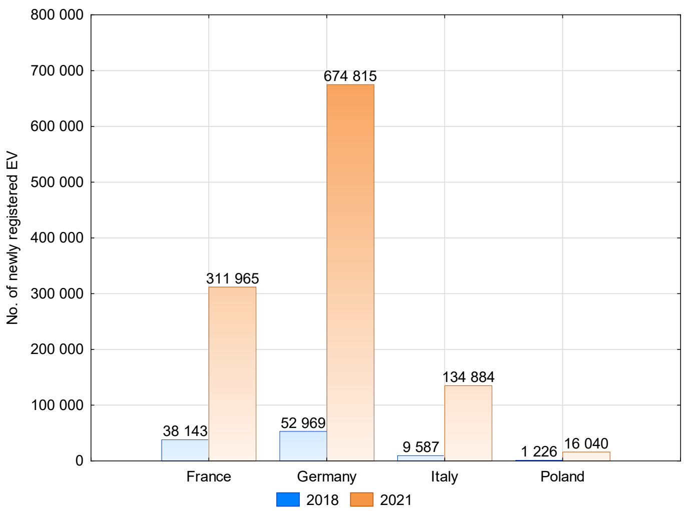

Fig. 3. Number of newly registered EVs in selected EU countries

Source: own elaboration based on (EEA, 2022).

Table 1. The equation for the growth rate of newly registered EVs

Country	Equation[a]	R^2
France	$y = 2.2725e^{0,9524x}$	0.960
Germany	$y = 5.2764e^{0,9098x}$	0.939
Poland	$y = 4.7113e^{0,6225x}$	0.971

[a] *y* = number of newly registered EVs.

Source: own work based on (EEA, 2023).

and from 52,000 to 674,000 per year in Ger-many (Figure 3). In Poland, the growth rate has been exponential (Table 1). Therefore, it is possible to accept the validity of the assumptions made in the first hypothesis.

When analysing the growth in the number of cars in Poland and the available charging stations for EVs, it should be noted that the number of the latter is also increasing systematically. According to data from the PSPA and PZPM, a total of more than 2,500 charging stations (AC and DC) are available in Poland for more than 57,000 EVs (Figure 4). However, the rate of growth in the number of vehicles is faster than in the number of charging stations (although both trends are exponential by nature). The results of the Mann-Whitney U test indicate a very high statistically significant difference in this respect ($p = 0{,}000000^{***}$).

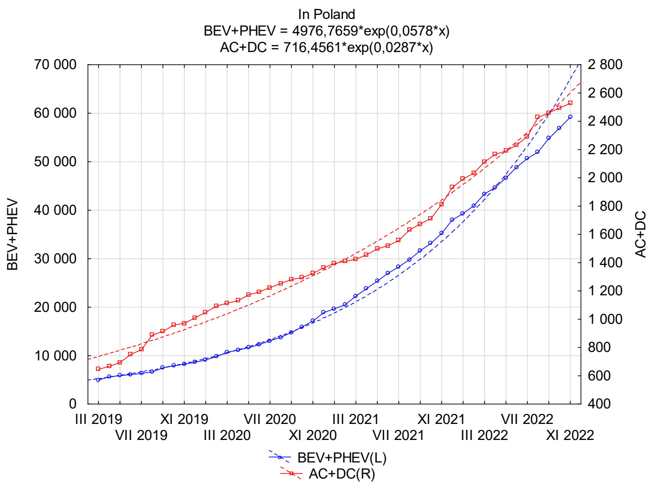

Fig. 4. Number of EVs and charging stations in Poland (with trends)

Source: own elaboration based on (PSPA and PZPM, 2022).

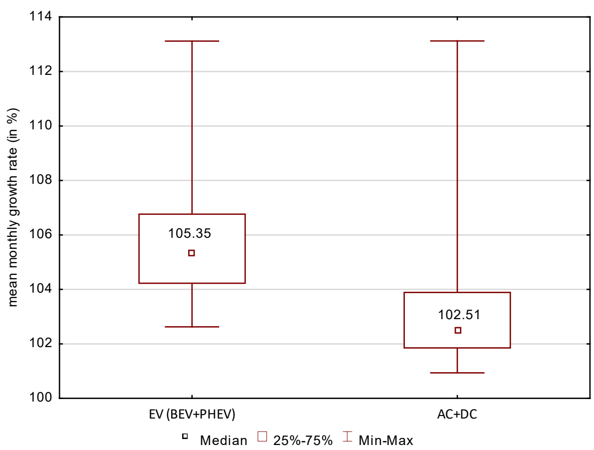

Fig. 5. Mean monthly growth rate of EVs and charging stations in Poland

Source: own elaboration based on (PSPA and PZPM, 2022).

The average monthly growth rate in both cases was 105.3% for EVs and 102.5% for charging stations (Figure 5). Thus, the validity of the assumptions made in the second hypothesis can be proved.

When looking at the reasons for the increase in the number of electric vehicles, economic growth is cited as a key factor (Table 2). Analysing the number of electric cars between 2010 and 2021 in Poland and the EU and the GDP per capita, there is a strong and very high correlation between these values. This may be due to the fact that the increasing affluence of the population enables the purchase of such vehicles, which results from the desire to care for the environment. Looking at individual countries, the correlation ranges from -0.003 in Austria for all EVs to 0.89 in Bulgaria. For BEVs and PHEVs, the linear correlation coefficient values show slight differences. The highest value of the correlation coefficient for individual EV types was recorded in Bulgaria (0.87 for BEVs and 0.81 for PHEVs) and in Ireland (0.89; 0.83 and 0.87 for all EVs). The lowest value of the correlation between GDP per capita and BEV, PHEV and total EVs over the reporting period was found in Austria (0.054; -0.12 and -0.003) and in France (0.11; 0.07 and 0.09). When analysing these issues in more detail, the additional factor of social development should also be considered. The Human Development Index (HDI) is also positively correlated with the number of EVs. Pearson's linear correlation coefficient for all EVs types ranged from -0.018 in Bulgaria to 0.87 in Luxembourg. The lowest value of the correlation between HDI and BEV, PHEV and total EVs over the reporting period was found in Bulgaria (0.09; -0.16 and -0.018) and in the Czech Republic (0.29; 0.21 and 0.25). In general, the correlation between HDI and the number of EVs is weaker than when GDP is taken into account, so GDP was used in the following analysis. At this point, it is worth noting that the correlation between the number of cars and greenhouse gas emissions in Europe was lower (0.522) than in Poland (0.970). This may suggest some delay in EV equipment in Poland compared to the EU average, as the effects of pollution reduction thanks to EVs are felt throughout the EU (Figure 6). Interestingly, carbon dioxide emissions alone have a variable correlation

Table 2. Pearson's correlation coefficient for GDP per capita and HDI and number of EVs in the EU and in Poland

EVs	Correlation (EU)		Correlation (PL)	
	GDP	HDI	GDP	HDI
BEV	0.903	0.636	0.833	0.545
PHEV	0.963	0.580	0.732	0.436
Total cars	0.967	0.621	0.881	0.478

Source: own work based on (EEA, 2023, EUROSTAT, 2023).

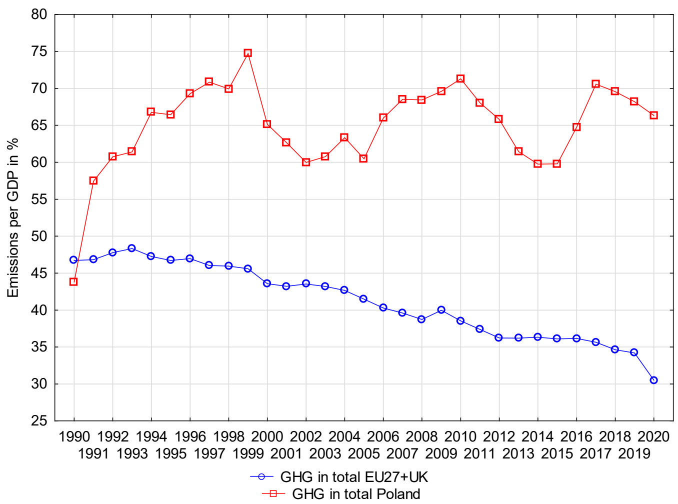

Fig. 6. GHG emission from passenger cars in EU and Poland as GDP per capita percent

Source: own elaboration based on (EEA, 2023).

with the number of EVs. For example, CO_2 emissions are negatively correlated with the number of EVs in all EU countries except Cyprus, Croatia, Greece and Spain. However, when looking at the strength of this correlation, it was highest in Sweden (for CO_2 and BEV = -0.85; for CO_2 and PHEV = -0.90 and for CO_2 and EV = -0.89), and in Finland (-0.72; -0.79 and -0.77).

The lower correlation between both types of EVs in Poland and GDP per capita compared to EU data suggests the lower importance of GDP per capita for the number of EVs. This is also confirmed by the results of the regression analysis, where the independent variable was GDP per capita and the dependent variable was each of the EV types in Poland and the EU (Table 3).

Table 3. Linear regressions models of the number of EVs and GDP per capita in the EU and Poland

EVs	R^2	Model for EU	R^2	Model for PL
BEV	0.789	$y = 30x - 799488$ (5.1) (146921.4)	0.663	$y = 0.73x - 7625.87$ (0.15) (1817.7)
PHEV	0.915	$y = 20x - 521774$ (2.33) (67933.6)	0.489	$y = 1.2x - 12715.1$ (0.357) (4201.7)

Note: *y* – number of BEV or PHEV; *x* – GDP per capita; in () – standard error for parameter

Source: own work based on (EEA, 2023, EUROSTAT, 2023).

All models have very high statistical significance (***), except for the model for the number of PHEVs in Poland, which is highly statistically significant (**). The rest of the models have a normal distribution. In assessing these results, the correlation between GDP per capita and the number of other types of cars (diesel, petrol, and others) was also taken into account (Table 4).

Table 4. Linear regressions models of the number of other types of cars and GDP per capita in the EU and Poland

Type of fuel	*r*	R^2	Model for EU	*r*	R^2	Model for PL
Diesel	0.822	0.635	$y = 780x –20821032.2$ (191) (5455613.6)	0.726	0.479	$y = 21x - 191893.9$ (6.27) (73935.8)
Petrol	0.81	0.614	$y =1408x–37840545.3$ (359) (10264412.2)	0.90	0.789	$y = 82x - 802943,5$ (12.5) (147788.7)
Other	0.729	0.473	$y = 41x - 1088199,25$ (13.5) (384737.5)	0.731	0.487	$y = 2.3x - 21838,2$ (0.66) (7854.3)

Note: *y* – number of cars; *x* – GDP per capita; in () – standard error for parameter; *r* – Pearson's linear correlation coefficient

Source: own work based on (EEA, 2023; EUROSTAT, 2023).

It was observed that in the EU, the highest correlation between GDP per capita applied to PHEV and BEV. Analysing in detail the EU countries that could be similar in terms of EV numbers to Poland, the agglomeration method (Ward's method, Euclidean Distance) was used. The result was that in terms of the number of BEV and PHEV, Poland was similar to the following countries: Bulgaria, Croatia, Cyprus, Czechia, Estonia, Greece, Hungary, Ireland, Latvia, Luxembourg, Lithuania, Malta, Romania, Slovenia and Slovakia (Figure 7). From among these countries, those with a correlation coefficient between GDP per capita and the number of EVs greater than 0.765 (the value for Poland) were selected for further analysis: Bulgaria, Estonia, Hungary, Ireland, Lithuania and Slovenia.

Only the Bulgarian model explained better the effect of GDP on the number of BEVs (76.4%). For PHEVs, in principle, only the model for Lithuania had a lower explanatory power than the model for Poland, although it is worth noting that for most of the group, the models for PHEVs had a lower explanatory power (except for the model for Slovenia, which explained 76% of the variation in the number of PHEVs by GDP).

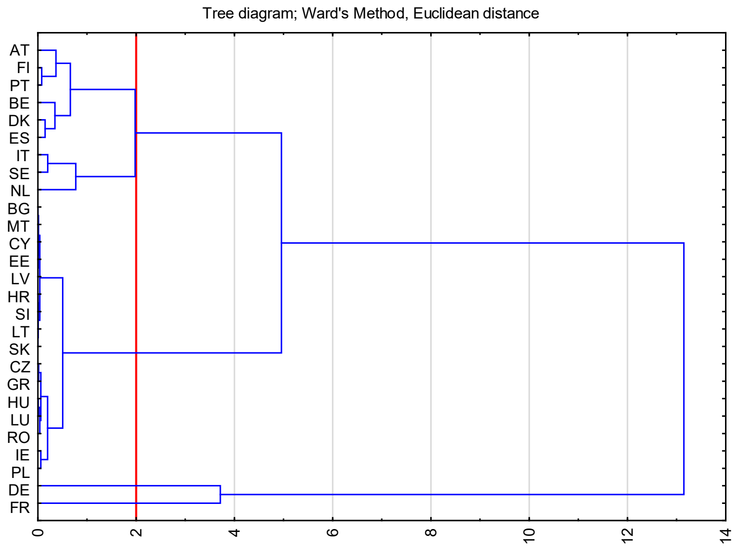

Fig. 7. Results of clustering analysis – tree diagram

Source: own elaboration based on (EEA, 2023, EUROSTAT, 2023).

Table 5. Linear regressions models of the number of EVs and GDP per capita in selected European countries

Model for	R^2	BEV	R^2	PHEV
Bulgaria	0.764	$y = 0.29x - 1595.57$ (0.04) (287.3)	0.521	$y = 0.20x - 1073.51$ (0.05) (320.75)
Estonia	0.504	$y = 0.06x - 832.66$ (0.01) (263.9)	0.531	$y = 0.03x - 376.8$ (0.008) (114.7)
Hungary	0.633	$y = 0.86x - 9046.9$ (0.19) (2226.0)	0.481	$y = 0.76x - 8026.5$ (0.22) (2630.6)
Ireland	0.660	$y = 0.18x - 7627.8$ (0.03) (1971.3)	0.542	$y = 0.15x - 6185.7$ (0.03) (1985.7)
Lithuania	0.429	$y = 0.13x - 1353.9$ (0.04) (504.0)	0.465	$y = 0.04x - 500.1$ (0.01) (175.2)
Slovenia	0.556	$y = 0.35x - 6130.2$ (0.09) (1704.2)	0.760	$y = 0.1x - 1778.1$ (0.01) (316.7)

Note: y – number of BEV or PHEV; x – GDP per capita; in () – standard error for parameter

Source: own work based on (EEA, 2023 & EUROSTAT, 2023).

This dependence applies to a lesser degree to cars powered by other fuel types. In Poland, the highest level of correlation involved GDP per capita and petrol cars. It is worth noting that while the EU-wide GDP per capita as an explanatory variable explains 78 to 92% of the variation in the number of electric vehicles, in Poland this was from 49 to 66%. Thus, in Poland, the number of EVs may also be influenced by other factors unrelated to a country's GDP per capita. It should be noted that in the period 2011-2021, across the European Union as a whole, a very weak correlation was observed between the GDP growth rate and the increase of new EVs, which was negative (r = -0.209), whereas in Poland it was also weak but positive (r = 0.201). These values may have been affected by the drop in GDP in 2020 due to the COVID-19 pandemic. Without taking this year into account, the correlations were as follows: for EU r = 0.837, and for Poland r = 0.616 (Table 6).

Table 6. Linear regressions models of GDP per capita growth rate and growth of the number of EVs in the EU and Poland (without the year 2020)

Type of fuel	*R*	R^2	Model for EU	*r*	R^2	Model for PL
EVs	0.837	0.663	*y* = 106002.7*x* (24497.3)	0.616	0.302	statistically insignificant

Note: *y* – growth of the number of cars; *x* – GDP per capita growth rate

Source: own work based on (EEA, 2023, EUROSTAT, 2023).

Therefore, it can be said that across the EU, as GDP per capita increased, there was a year-on-year increase in the number of electric vehicles, which was not the case in Poland. It follows that in some cases an increase in GDP may result in an increase in the popularity and use of electric cars, but in less affluent countries (such as Poland), other factors may determine the popularity of this type of vehicles. This topic will be explored further by the authors in future.

5. Conclusion

In most countries, the charging infrastructure for electric cars is not developing as fast as the number of electric cars is growing – as demonstrated in this study. This is a complex problem as in addition to range anxiety, EV drivers' frustration is further 'fuelled' by the uncertainty of finding an available charging point along their route (Alanazi 2023; Flocea et al., 2022).

The energy supply for cars requires a very different infrastructure, with electric charging stations replacing fuel stations. In France, for example, local subsidies and chargers (with a power higher than 45kW) correlate positively with the BEV market. In addition, the slowly increasing density of chargers and solar power production are positively associated with PHEV sales (Haidar et al., 2022). This is a challenge that creates new investments for utilities and other newcomers (Altenburg et al., 2022). Even if from now on every new car was electric, it would still take about 15-20 years to supersede fossil fuel cars worldwide. It should be taken into account that emissions over the entire life cycle of electric vehicles are highly dependent on the type of electricity source, the condition of the battery, and the materials used (World Economic Forum, 2021). Many factors influence electric car purchase decisions.

Energy consumption depends on many factors. For example, when the battery is new, it appears to charge quickly, but over time and use its capacity will decline, and its charging time will increase. Even if the loss is only around 2.3% per year, it is still significant when considering a charging reservation (Ryan, 2021). Another reason for the inevitable changes in charging times are factors related to weather conditions, such as low temperatures. The degradation of charging performance is caused by the electrochemical reaction. The management system limits the charging rate at low temperatures for a longer time to avoid damaging the battery (Shepard, 2018). Driver behaviour and controlling the interior temperature can optimise or dilute electricity consumption, which will certainly also affect charging times (Renault Group, 2020).

In light of the authors' own research results, the development of electric cars is strongly linked to economic growth. There is an important question: how can countries can support the expansion of electromobility on their territory?

Implementing electric vehicles (EVs) faces challenges such as high upfront costs, limited driving range, charging infrastructure inadequacy, and public perception. However, these challenges can be addressed via government policies, private sector investment, and public education to: 1) increase EV adoption, 2) develop new business models that enable EV use, 3) invest in charging infrastructure, 4) improve battery technology and charging speeds, 5) increase awareness about the benefits of EVs. Overcoming these challenges can accelerate the transition to a sustainable transportation system and mitigate climate change impacts (Alanazi, 2023).

As rightly pointed out by Rovňák et al. (2022), to support the rise of electromobility and the consequent interest in purchasing electric vehicles, a possible solution could be to build a permanent organizational unit in the form of an information and counselling awareness centre at least in regional cities, where the necessary data could be gathered for e-mobility development and decision-making regarding the use of e-mobility. There is a need to prepare, use and develop complex university programmes (in areas related to computer science, mechanical and electric engineering, law, marketing, and public policy) that fulfils the needs of a graduate student who will later work in a smart electro-mobility environment. Virtual and physical model labs with a balanced curriculum that includes technical, business, and social courses are already available (Curiel-Ramirez et al., 2022).

From some researchers' points of view, there is a flexible potential for aggregated electric vehicle fleets to reduce transmission congestions and the re-dispatch needs, see a case study from Austria (Loschan et al., 2023).

It is proven that the price of, for example, the vehicle, the fuel and / or electricity, the cost of maintaining an electric car, and different encouragement provided by the state) is, and will be, a priority factor for most customers when they decide to buy an electric vehicle (Higueras-Castillo et al., 2021; Singh et al., 2021).

Public procurement (tendering) that includes sustainable transport requirements, as well as longer-term contracts, can also help organizations to make decisions about investments in electric freight vehicles (Melander et al., 2022). In each country, long-term commitments and the clear communication of future changes in taxes, subsidies, and regulations could enable stakeholders to engage with electromobility at different levels.

References

Adnan, N., Md Nordin, S., Rahman, I., Vasant P., and Noor, M. A. (2016). An Integrative Approach to Study on Consumer Behavior Towards Plug-In Hybrid Electric Vehicles. In R. Ianole (Ed.), *Applied Behavioral Economics Research and Trends* (pp. 183-213). IGI Global.

Alanazi, F. (2023). Electric Vehicles: Benefits, Challenges, and Potential Solutions for Widespread Adaptation. *Applied Sciences*, *13*(10), 6016. https://doi.org/10.3390/app13106016

Altenburg, T., Corrocher, N., and Malerba, F. (2022). China's Leapfrogging in Electromobility. A Story of Green Transformation Driving Catch-Up and Competitive Advantage. *Technological Forecasting and Social Change*, (183). https://doi.org/10.1016/j.techfore.2022.121914

Anastasiadou K., and Gavanas, N. (2022), State-of-the-Art Review of the Key Factors Affecting Electric Vehicle Adoption by Consumers. *Energies, 15*(24), 9409. https://doi.org/10.3390/en15249409

Bełch, P., Bełch, P., and Bednarska, P. (2021). Mierniki w controllingu przedsiębiorstwa transportu samochodowego w dobie pandemii Covid-19. In P. Bełch, P. Bełch (Eds.), *Transport w obliczu wyzwań XXI wieku – wybrane problemy.* Oficyna Wydawnicza Politechniki Rzeszowskiej.

Bełch, P., and Rogaczewski, R. (2020). Management of an Energy Company Using the SENT Transport Registration and Monitoring System, *Acta Universitatis Nicolai Copernici – Zarządzanie*, *47*(2). Wydawnictwo Uniwersytetu Mikołaja Kopernika w Toruniu.

China Considers Extending Its EV Subsidies to 2023. (n.d.). Retrieved November 23, 2023 from https://www.china-briefing.com/news/china-considers-extending-its-ev-subsidies-to-2023/

Chinoracký, R., Stalmašeková, N., and Corejova, T. (2022). Trends in the Field of Electromobility–From the Perspective of Market Characteristics and Value-Added Services: Literature Review. *Energies, 15*(17):6144. https://doi.org/10.3390/en15176144

Curiel-Ramirez, L. A., Bautista-Montesano, R., Galluzzi, R., Izquierdo-Reyes, J., Ramírez-Mendoza, R.A., and Bustamante-Bello, R. (2022). Smart Automotive E-Mobility – A Proposal for a New Curricula for Engineering Education. *Education Sciences, 12*(5).

De Moraes, D. R., Soares, L. O., De Almeida Guimarães, V., De Oliveira, K. F., Hernández-Callejo, L., Vieira, G. M. R., and Boloy, R. A. M. (2022). Energy-ecological Efficiency of the Fuel Cell Electric Vehicle Powered by Different Biofuels. *Clean Technologies and Environmental Policy*, *24*(5), 1389-1402.

Deqiang, S., Zhijun, Ch., Hajduk-Stelmachowicz, M., Larik, A. R., and Rafique, M. Z. (2021). The Role of the Global Value Chain in Improving Trade and the Sustainable Competitive Advantage: Evidence From China's Manufacturing Industry. *Frontiers in Environmental Science*, (9).

Dobrzański, P., Śmieszek, M., and Dobrzańska, M. (2020). Bicycle Transport Within Selected Polish and European Union Cities. *Humanities and Social Sciences*, *27*(2), https://doi.org/10.7862/rz.2020.hss.16

European Environment Agency [EEA]. (2023). *Database: CO2 Emissions from New Passenger Cars*. Retrieved November 4, 2023 from http://co2cars.apps.eea.europa.eu/

Egbue, O., Long, S., and Samaranayake, V. A. (2017). Mass Deployment of Sustainable Transportation: Evaluation of Factors That Influence Electric Vehicle Adoption. *Clean Technol. Environ. Policy 2017*, (19), 1927–1939. https://doi.org/10.1007/s10098-017-1375-4

EUROSTAT. (2023). https://ec.europa.eu/eurostat/databrowser

Fatima, S., Mishra, S. K., Ahlawat, A., and Dimri, A. P. (2022). Physico-Chemical Properties and Deposition Potential of PM2.5 during Severe Smog Event in Delhi, India. *Int. J. Environ. Res. Public Health*, *19*(15387). https://doi.org/10.3390/ijerph192215387

Flocea, R., Hîncu, A., Robu, A., Senocico, S., Traciu, A., Remus, B., Răboacă, M., and Filote, C. (2022). Electric Vehicle Smart Charging Reservation Algorithm. *Sensors*, *22*(8), 2834. https://doi.org/10.3390/s22082834

Guo, L, Han, X., and Li, Y. (2023). The Smog That Hovers: Air Pollution and Asset Prices, *Finance Research Letters*, 103633, https://doi.org/10.1016/j.frl.2023.103633

Haidar, B., and Aguilar Rojas, M. T. (2022). The Relationship between Public Charging Infrastructure Deployment and Other Socio-Economic Factors and Electric Vehicle Adoption in France. *Research in Transportation Economics, 95*(101208).

Hajduk-Stelmachowicz, M. (2018). Audyt energetyczny przedsiębiorstw jako wyzwanie w kontekście poprawy efektywności energetycznej. *Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią Polskiej Akademii Nauk*, (104), 43-54. https://orcid.org/10.24425/124367

Hajduk-Stelmachowicz, M., and Makowiecki, S. (2021). Wpływ pandemii Covid-19 na proces przeprowadzania kursów prawa jazdy. In: P. Bełch (Ed.), *Logistyka i transport – wybrane zagadnienia w świetle badań naukowych i praktyki gospodarczej*. Oficyna Wydawnicza Politechniki Rzeszowskiej.

Hájnika, A., Harantováa, V., and Kalašováa, A. (2021). Use of Electromobility and Autonomous Vehicles at Airports in Europe and Worldwide. *Transportation Research Procedia,* (55), 71-78.

Hecht, C., Figgener, J., and Sauer, D. U. (2022). Mobility Charts: Deutschlands Elektromobilität im Überblick. Retrieved August 29, 2022 from https://www.mobility-charts.de/

Helmers, E., and Marx, P. (2012). Electric Cars: Technical Characteristics and Environmental Impacts. *Environmental Sciences Europe*. 24, 1-15.

Higueras-Castillo, E., Guillén, A., Herrera, L.-J., and Liébana-Cabanillas, F. (2021). Adoption of Electric Vehicles: Which Factors Are Really Important? *International Journal of Sustainable Transportation*, *15*(2), 799-813.

Huber, S., Klauenberg, J., and Thaller, C. (2015). Consideration of Transport Logistics Hubs in Freight Transport Demand Models. *European Transport Research Review*, *7*(32). https://doi.org/10.1007/s12544-015-0181-5

Loschan, Ch., Schwabeneder, D., Lettner, G., and Auer, H. (2023). Flexibility Potential of Aggregated Electric Vehicle Fleets to Reduce Transmission Congestions and Redispatch Needs: A Case Study in Austria. *International Journal of Electrical Power&Energy Systems*. https://doi.org/10.1016/j.ijepes.2022.108802

Melander, L., Nyquist-Magnusson, C., and Wallström, H. (2022). Drivers for and Barriers to Electric Freight Vehicle Adoption in Stockholm. *Transportation Research Part D: Transport and Environment, 108*(103317). https://doi.org/10.1016/j.trd.2022.103317

Mentel, U., and Hajduk-Stelmachowicz, M. (2020). Does Standardization Have an Impact on Innovation Activity in Different Countries? *Problems and Perspectives in Management*, *18*(4), 486-503.

Ministerstwo Energii Plan Rozwoju Elektromobilności w Polsce „Energia do przyszłości". (n.d.). Retrieved January 31, 2023 from https://www.gov.pl/web/klimat/elektromobilnosc

Moriarty, P., and Honnery, D. (2012). Energy Efficiency: Lessons from Transport. *Energy Policy,* (46). https://doi.org/10.1016/j.enpol.2012.04.056

PSPA. (2022). Polish Alternative Fuels Association, Database. *Licznik Elektromobilności* (*The Electromobility Meter*). Retrieved January 31, 2023 from https://pspa.com.pl/

PZPM. (2022). Polish Association of Automotive Industry, Database. *Licznik Elektromobilności* (*The Electromobility Meter*). Retrieved January 31, 2023 from https://www.pzpm.org.pl/

Raport Polish EV Outlook 2023 już dostępny! (n.d.). Retrieved April 5, 2023 from https://www.ccifp.pl/komunikacja/aktualnosci-ccifp/n/news/raport-polish-ev-outlook-2023-juz-dostepny.html

Renault Group. (2020). *Electric Mobility, Everything You Need to Know about Charging Electric Cars*. Retrieved February 25, 2023 from https://www.renaultgroup.com/en/news-on-air/news/everything-you-need-to-know-about-charging-electric-cars

Rokicki, T., Bórawski, P., Bełdycka-Bórawska, A., Żak, A., and Koszela, G. (2022). Development of Electromobility in European Union Countries under COVID-19 Conditions. *Energies, 15*(1), 9. https://doi.org/10.3390/en15010009

Rovňák, M., Kalistová, A., Štofejová, L., Benko, M. i Salabura, D. (2022). Management of Sustainable Mobility and the Perception of the Concept of Electric Vehicle Deployment. *Polish Journal of Management Studies, 25*(2).

Ryan, A. (2021). *Make Your Electric Vehicle Battery Last Longer*. Retrieved February, 24 2023 from https://www.fleetnews.co.uk/electric-fleet/charging-and-infrastructure/make-your-electric-vehicle-battery-last-longer

Šafrová, D., and Hejduková, P. (2021). Covid-19 Pandemic and the Sharing Economy. *Humanities and Social Sciences*, *28*(3). https://doi.org/10.7862/rz.2021.hss.24

Shepard, P. (2018). *Quantifying the Negative Impact of Charging EVs in Cold Temperatures*. Retrieved February 25, 2023 from https://eepower.com/news/quantifying-the-negative-impact-of-charging-evs-in-cold-temperatures

Singh, V., Singh, V., Vaibhav, S. (2021). Analysis of Electric Vehicle Trends, Development and Policies in India. *Case Studies on Transport Policy,* **(**9), 1180-1197.

Straka, M., Chovan, T., Bindzár, P., Žatkovič, E., Hricová, R. (2015). Possibilities and Limitations of Electromobiles Utilization. *Applied Mechanics and Materials*, (708), 159-164

Trends in Electric Light-Duty Vehicles – Global EV Outlook 2022 – Analysis – IEA. (n.d.). Retrieved Novemeber 4, 2023 from https://www.iea.org/reports/global-ev-outlook-2022/trends-in-electric-light-duty-vehicles

Tucki, K., Orynycz, O., and Dudziak, A. (2022). The Impact of the Available Infrastructure on the Electric Vehicle Market in Poland and in EU Countries. *Int. J. Environ. Res. Public Health, 19* (16783). https://doi.org/10.3390/ijerph192416783

United Nations. (n.d.). *Climate Action, COP 27, Delivering for People and the Planet* (The 27th Conference of the Parties to the United Nations Framework Convention on Climate Change, Paris Agreement, was held from 6 to 20 November 2022 in Sharm El-Sheikh, Egypt). Retrieved February 25, 2023 from https://www.un.org/en/climatechange/cop27

Van Dender, K. (2009). Energy Policy in Transport and Transport Policy. *Energy Policy*, *37*(10). 3854-3862. https://doi.org/10.1016/j.enpol.2009.07.008

Wiśniewski, J., and Witkowski, Ł. (2023). *Year 2022 in Polish e-mobility*. PSPA. Retrieved Novemeber 4, 2023 from https://pspa.com.pl/wp-content/uploads/2023/01/PSPA_Rok_2022_w_polskiej_elektromobilnosci_Raport-3.pdf

World Economic Forum. (2021). *Technical Transformation. 7 Reasons Why Global Transport Is So Hard to Decarbonize*. Retrieved Novemeber 4, 2023 from https://www.weforum.org/agenda/2021/11/global-transport-carbon-emissions-decarbonise/

Wu, H., Fareed, Z., Wolanin, E., Rozkrut, D., and Hajduk-Stelmachowicz, M. (2022). Role of Green Financing and Eco-Innovation for Energy Efficiency in Developed Countries: Contextual Evidence for Pre- and Post-COVID-19 Era*. Frontiers in Energy Research*, (10). https://orcid.org/10.3389/fenrg.2022.947901

Xu, L., Yilmaz, H. Ü., Wang, Z., Poganietz, W. -R., Jochem, P. (2020). Greenhouse Gas Emissions of Electric Vehicles in Europe Considering Different Charging Strategies. *Transport. Res. Part D: Transp. Environ,* (87). https://doi.org/10.1016/j.trd.2020.102534

Ziółko, M. (2021). Ekopatrole – elektryczne u hybrydowe radiowozy w Policji. In P. Bełch (Ed.), *Logistyka – teoria i praktyka*. Oficyna Wydawnicza Politechniki Rzeszowskiej.

Elektromobilność w Polsce i Unii Europejskiej – wyniki wstępnej analizy porównawczej

Streszczenie: Artykuł ma na celu analizę trendów w rozwoju pojazdów elektrycznych (EV) w Polsce na tle Europy. Weryfikacja założonego celu wymagała zastosowania metod badawczych, tj. analizy literatury krajowej i zagranicznej, analizy danych statystycznych oraz wnioskowania statystycznego. Niniejszy artykuł rozpoczyna cykl publikacji poświęconych zrównoważonemu zarządzaniu transportem i elektromobilności w Polsce i wybranych krajach Europy. Liczba pojazdów elektrycznych (BEV i PHEV) wciąż rośnie w Europie, w tym w Polsce. W 2010 roku zarejestrowano tylko 591 pojazdów elektrycznych, co stanowiło zaledwie 0,005% ogólnej liczby samochodów zarejestrowanych w Europie. Po raz pierwszy udział EV przekroczył 1% w roku 2015 (130,9 tys. pojazdów elektrycznych), a w 2020 roku w Europie było ponad 10% EV (w 2021 roku było to 17,8%). Największy udział EV w ogólnej liczbie samochodów odnotowano w 2021 roku w Norwegii (86%), na Islandii (64%) oraz w Szwecji (46%). Wśród krajów o największej liczbie EV są Niemcy (ponad 2,5 mln), Francja (1,7 mln) i Włochy (1,4 mln).

Słowa kluczowe: elektromobilność, Polska, Unia Europejska, transport, zarządzanie zrównoważonym transportem