Transport Geography Papers of PGS

2022, 25(4), 7-25

DOI 10.4467/2543859XPKG.22.018.17142

Otrzymano (Received): 09.10.2022
Otrzymano poprawioną wersję (Received in revised form): 28.11.2022
Zaakceptowano (Accepted): 09.12.2022
Opublikowano (Published): 31.12.2022

CONDITIONS FOR THE SUSTAINABLE DEVELOPMENT OF ELECTROMOBILITY IN THE EUROPEAN UNION ROAD TRANSPORT FROM THE PERSPECTIVE OF THE EUROPEAN GREEN DEAL

Uwarunkowania zrównoważonego rozwoju elektromobilności w transporcie samochodowym Unii Europejskiej z perspektywy Europejskiego Zielonego Ładu

Urszula Motowidlak

Department of Logistics and Innovation, Institute of Logistics and Computer Science, Faculty of Economics and Sociology, University of Lodz, Rewolucji 1905 r. 37/39, 90-214 Lodz, Poland

e-mail: urszula.motowidlak@uni.lodz.pl

https://orcid.org/0000-0002-2777-9451

Citation: Motowidlak U., 2022, Conditions for the sustainable development of electromobility in the European Union road transport from the perspective of the European Green Deal, *Prace Komisji Geografii Komunikacji PTG*, 25(4), 7-25.

Abstract: The article concerns the analysis of trends and policies supporting the development of zero-emission mobility, in accordance with the assumptions of the European Green Deal. The aim of the study is to identify and assess the essential factors determining the level of sustainability of the electromobility system in relation to individual car transport in the European Union. he article reviews strategies for the development of climate-neutral mobility as outlined in strategic documents, the European Green Deal and the "Fit for 55" package. The current state of development of the electric vehicle market and charging infrastructure is shown, which implies a number of challenges in the pursuit of emission-free mobility. A review of the literature on the subject and the results of the expert analysis confirmed the importance of national and regional policies in the uptake of electric vehicles. Taking active measures to increase the level of sustainability of the electromobility system should first focus on the further development of charging infrastructure, the creation of an EV battery value chain and the uptake of cars. The main expectations for the development of electromobility are to reduce CO_2 emissions, reduce dependence on the supply of fossil fuels, increase the competitiveness and innovation of the economy, and reduce the social costs generated by transportation.

Keywords: low-emission mobility, electric vehicles, charging infrastructure, electromobility, the European Green Deal

Introduction

In the ongoing discussion regarding the zero-carbon economy model, the development of a competitive and emission-free mobility system is presented as a prerequisite for achieving climate neutrality (Ueda et al., 2010; Philip, Taylor, 2017; Kumar, Kumar, 2020). Passenger and cargo transportation accounts for ¼ of the European Union's (EU) CO_2 emissions and is a significant source of urban air pollution. At the same time, taking into account that among global economic sectors, transport is responsible for the largest increase in CO_2 emissions (Global Energy..., 2022), the implementation of low- and zero-emission mobility systems is a prerequisite for achieving the goals of the Paris Agreement (Du et al., 2018). The process of transitioning to climate-neutral mobility has already begun but its pace must accelerate. Future efforts should focus on further improvements in system efficiency, development of low-carbon alternative fuels and energy sources for all modes of transport, dissemination of low- and zero-emission vehicles, including those powered by batteries and fuel cells, and implementation of appropriate infrastructure. Successful implementation of these measures requires a systemic approach to the development of zero-emission mobility (Gallo, Marinelli, 2020; Jagiełło, 2021). At the core of the transformation is investment in new technologies and digital solutions and mobility patterns that will foster new business models. However, the development and diffusion of innovations often faces market, organizational and institutional failures, pointing to the need for policy interventions (Weber, Rohracher, 2012; Liao et al., 2017).

Mobility in EU Member States, heavily influenced by global development trends, shows a strong preference for individual motorization. These trends determine the increase in demand for petroleum-based fuels, resulting in increasingly high levels of CO_2 emissions generated by passenger cars. The lack of a currently viable option for replacing these fuels, does not support the development of sustainable mobility. A factor supporting this possibility, especially in the medium term, may become the use of electricity in motor transport, including mainly from renewable energy sources (RES) (Renewable energy..., 2018).

Electric vehicle technology[1] has the potential to make a significant contribution to addressing the numerous challenges facing the EU, such as global warming and dependence on fossil fuels (IPCC, 2022). The European Green Deal strategy (2019) includes ambitious expectations for Electric Vehicle (EV) uptake and charging infrastructure deployment. It assumes that some one million public charging points will be needed by 2025 for the 13 million low- and zero-emission vehicles expected on EU roads. The market for EVs, mainly passenger cars, has grown steadily over the past few years. However, this development in the EU has been concentrated in only a few European markets. Member states and local governments will therefore have to make great efforts to accelerate the transition to electromobility. This means developing and implementing effective policy implementation instruments at the national and local levels to increase the popularity of EVs and develop the necessary public charging infrastructure.

The purpose of the study, the results of which are presented in this article, is to identify and assess the essential factors determining the level of sustainable development of electromobility in relation to individual car transport in the EU. The specific tasks concern the analysis of: the EU strategic documents in relation to electromobility, the development of the EV market, the implementation of EV charging infrastructure, national policies on the electrification of passenger cars. The focus of the research on the search for links between the concept of sustainable mobility development and the development of electromobility determined the main research hypothesis (H_M), which is: in view of the high importance of individual car transport in EU Member States and the increase in CO_2 emissions generated, the development of the EV market and the corresponding charging infrastructure has great potential, in the medium term, for shaping sustainable, innovative and resilient mobility. According to the supporting hypotheses:

- the assumptions of the EU policy create a strategic framework conducive to (directly and indirectly) increasing the added value in the electromobility supply chain in relation to EV cars (H_{S1}),
- national policies of the EU Member States regarding the promotion of electromobility have a positive impact on purchasing preferences for EV cars (H_{S2}).

The structure of this article is organized as follows. After the Introduction section, a review of existing, selected research results is presented (Literature review section) and the methodological approach (Research materials and methods section). The Results section contains the conceptual assumptions of the sustainable electromobility model in the field of passenger cars, an overview of strategic directions of action resulting from the assumptions of the transport, climate and sustainable development policies. In addition,

[1] Electric vehicles include electric vehicles (EVs) and fuel cell electric vehicles (FCEVs). Both types are driven by an electric motor, but each requires different infrastructure (W kierunku…, 2020). The analyzes presented in the article concern electric cars, which include fully electric battery cars (BEVs) and plug-in hybrids (PHEVs), both of which require charging infrastructure, for which they connect to the electricity grid.

research findings on EV market development and charging infrastructure and national policies to support this development are presented. The Discussion section presents the conclusions of the analysis and the study's contribution to the literature. The Conclusion section includes recommendations and suggestions for potential directions for further research, as well as the most important limitations with respect to the ongoing study.

1. Literature review

The increasing pressure of transportation, especially motorized transport, on the environment and on people's health and lives has resulted in a change in the approach to policy-making for mobility development. It mainly concerned the discussion of the proper understanding of its development taking into account the principles of the idea of sustainable development and the appropriate ways of implementation in the form of implemented strategies and policies and implemented research (Magalhães, Santos, 2022; Silvestri et al., 2021; Ren et al., 2020). The 1992 Green Paper and 1992 White Paper set out the first assumptions of the concept of sustainable mobility and proposed measures for sustainable movement (Mężyk, Zamkowska, 2017). The term "sustainable mobility" is derived from the concept of "sustainable development". Thus, mobility is supposed to meet the needs of society in economic, social and environmental dimensions, while minimizing their undesirable impact on each of these dimensions (Gallo, Marinelli, 2020). In subsequent transportation strategies and policies, the pursuit of sustainable mobility has set priority courses of action, at the European and national levels, as well as at the local level. Their goal, from the point of view of the transport system as a whole, was to improve the efficiency of the use of limited environmental resources, which are necessary to achieve other goals that co-determine the level of social well-being (de Souza et al., 2019). Recognition of contemporary problems of mobility functioning triggered the need for multifaceted analysis and interdisciplinary studies in an effort to develop a new quality of sustainable mobility (Załoga, 2013; Wojewódzka-Król, Załoga (eds.), 2016).

The review of the literature on the subject shows that the understanding and interpretation of the concept of sustainable mobility has changed over the decades (Holden et al., 2019). The changes concerned research goals and questions, methodological aspects and dimensions of sustainable mobility, as well as scientific disciplines dealing with the subject of sustainable mobility. Decisive changes regarding sustainable mobility have also taken place in terms of research priorities. They concern e.g. development of alternative fuels for transport and low-emission mobility (Ajanovic, Haas, 2017), shaping electromobility (Zhao et al., 2020) and autonomous mobility (Mantouka et al., 2022), changing social behavior towards green mobility (Zuo et al., 2021) and issues related to shared mobility (Mouratidis, 2022).

The symbiosis between research and policy has fostered the development of mobility on the one hand, and highlighted the problems of implementing sustainable development principles on the other. The 2011 White Paper confirmed that the transportation system is unsustainable, but restricting mobility is not the solution (White Paper, 2011). Recognizing the need to develop sustainable mobility, the European Commission (EC) stressed that it will not happen without decisive action to decarbonize transportation, aiming to limit temperature increases to a maximum of 2°C and slow climate change. Striving to shape low- and zero-emission mobility systems has become one of the priorities of transport policy in the 2050 horizon, given the impact of mobility and transportation on the achievement of sustainable development goals.

The increase in the mobility of society and the accompanying development of individual motorization have led to the strengthening of the dominant position of passenger cars in transportation. In 2019, their share in the branch structure of land passenger transport was about 78.1%, while bus and coach transport accounted for 8.7%, rail transport services 8.9%, two-wheelers 2.4%, and streetcars and subways 1.8% (The first ..., 2020). In 2019, passenger cars were the main source of pollution, accounting for about 61% of the EU's total vehicular CO_2 emissions. At the same time, they reported the highest demand for petroleum-based raw materials, which supplied about 93% of transport energy needs (Eurostat. Final energy..., 2022).

With an average of 1.6 passengers per passenger car in Europe, public transportation is now a more environmentally friendly land transport alternative compared to individual motorization. However, despite intensified efforts to popularize passenger transportation by public transport, the share of public transport in land passenger traffic as a whole continues to decline in many EU Member States. In 2019, its average EU share was 20%. For the development of climate-neutral mobility, it will therefore be important to rapidly deploy low- and zero-emission passenger cars, The transition to climate-neutral mobility must parallel the dissemination of low- and zero-emission solutions for other branches and means of transport.

In the process of shaping the concept of low- and zero-emission mobility, the electrification of automobile transport has been a subject of particular interest in the last decade in EU transport policy and research work[2]. Taking into account economic and political conditions, as well as the level of technological development and changing expectations of society, EV cars show potential for development in the years to come (Weber, 2022; Chinoracky et al., 2022).

The introduction of electricity into the motor vehicle fuel market significantly changes the organization of transportation processes and makes the relationships governing the operation of motor transportation and the reactions between this operation and the environment more diverse and complex.

The multidimensionality of the development of the electromobility system was pointed out in their study by R. Chinoracky et al. (2022), treating the system as a "complex construct" whose meaning is interpreted by researchers in many ways. D. Kolz and M. Schwartz (2017) in their study identified key areas influencing the development of electromobility, both globally and locally. They identified a total of 55 impact factors, including 29 that have a global dimension and 26 that have a local impact. They stressed that due to the small scale to date and the relatively short period of use of electric propulsion in cars, it is difficult to clearly assess the directions and magnitudes of their impact on the development of a sustainable and innovative mobility system. However, they can be identified, described and analyzed.

According to E. Šoltés et al. (2021), it is currently impossible to demonstrate the impact of electromobility development on CO_2 reduction on an individual EU member state level. Instead, it can be assumed that as the share of EVs in the total number of cars on the road increases, there will be a decrease in mobility emissions (Rabiega et al., 2021). M. Wołek et al. (2021) prove in their research that in order to reduce CO_2 emissions generated by EVs, it is necessary to change the structure of electricity generation, in the direction of increasing the share of less carbon-intensive raw materials (RES, nuclear energy). According to a study by E. Helmers et al. (2020), shows that increasing the share of RES energy for the production of lithium-ion batteries has a positive effect on reducing CO_2 emissions during the production cycle. When wind energy is used, the carbon footprint of battery production is negligible, amounting to about 0.4% of the total emissions dominated by the supply of mineral battery components. The degree of CO_2 emission reduction also depends on the size and weight of the car, which is particularly important for BEVs (Battery Electric Vehicle), due to the high demand for energy raw materials to manufacture not only the battery, but also the electric motor (Electric Vehicle..., 2020). According to a study by the Swedish Energy Agency, the life-cycle assessment of a BEV is more favorable after 30,000 km (small vehicle) to 100,000 km (large vehicle) than that of an Internal Combustion Engine Vehicle (ICEV) of the same size (van Loon et al., 2019). At the same time, a clear disadvantage of BEVs remains their limited range and incomplete charging infrastructure. Also ecologically critical is the need for scarce mineral resources (e.g., lithium) for battery production (Romare, Dahllöf, 2017). The impact of electromobility will also be important for supply chain architecture. They will cause key, changes among suppliers of new technologies and materials (Electro-Mobility..., 2018). J. Barrett and J. Bivens (2021), in their study, also highlight the economic impact, related to job losses, mainly due to simpler powertrain design.

2. Research material and methods

Selected research methods and techniques were used to verify the main hypothesis and auxiliary hypotheses. Descriptive analysis was used to define the subject of the study and identify within it the basic relationships. With the help of causal analysis, the relationships occurring between general development trends concerning individual motorization, the EV market, charging infrastructure, EU policies and strategies, and national policies for electromobility development were defined.

To systematize the existing body of scientific work and the state of knowledge on the essence and motives for the development of sustainable mobility and electromobility in the context of individual motorization, the method of literature analysis and criticism proved useful. The review of the literature on the subject was carried out according to the classical approach, i.e.: selection of sources, search by keywords, review and selection of articles, in-depth analysis of selected publications in relation to the subject of the study, taking into account, among other things, the latest publications and the number of citations. The analyzed scientific articles are indexed in databases: Scopus, Science Direct, MDPI and Google Scholar. The compact scientific publications, scientific expert reports and statistical data used in the study were published by recognized publishing houses and foreign and domestic institutions. The literature review identified a general knowledge gap in the integrated approach to decision support objectives for sustainable electromobility development. Using logical analysis and construction, as well as qualitative analysis, a conceptual framework for a model for sustainable development of electromobility in individual

[2] The word "electromobility" appeared in more than 1,700 publications indexed in Science Direct, in the period 2012-2022, while the issue of low-carbon mobility was analyzed in nearly 800 scientific papers.

automobile transportation was developed, from the perspective of the system value chain and general Life Cycle Assessment (LCA) assumptions. Its application requires consideration of many variables, given the complexity of electromobility system development. It is expected that it can contribute to refining algorithmic approaches to improve decision support tools for sustainable electromobility development.

Using the general assumptions of the qualitative model, an assessment was made of strategic documents and national policies in the context of electromobility development in relation to passenger cars and charging infrastructure.

3. Result

3.1. Conceptual framework for sustainable development of electromobility

Electric vehicle technology is now considered a future-proof alternative to internal combustion engines. Powered by renewable energy, EV vehicles have a low environmental impact during their use. From the point of view of the greenhouse effect, this is key to meeting the European Green Deal goals of achieving zero net emissions by 2050. In addition, they have very low levels of noise and air pollution (Jochem et al., 2018; Kester et al., 2018). As mobile energy storages, they have great potential to increase power system (SEE) resilience and mobility to disruptions and create value-added services (Vilathgamuwa et al., 2022; Coban et al., 2022).

The potential benefits of this propulsion system have contributed to efforts to electrify EU automobile transport. The electromobility development strategies and programs adopted by the EU and national governments were intended to accelerate the process of shaping sustainable mobility. Its development should support the realization of the principles of sustainable development, assuming the conduct of all activities so as to reduce CO_2 emissions. Today, this goal has become even more relevant, and one of the important tools for its realization is to accelerate the development of emission-neutral ("clean") and intelligent mobility (Sustainable and Smart..., 2020).

A number of conceptual and strategic documents have been published that indicate the desired directions for the electrification of automobile transportation. Unfortunately, these concepts, all too often, are narrowed and shallowed, identified with environmentally sustainable development, whose goal is primarily to reduce CO_2 emissions. This is a natural-centric interpretation that treats electromobility as a concept for greening the economy. Meanwhile, J. V. R. de Souza et al. (2019) point to a much broader understanding of the concept of electromobility. It represents a new ecosystem of shared value creation, the result of interactions taking place between the transportation sector, the automotive industry, the electric power sector, the petrochemical and chemical industries. The result of this cooperation is the pursuit of:

- improving the energy efficiency of EVs and the possibility of using them as energy storage,
- resource-efficient use of raw materials and materials, with a focus on critical minerals,
- value creation from waste,
- use of RES, and development of smart grids (Smart Grid),
- development of electromobility as a service,
- developing the right relationship in consumption and production, including by extending the life cycle of EV batteries, developing Vehicle to Grid technology (V2G),
- developing solutions to increase economies of scale.

Recognizing the interdependencies mentioned above, it can be concluded that in thinking about the development of electrification of automobile transport, a systemic approach, the implementation of technological innovations, and an increase in corporate responsibility and public awareness are necessary. Such an approach will be conducive to the main goals of sustainable electromobility development, seen in economic, social, environmental and institutional contexts (Fig. 1). Their manifestations include: striving to reduce the cost and decrease the price of EVs, improving the quality and availability of charging infrastructure, as well as realizing functions related to preemptive environmental and climate impacts.

The development of a strategic approach that guarantees the consistency of actions in the various dimensions of sustainability, taking into account the win-win principle, can be considered crucial to the development of the electromobility system. The essence of this principle is the basis for the selection of such initiatives that, while achieving one specific goal, simultaneously contribute to the achievement of other important social, environmental, economic and institutional objectives. Good examples of such measures with regard to the electrification of automobile transportation, in accordance with the principles of sustainable development, are the promotion of RES, the development of the Smart Grid, or the construction of blue-green infrastructure (Gómez et al., 2022). Their implementation has many more positive implications than simply reducing climate change. Among other things, it promotes improvements in the competitiveness of transportation and the economy, as well as the quality of life of society.

Low-carbon technologies in transportation, including electromobility, have the potential to increase the competitiveness of the mobility ecosystem. Exploiting it requires increasing the EU industry's ability to continuously adapt and innovate to fill the missing links in the relevant value chains. Investment in batteries for electric vehicles is of strategic importance. A modern and competitive automotive industry is crucial to the EU economy and job creation.

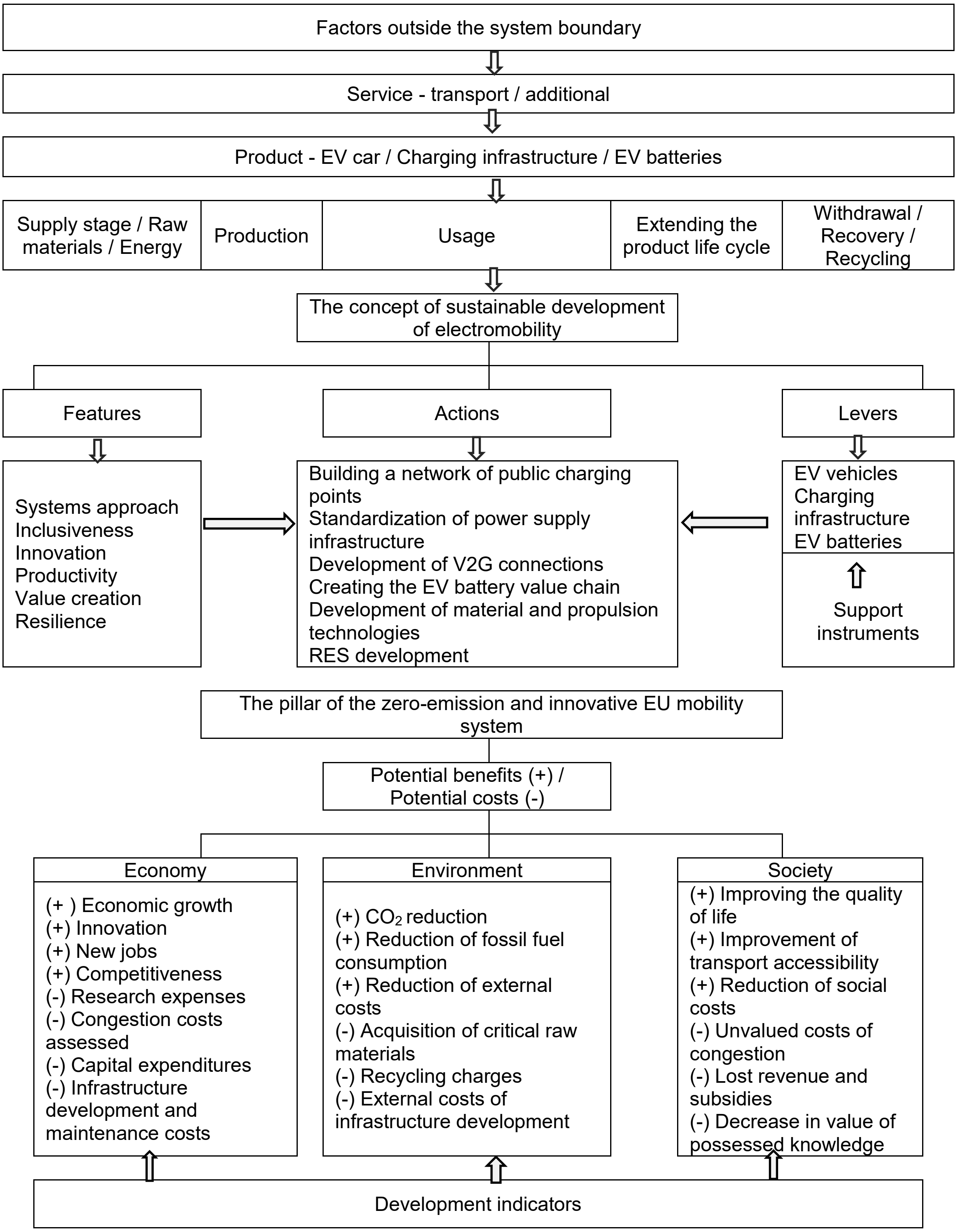

Fig. 1. Conceptual framework of the model for sustainable development of electromobility in car transport taking into account the life cycle of the product /service.

Source: own study.

The environmental effects of using BEVs should be evaluated taking into account the vehicle's life cycle and fuel (Prussi et al., 2020). Research shows that the production and permanent storage of an electric car is more burdensome for the environment than in the case of a car with an internal combustion engine. At the same time, the level of CO_2 emissions from BEVs depends on how the electricity is generated (Fig. 2). However, given the average CO_2 emission levels set for the averaged electricity generation mix in the EU, BEV cars are already proving to be less burdensome to the environment than conventionally powered cars. In the future, with greater use of RES in the electricity generation mix, a comprehensive assessment confirms the clear advantage of BEVs in reducing CO_2 emissions and improving air quality compared to petroleum-fueled vehicles (Renewable energy..., 2018). The development of electromobility also brings with it changes in the way GHG emissions are controlled.

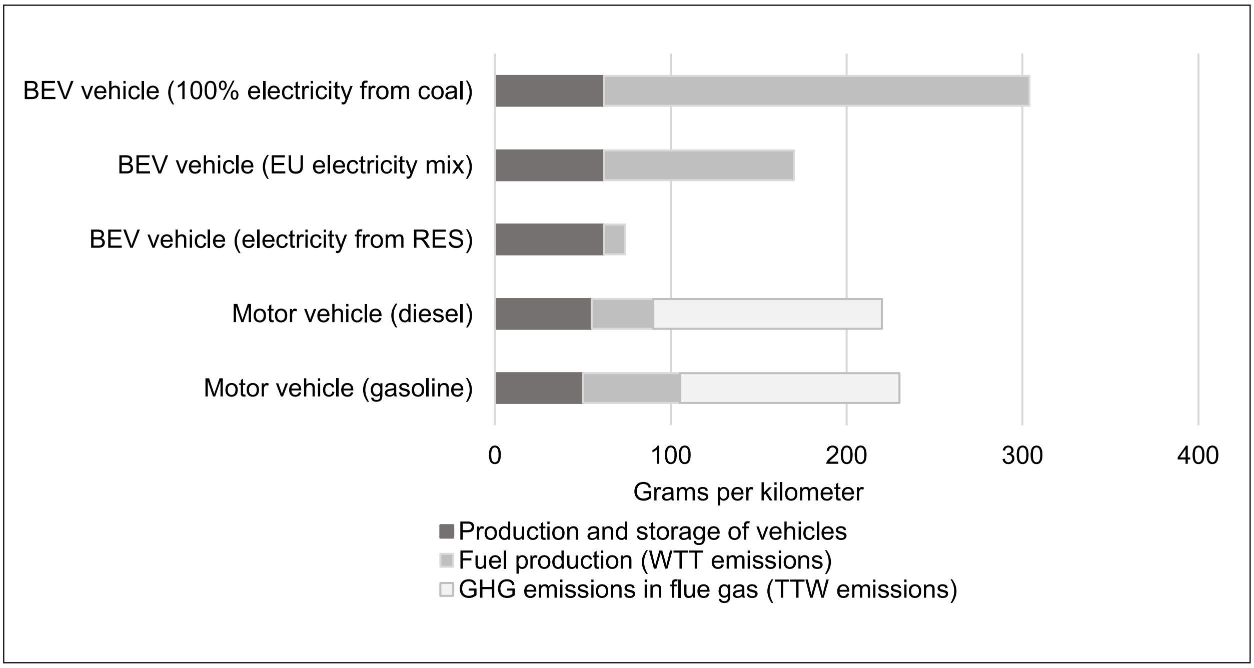

Fig. 2. GHG emission levels in the life cycle of selected motor vehicles and fuels.

Source: Motowidlak (2020, p. 99).

A comprehensive assessment of the environmental impact of electric vehicles also requires attention to the risks associated with the production, use and disposal of batteries (Moćko et al., 2011). These risks include the problems of sourcing lithium, copper, silicon and aluminum, which are necessary for their production. Batteries, due to their relatively short lifespan, also require large energy inputs for disposal. In addition, they can pose a danger to people and the environment if they are destroyed in an accident.

3.2. Strategic framework for electromobility development

The directions of development of sustainable, innovative and resilient EU mobility are in line with the implementation of the goals contained in the currently applicable strategic documents, i.e. the UN 2030 Agenda constituting an action program for sustainable development until 2030 and the adopted Paris Agreements. At the same time, they are consistent with the guidelines of the EU transport and climate policy. Intensifying climate and environmental changes have prompted the EU to take urgent and ambitious action under the European Green Deal. In the adopted communication, a commitment was made to achieve climate neutrality by 2050, including the "green transformation" in key cross-cutting programs and sectoral policies. However, a net-zero society and economy will not be possible without a sustainable and innovative transport system. It is estimated that achieving climate neutrality will require a 90% reduction in transport emissions by 2050. One of the strategic directions of the transition to a "clean", safe and intelligent transport network was the development of the EV car market and the appropriate charging infrastructure. The importance of a holistic approach to infrastructure planning for EVs in the context of energy system and transport integration was emphasized. Electromobility is key to accelerating decarbonization and reducing pollution, especially in cities, and new mobility services will increase the efficiency of the transportation system and reduce congestion. The projected decline in the cost of EVs means that around 2025 they could become competitive with internal combustion engine vehicles in terms of total cost of acquisition and use (Electric Vehicle…, 2020).

The current Sustainable and Smart Mobility Strategy ("EUSSSM"), dated December 9, 2020, contains a total of 82 initiatives in 10 key areas and concrete actions to significantly reduce the current dependence on fossil fuels, increase the use of sustainable modes of transportation, and internalize external costs, particularly for access to infrastructure and through CO_2 pricing mechanisms. Regarding EVs, he points out that at least 30 million BEVs and PHEVs will be on European roads by 2030. By 2050, on the other hand, almost all motor vehicles will be emission-free. Potential in this regard is shown by fuel cell hydrogen vehicles, which are currently in the early stages of research and development.

The European Commission's new legislative proposals, presented in July 2021 in its "Fit for 55" (2021) package, aim to reduce greenhouse gas (GHG) emissions by at least 55% by 2030 compared to 1990 levels, and to achieve climate neutrality by 2050. The Commission's proposals include stricter regulations to reduce emissions, with a particular focus on the transportation sector. The set of priority actions for the sustainable development of the electric car market reflects a coherent and integrated approach to sectoral policies (Tab. 1).

The amendment to the Alternative Fuels Infrastructure Directive (Proposal for a Regulation..., 2021) provides for:

- development of publicly accessible charging points, intended for passenger cars and light commercial vehicles distributed at maximum intervals of 60 km along the core network,
- creation of all-access charging points, intended for heavy vehicles, distributed at a maximum of every 60 km along the TEN-T core network and every 100 km along the comprehensive network,
- ensuring full interoperability of infrastructure, including taking into account cross-border infrastructure,
- providing complete user information and appropriate payment options.

Tab. 1. Coherence of initiatives under the "Fit for 55" package and the "EUSSSM" strategy for the sustainable development of EVs, charging infrastructure and energy.

Initiatives of the Strategy for Sustainable and Intelligent Mobility „EUSSSM"	**Alternative Fuels Infrastructure Directive**	**Effort Sharing Regulation**	**Regulation on batteries and waste batteries**	**Regulation on CO_2 emission standards for cars**	**Renewable Energy Directive**	**Energy Taxation Directive**	**Energy Efficiency Directive**	**Coal Limit Adjustment Mechanism**
Popularization of EV cars (passenger and freight transport)	xx	x	xx	xx	xx	x	x	x
Expansion of the charging infrastructure	xx	x	xx	xx	x	x	x	xx
Sustainable and health-neutral electromobility between cities	xx	x	x	xx	x	xx	x	
Decarbonisation of energy, development of RES	x	x	xx	xx	xx	xx	xx	x
Sustainable EV battery chain		x	xx		xx	x	xx	x
CO_2 emissions charges	x		xx	xx	x	xx	x	xx
Coherence of the development of the TEN-T network and electromobility	xx	x		x	x	x	x	x
Innovation and artificial intelligence	x	x	xx	xx	x	x	x	x
Strengthening the competitiveness of the single market	xx	x	xx	xx	xx	x	xx	x
Fair and equitable electromobility for all	xx	xx	xx	xx		x		x
Improving the safety and security of transport	xx	x	xx	xx	x		x	

X – coherence; xx – strong synergy effect

Source: own study.

In the "Fit for 55" package, the Commission has proposed to revise regulations on CO_2 emissions from cars and vans. CO_2 emission standards provide a strong stimulus to the EV market, creating demand for charging infrastructure. EU reduction targets for 2030 are to be increased to 55% for cars and 50% for light commercial vehicles. In addition, the reduction should reach 100% by 2035.

The EUSSSM strategy also works in synergy with the Energy Performance of Buildings Directive, which addresses the issue of private charging infrastructure by setting requirements for the development of charging infrastructure in buildings. By ensuring the implementation of the necessary infrastructure for EVs, the strategy will also complement efforts on charging policies, which also aim to increase demand for this type of vehicle. Another policy instrument aimed at accelerating the spread of EVs is the Clean Vehicles Directive. Wider infrastructure availability and faster development of EVs will indirectly facilitate the spread of "clean" vehicles in public fleets. The use of more hydrogen and battery electric vehicles in the EU fleet is also an important part of the Commission's hydrogen strategy and smart energy system integration strategy.

The above correlations and conclusions allow positive verification of the first auxiliary hypothesis, according to which the EU policy assumptions create a strategic framework conducive (directly and indirectly) to increasing the added value in the electromobility supply chain for EVs. However, the achievement of the adopted goals requires the implementation of investment activities in individual EU Member States in the development of the necessary infrastructure and market for EVs, as well as increasing public acceptance of their use. At the same time, given the capital-intensive and complex nature of infrastructure investment, it is important that electromobility development strives to simultaneously achieve economic, social, environmental goals.

3.3. Development of the electric vehicle market

The high growth rate of the EV sales market that has been occurring in recent years continues unabated. The development of transportation electrification has been focused on the passenger car segment. Increased policy support for EVs as part of economic recovery packages has contributed to sales growth, especially in the second half of 2020 in Europe, when the share of EVs among new registrations in the EU tripled compared to 2019. This growth came despite the COVID-19 crisis, which caused a 22% decline in European EV market sales compared to 2019. As a result, the EV market in Europe saw the highest growth in 2020, and with 1.4 million units sold, Europe became the leader, overtaking China (Fig. 3). The following year, public spending on subsidies and incentives for EVs nearly doubled to nearly USD 30 billion by 2020. At the same time, an increasing number of countries have pledged to phase out internal combustion engines or set ambitious vehicle electrification targets for the coming decades, further boosting EV sales. In

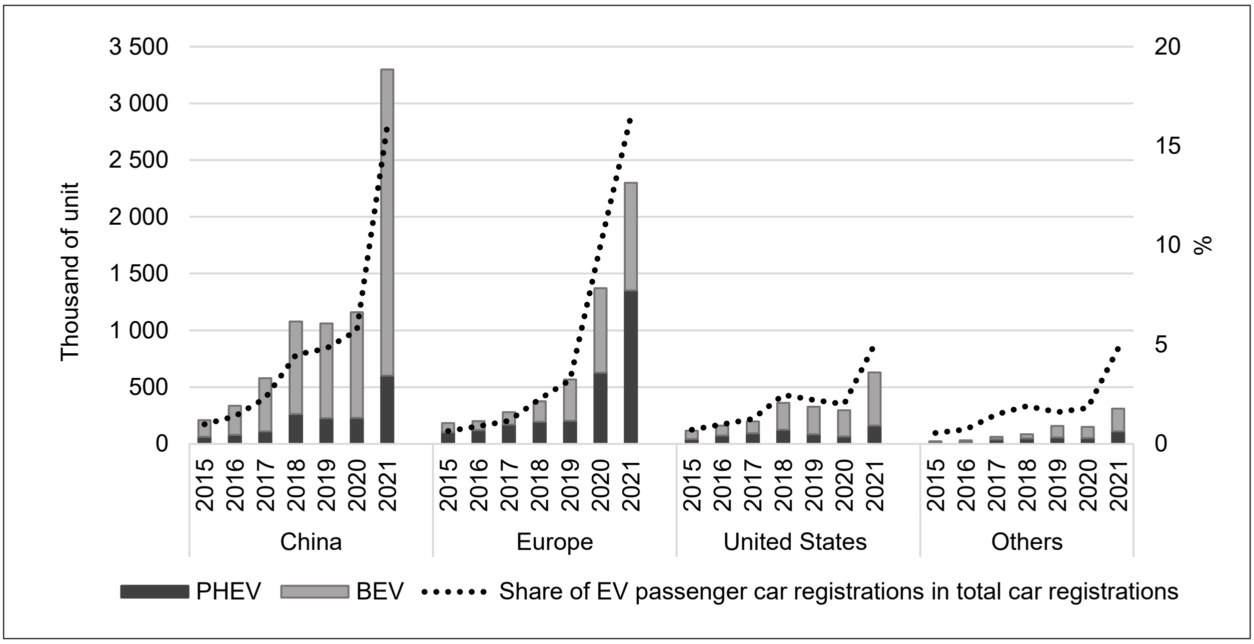

Fig. 3. EV (BEV and PHEV) passenger car sales and share of EVs in total car registrations in selected world regions.

Source: based on Global EV Outlook (2022).

2021, their sales doubled compared to 2020, reaching 6.6 million EVs. China sold the most EVs in the year under review (3.3 million). Sales in Europe showed continued strong growth (up 65% from 2020) and amounted to 2.3 million. However, as a share of the total vehicle fleet, EVs accounted for about 1.2% (EAFO, 2021b). Global EV sales maintained strong growth in 2022, with 2 million vehicles sold in the first quarter, up 75% from the same period in 2021 (Global EV…, 2022).

The uptake of EVs in the EU is concentrated in a small number of countries. In 2021, the seven EU Member States with the most EVs accounted for a combined 85.3% of the EV fleet (EAFO, 2021b). This group included Germany, France, the Netherlands, Sweden, Denmark, Spain and Italy. In terms of the share of EV vehicles in the car fleet, three of these countries with the largest share are Sweden (3.7%), the Netherlands (3.2%) and Denmark (2.1%). In recent years, EV car sales have been concentrated mainly in European countries with a relatively high GDP per capita (ACEA, 2021), where more people can afford to buy an electric car with current policies. Among countries with similar income levels, the interest in EVs was largely determined by the available support instruments at the national and local level (Wapelhorst, 2021a; 2021b).

The number of EU customers choosing to purchase a BEV is steadily increasing (Fig. 4). In 2021, the largest number of these vehicles was sold in Germany with 360,000 units. (up 89% y/y), France with a registration level of 170 thousand units. (+65% y/y). The country with the largest share of EV registrations in total car registrations in 2021 was Sweden (43%). Second place went to Denmark (35%), while third place went to the Netherlands (30%), a significant result for countries of this size.

In Poland, the first registrations of EV cars took place in 2011. In the period 2011-2013, their number was on average around 30 vehicles per year. In 2014, 141 registrations of EV cars were recorded, which started a clear growing trend (Fig. 5). In 2017, the number of registered EV cars exceeded 1,000. In 2019, their sales amounted to 2,690 units, including 1,490 BEV cars. According to data from the Polish Alternative Fuels Association (Licznik elektromobilności, 2022), at the end of January 2021, 17,800 EV passenger cars were registered in Poland, of which 50% were BEVs and the remainder PHEVs.

The values of the indicators of electromobility development in Poland significantly deviate from the values of analogous indicators, characterizing the leading countries in this development, although the distance separating Poland from these countries has decreased. Still, there are definitely more new and especially used ICEV cars registered in our country, which at the same time slows down the sustainable development of the EV market. The market needs clear and transparent information on the financial support system in the coming years. Without a stable and well-considered EV policy, the development of electromobility may be slowed down.

The inevitability of the development of electromobility means that the world's automotive market leaders are incorporating this development into their market strategies. One of the core tenets of these

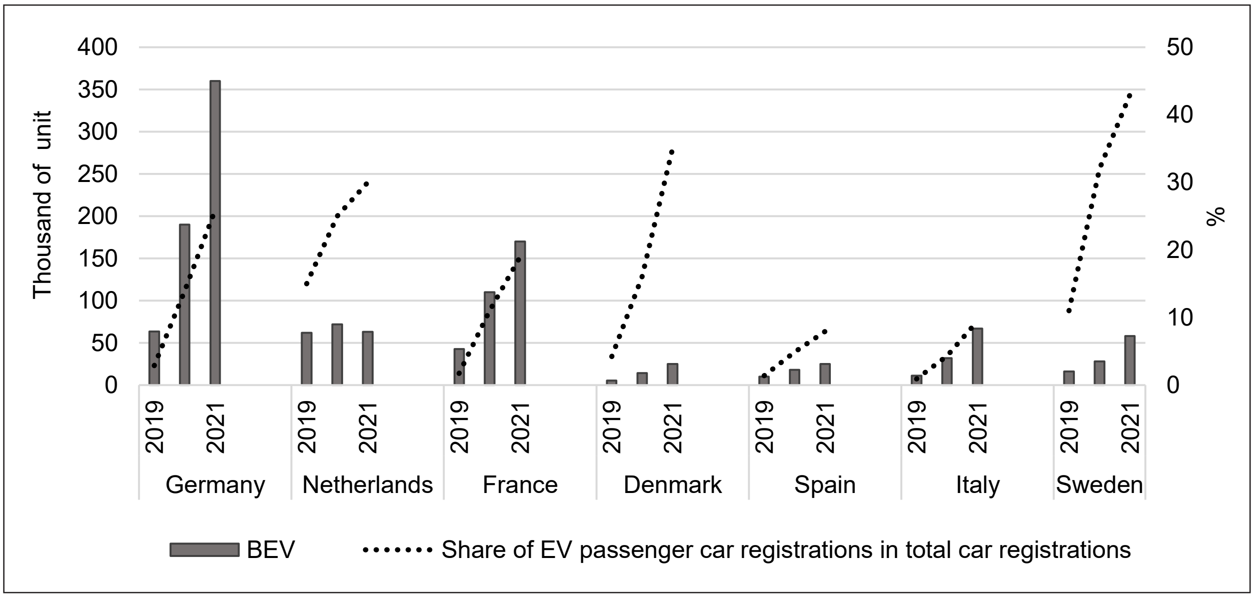

Fig. 4. BEV passenger car sales and share of EVs in total car registrations in selected EU Member States in 2019-2021.

Source: own study based on Global EV Outlook (2022).

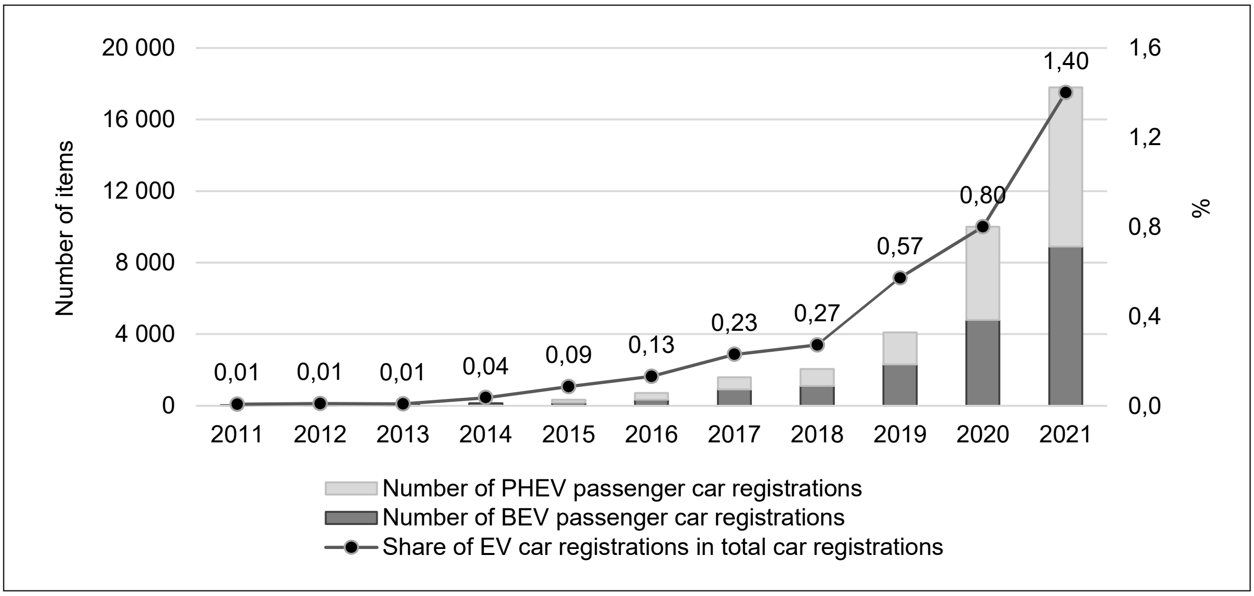

Fig. 5. Development of the EV passenger car market in Poland.

Source: own study based on IEA data (2022).

strategies is to conduct research and development work aimed at reducing the cost of manufacturing EVs and their components, which is key to increasing the availability and sales of vehicles and the evolution of electromobility in accordance with the principles of sustainable development.

3.4. Development of electric vehicle charging infrastructure

In the European Union, the 2014 Alternative Fuels Infrastructure Directive (Directive..., 2014) regulates the deployment of public chargers to power electric vehicles. The policy recommended that in EU Member States, the average number of publicly available charging points (Electric Vehicle Supply Equipment, EVSE) in 2020 should be equivalent to at least one charging point per 10 EVs. The proposed new EU legislation (Proposal for a Regulation…, 2021) would mandate 1 kW of publicly accessible charger per BEV and 0.66 kW per PHEV, as well as a minimum range of public chargers on highways. At the same time, the optimal number of publicly accessible charging points would depend on location-specific factors, such as travel patterns, the number of BEVs and PHEVs, the number of EV owners with a dedicated private charging point, and with access to workplace charging points.

A European Commission report, published in 2021, indicates that there has been some progress in the development of EV charging infrastructure (State of the art..., 2021). However, despite successes, such as the promotion of a common EU plug-in standard, significant obstacles remain in terms of infrastructure availability. An assessment by the European Court of Auditors (Charging infrastructure..., 2021) found that the distribution of charging stations varies greatly from country to country, payment systems are not harmonized with minimum requirements, and available funds are not properly spent. It found that the EU is still far from achieving the European Green Deal goal of one million charging points by 2025.

According to the European Alternative Fuels Observatory, in 2020 the number of public charging points in the EU was about 224,200, of which 11% were fast chargers (≥22 kW) (EAFO, 2021a). However, their geographic distribution is uneven. In addition, European Observatory data show an increasing number of EVs per public charging point, as vehicle registrations grew faster than the number of public charging points.

In 2021, the average EV to charger ratio was 14, up from 11 in 2020 and above the recommendation of 10. Some countries have performed better, e.g. the Netherlands (ratio of 5 and 2.6 kW per EV), where a large-scale strategy of slow deployment of on-demand chargers has been applied (Fig. 6). In fact, the share of fast chargers in the country remains low overall at around 3%. Italy approximately meets the recommended charger ratios (11 EV per charger). The outlook is promising in Spain, which had 20 EVs per charger and 1.2 kW per EV and more than 30% fast charging in 2021. In contrast, France and Germany are not meeting the recommendations for public charger availability.

Meanwhile, publicly available charging installations, especially fast charging, encourage the purchase of EVs and facilitate longer journeys. In 2021, the number of publicly available fast chargers was 9.2 thousand

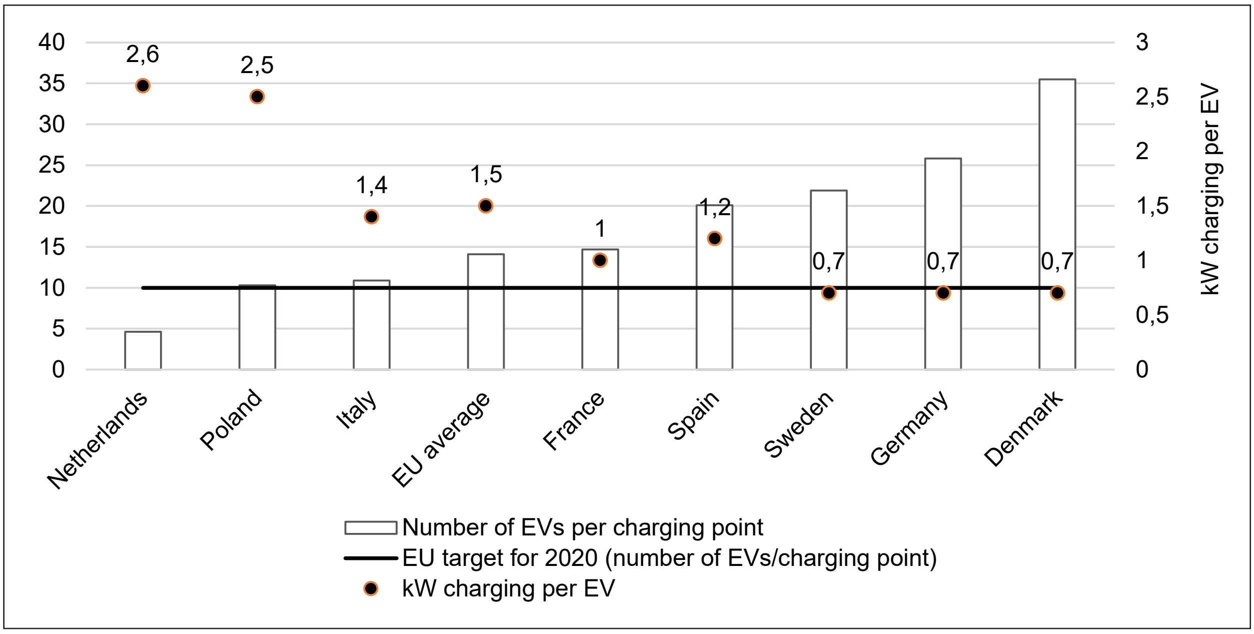

Fig. 6. Number of EVs per charging point and kW of charging per EV in selected EU Member States in 2021.

Source: own study based on IEA data (2022).

in Germany, 4.5 thousand in France and 2.6 thousand in Spain and the Netherlands. The availability of slow charger installations in EU Member States is definitely greater. More than 80,000 slow chargers were installed in the Netherlands in 2021, followed by 50,000 in France and 40,000 in Germany.

The current momentum in EV sales can only be sustained if an increasing proportion of the population has access to convenient and affordable charging infrastructure, both publicly available and private chargers in homes and workplaces. Governments will need to continue to support investment and minimize barriers to the development of charging infrastructure. Policies that can contribute to removing barriers to the development of EVs include building regulations for the installation of charging infrastructure. An amendment to the EU Directive on the Energy Performance of Buildings (Proposal for a Directive ..., 2021) includes measures to ensure that parking lots next to buildings are gradually equipped with EV charging points. The directive includes provisions for equipping new or renovated buildings with dedicated energy infrastructure suitable for the subsequent installation of charging points.

3.5. Analysis of national policies for the sustainable development of the EV market and charging infrastructure in the EU

The implementation of low- and zero-emission solutions in electromobility systems involves a number of investment projects that will not be economically viable in the short term. Among other things, they are characterized by a high degree of capital intensity and complexity of implementation, with the effectiveness of their implementation associated with certain risks and uncertainties in the context of interoperability and consistency of charging infrastructure, the expected level of public acceptance crucial for increasing the level of EV uptake (Tab. 2). As a rule, the activities accompanying investment projects for the development of the EV market and charging infrastructure are treated as those whose costs are as real and measurable as possible at a given moment, while the benefits are often quite postponed.

Analysis of investment project feasibility studies confirms that the highest levels of complexity and risk are demonstrated by projects in the development of infrastructure and low-carbon propulsion technologies, as well as solutions to foster greater cross-border interoperability and data sharing capabilities. At the same time, these projects can be credited with high efficiency in the implementation of EVs. Information and promotional activities, characterized by a low level of complexity, show great potential for efficiency and effectiveness in the development of electromobility. They are aimed primarily at raising awareness and creating environmentally friendly transportation behavior. Achieving these benefits is important for the gradual uptake of low-carbon mobility systems, which will result in, among other things, an increase in the economic viability of their implementation and an improvement in the state of the climate (Gevaers et al., 2014). Legislative support is also key in this process.

The literature review and expert analysis were the starting point for assessing the consistency of national

Tab. 2. Degrees of complexity of implementation of investment projects in the development of the electromobility system.

The degree of economic and technological complexity		The degree of legal and informational complexity: Low	The degree of legal and informational complexity: High
	High	Organizational and implementation activities: – integrated research and innovation strategies, – digital market strategies, – industrial and investment policies, – environmental expertise of EV technologies, – fleet purchasing, – new models of cooperation.	Activities in the field of new technologies: – standardization of technical specifications of EVs and relevant infrastructure, – costs (investment and environmental) of developing new zero-emission technologies, – developing common solutions between transport and the energy market, – solutions in the field of cross-border interoperability and the possibility of data exchange and cyber security, – creating the EV battery value chain.
	Low	Information and promotional activities: – public campaigns to raise awareness of the escalating effects of climate change, – access to information on travel costs, EV emissions, etc, – EV travel advice and training, – zero-emission zones.	Legislative actions: – legislation to promote electromobility, – government strategies for financial support for EVs, – green public procurement procedures to promote the introduction of EVs on the market, – tax exemptions and reliefs.

Source: own study.

policies with current EU strategies for the sustainable development of carbon-free mobility. The analysis conducted indicates that the main lines of action of national policies are consistent with EU policies. However, there is a wide variation in the detail of the implementation of the adopted measures, especially with regard to the proposed instruments to support the uptake of EVs. However, despite some diversity in terms of proposed support instruments, it was possible to identify four categories of activities for the development of the electromobility system, i.e. legislation, incentives for individual customers, infrastructure, requirements for institutions/collective customers. An overview of the applicable categories of national policy actions in selected EU countries regarding EV market development and charging infrastructure is presented in Tab. 3.

In Germany, the government has funded a wide range of measures to promote EVs. A key funding measure is a one-time vehicle purchase bonus introduced in 2016. Additional benefits include the exemption of EVs from annual ownership tax and a lower tax base for electric company cars. The German government has also established various funding programs at the national level to build a public EV charging infrastructure network (Federal Ministry..., 2020). At the end of 2019, the government adopted a “Master Plan” that sets out goals and measures for the development of a public and non-public charging network.

Sweden has also set ambitious targets for increasing the number of EVs and public charging infrastructure. The government intends to ban the sale of new petrol and diesel cars from 2030 (Wappelhorst, 2021a). To achieve this goal, a number of incentives have been implemented in the country to promote EVs and deploy public charging infrastructure. For example, already in 2012, the government introduced a bonus for the purchase of an EV vehicle. In mid-2018, it adopted the “bonus-malus” tax system, providing even higher incentives for the purchase of an electric vehicle. Various financing programs for the installation of normal and high-powered public charging infrastructure have also been adopted in recent years, resulting in the steady expansion of public charging points. A wide

Tab. 3. Overview of national policies in selected EU countries for the development of the EV market and charging infrastructure.

Country	Legislation	Incentives	Infrastructure	Requirement
Denmark	x	x	x	
France	x	xx	xx	x
Germany	x	xx	xx	x
Italy	x	xx	xx	
Netherlands	x	xx	xx	x
Spain	x	x	xx	
Sweden	x	xx	xx	x
Poland	x	x	x	

xx – wide range of support

Source: own elaboration based on Hall et al. (2021).

range of measures to support the uptake of EVs and funding mechanisms for public charging points have also been included in their plans by the Netherlands, France and Spain.

The Dutch support model works on a partnership basis, where thoughtful and supported policies are created through consultation with private entities and local governments (Netherlands Enterprise Agency, 2022). Provinces and municipalities are preparing tenders for public charging infrastructure, i.e.: smart charging, open protocols and cyber security. Many cities and regions are implementing initiatives and operational policies to accelerate the development of electric transportation. For example, Amsterdam, Utrecht, Rotterdam and The Hague have grants to purchase electric passenger vehicles, trucks and cabs for commercial use. In addition, there are subsidies for the demolition of old internal combustion engine vehicles. In recent years, a number of Dutch cities have already introduced green zones to support the introduction of green transportation. If residents buy an EV and don't have their own parking space, they can apply for a charging point to be installed in a public space at no cost.

The ecological transformation of the French economy is described in the "France Revival Plan 2030" (2020). France plans to install 7 million charging points for hybrid and electric vehicles by 2030 in partnership with OEMs, energy suppliers and charging station infrastructure providers.

Spain's program to promote electric and sustainable mobility, "MOVES Plan" (Spain mobility..., 2020), targets four activities, including the acquisition of EVs and the expansion of charging infrastructure, with a focus on job creation and leveraging the industrial value of the chain. The program has a budget of EUR 100 million. In 2021 and 2022, the Spanish government has earmarked additional funds, amounting to EUR 570 million, for the promotion of electric mobility.

There are a number of barriers to EV market development in Poland. The key one is considered to be the low availability of publicly accessible charging points (Smardz, 2022). Existing financial support programs (e.g. "My electrician", "Support for EV charging and refueling infrastructure", "Development of electricity infrastructure for the development of EV charging stations") are insufficient to meet the goals of electrification of mobility by 2050.

The conducted policy analyzes confirm that a wide range of promotional activities removing consumer barriers in terms of affordability, convenience and awareness is of key importance for accelerating the process of popularization of electric vehicles, which allowed for a positive verification of the second supporting hypothesis.

Discussion

Taking into account the assumed aim of the article, the results of the conducted analyzes indicate several important findings that allow to positively verify the main hypothesis.

The concept of electromobility is becoming more and more popular in scientific research and is a frequent element of discussions among government decision makers. Previous research confirms the growing importance and management of electrification of motor transport and provides guidance on what direction this process should take. This article provides several findings that contribute to the development of research in the field of shaping the electromobility of passenger cars, taking into account the assumptions of sustainable development.

The proposed qualitative model of sustainable development of passenger car electromobility indicates the need for a systemic approach, in the context of the system value chain and general assumptions of the product and service life cycle. This model identifies the basic interactions between EV passenger cars, economy, environment and society (theoretical dimension). After giving it quantitative characteristics, it can support investment decisions in the field of sustainable electromobility development (practical dimension). In addition to the need to reduce CO_2 emissions (Woo et al., 2017; Yu et al., 2018) in pursuit of the goals of the Paris Agreement and European climate and transport policy goals, there are economic (Milakis et al., 2017) and social (Moreno et al., 2018) in favor of increasing the use of electricity to power passenger cars. The review of the literature on the subject also provided research results indicating that the production and use of EVs and batteries are associated with many challenges. Considering the guiding goal of electrification of individual motoring, priority should be given to changing the structure of electricity generation, towards increasing the share of less emission-intensive raw materials, with particular emphasis on RES. However, the development of electromobility based on renewable energy sources is very complex, which is why actions aimed at improving the quality of power systems, their capacity and the development of Smart Grids are important. At the same time, these networks would enable the use of EV cars as electricity storage units, generating economic and environmental benefits, and would contribute to the balancing and stability of the power system. Findings on the environmental aspects of the development of EV electromobility also indicate the need to extend the life cycle of EV batteries and improve the efficiency of their recycling, which has been confirmed in the proposals for new EU regulations on batteries (EU Battery…, 2022).

The development of electromobility is also associated with economic and social aspects. Based on the findings and conclusions of the research so far, several impacts of the development of EV electrification can be observed, from the perspective of costs and benefits in economic and social dimensions. Expenditures on research and development, changing the architecture of the EV supply chain, or uncertainty in terms of social acceptance do not change the general perception of electromobility as an innovation. It has great potential in terms of increasing added value for all participants in the chain, which is ultimately to lead to a reduction of CO_2 emissions.

The findings show that the development of sustainable, innovative and resilient mobility is the leading objective of the EU transport and climate policy and is in line with the priorities of the Paris Agreement and the UN 2030 Agenda. One of the key specific objectives to achieve the leading objective is to reduce CO_2 emissions from passenger cars. This goal is supported, directly and indirectly, by the EU. This is confirmed in many strategic documents. Studies by L. L. Li et al. (2020) and H. Du et al. (2018) reveal the positive impact of policy on socially acceptable electrification of passenger cars. However, R. Chinoracky et al. (2022) emphasize that if electromobility is to contribute to reducing CO_2 emissions in accordance with the assumptions of sustainable development, the political implications must have a long-term dimension.

The directions for the electrification of road transport and the necessary infrastructure as well as the means for its implementation are determined at the supranational level. However, the final mix of measures used and their weightings are the responsibility of EU Member States, who set the national action plans. These plans should include actions aimed at strengthening efforts to develop EV electromobility and build a coherent network, in line with EU policy. The analyzes carried out in this article confirm the results of previous research on the progress in the development of the EV market and charging infrastructure. The available data shows that despite the high dynamics of sales of EV cars, the market of these cars in the EU is still underdeveloped in relation to the market of combustion cars. In addition, it is characterized by very large disproportions between individual EU Member States in terms of the number of EV vehicles and charging stations. The study shows that the development of charging infrastructure is a key factor that affects the willingness to buy EV cars and their use. National policies should therefore prioritize the development of charging infrastructure. The analysis carried out in the article allows us to conclude that in some EU countries support under national policies has been dispersed, hence the goals set for the development of charging infrastructure have not been fully achieved. In the EU countries covered by the study, the analysis of national policies and instruments supporting the development of electromobility has a positive impact on shopping preferences. These countries account for over 80% of the EV market in the EU.

Conclusion

The identified dependencies between the development of mobility and the increase in demand for transport fuels, the combustion of which causes an increase in CO_2 emissions, indicate the extremely important role of the action plan aimed at solving the problem of the negative consequences of growing energy needs. In the case of the EU, an example of such a plan is the concept of developing electromobility in the field of individual motorization, which is an expression of the implementation of the assumptions of sustainable development. Based on the review of the literature on the subject and the results of the analyzes carried out, it can be concluded that the actions taken by the EU within the framework of transport and climate policy and the European Green Deal, inspired by climate protection and the pursuit of sustainable development of the economy, will require decisive solutions in the field of dissemination of EVs, development charging infrastructure and changes in the context of the value chain. The analyzes carried out show a large degree of differentiation in terms of the level of development of electromobility in the EU Member States.

Due to the complexity of the concept of developing the electromobility system in the EU, from the perspective of the added value chain and product/service LCA, it can be concluded that its implementation will be a gradual and long-term process, requiring a systemic approach. The proposed solutions are innovative with great potential. This potential relates primarily to reducing CO_2 emissions from transport, improving the competitiveness of transport, developing RES, increasing energy security and implementing new services, e.g. V2G. At the same time, it should be taken into account that the effectiveness of the measures implemented for the electrification of individual motoring will be partially compensated for by the costs associated with the dissemination of electromobility in road transport. In addition, due to the innovativeness of the proposed low- and zero-emission solutions in relation to EVs, their significant effects may appear in the long term. At the same time, obtaining them will require the implementation of specific actions as part of national and local policies, aimed not only at the implementation of EV technology, but also at increasing public awareness for new propulsion technologies. The implementation of the electromobility concept is an important element in the development of a competitive and innovative EU economy. At the same time, it can contribute to the achievement of an extremely important global goal, which is climate protection.

One of the key challenges in the field of future research directions is the development of algorithmic approaches that allow the use of the proposed qualitative model in the investment decision-making processes in the field of EV electromobility. From the perspective of the development of sustainable, innovative and resilient mobility of people, it can be considered important to study the potential of electromobility in relation to micromobility and urban transport.

The article does not attempt to quantify changes in CO_2 emissions related to the use of various financial support instruments in the countries covered by the study. A prerequisite for successfully performing such a task is the availability of a comprehensive and accurate dataset. The results of this analysis indicate that this may pose another challenge for future research.

References

ACEA, 2021, *Electric cars: lower-income countries fall behind, with uptake linked to GDP per capita*, https://www.acea.auto/press-release/electric-cars-lower-income-countries-fall-behind-with-uptake-linked-to-gdp-per-capita/ [access: 15.09.2022].

Ajanovic A., Haas R., 2017, The impact of energy policies in scenarios on GHG emission reduction in passenger car mobility in the EU-15, *Renewable and Sustainable Energy Reviews*, 68, 1088-1096, DOI: 10.1016/j.rser.2016.02.013.

Barrett J., Bivens J., 2021, *The stakes for workers in how policymakers manage the coming shift to all-electric vehicles. Report*, Economic Policy Institute, Washington.

Charging infrastructure for electric vehicles, 2021, European Court of Auditors.

Chinoracky R., Stalmasekova N., 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, DOI: 10.3390/en15176144.

Coban H. H., Rehman A., Mohamed A., 2022, Analyzing the Societal Cost of Electric Roads Compared to Batteries and Oil for All Forms of Road Transport, *Energies*, 15(5), 1925, DOI: 10.3390/en15051925.

de Souza J. V. R., de Mello A. M., Marx R., 2019, When is an Innovative Urban Mobility Business Model Sustainable? A Literature Review and Analysis, *Sustainability*, 11, 5-18.

Directive 2014/94/EU of the European Parliament and of the Council of October 22, 2014 on the development of alternative fuel infrastructure, 2014, OJ L 307, 28.10.2014, 1-20.

Du H., Liu D., Sovacool B. K., Wang Y., Ma S., Li R. Y. M., 2018, Who buys New Energy Vehicles in China? Assessing social-psychological predictors of purchasing awareness, intention, and policy, *Transportation Research, Part F: Traffic Psychology and Behaviour*, 58, 56-69, DOI: 10.1016/j.trf.2018.05.008.

EAFO, 2021a, *Alternative fuels (electricity), charging infra stats*, European Alternative Fuels Observatory, https://www.eafo.eu/ alternative-fue [access: 15.09.2022].

EAFO, 2021b, *Vehicles and fleet, passenger cars*, European Alternative Fuels Observatory, https://www.eafo.eu/vehiclesand-fleet/m1 [access: 10.09.2022].

EEA Report, 2022, *Transport and environment report 2021. Decarbonising road transport – the role of vehicles, fuels and transport demand*, No 2.

Electric Vehicle Outlook 2020, 2020, Bloomberg NEF.

Electric vehicles from life cycle and circular economy perspectives, 2018, TERM 2018: Transport and Environment Reporting Mechanism, EEA, 13.

Electro-Mobility Changes Rules of Game for Automotive Industry, 2018, The FINANCIAL, September 5.

EU Battery Regulation Make New Demands on Industry, https://www.stenarecycling.com/events/future-of-battery-recycling/eu-battery-regulations-make-new-demands-on-industry-3/ [access: 15.10.2022].

European Green Deal, Communication from the Commission to the European Parliament, 2019, the European Council, the Council, the Economic and Social Committee and the Committee of the Regions, COM(2019) 640, Brussels.

Eurostat. Final energy consumption in road transport by type of fuel, (online data code: TEN00127), https://ec.europa.eu/eurostat/databrowser/view/ten00127/default/table?lang=en [access: 05.09.2022].

Federal Ministry of Transport and Digital Infrastructure, 2020, *Funding guideline for charging infrastructure for electric vehicles*, https://www.bmvi.de/DE/Themen/Mobilitaet/Elektromobilitaet/Ladeinfrastruktur/ Ladeinfrastruktur.html [access: 27.09.2022].

France Relance recovery plan: building the France of 2030, 2020, France Diplomacy, https://www.diplomatie.gouv.fr/en/french-foreign-policy/ [access: 15.10.2022].

Gallo M., Marinelli M., 2020, Sustainable Mobility: A Review of Possible Actions and Policies, *Sustainability*, 12(18), 7499, DOI: 10.3390/su12187499.

Gevaers R., de Voorde E., van Vanelslander T., 2014, Cost Modelling and Simulation of Last-mile Characteristics in an Innovative B2C Supply Chain Environment with Implications on Urban Areas and Cities, *Procedia – Social and Behavioral Sciences*, 125, 410-411, DOI: 10.1016/j.sbspro.2014.01.1483.

Global Energy Review: CO_2 Emissions in 2021, 2022, IEA.

Global EV Outlook 2022, 2022, IEA, Paris.

Fit for 55: delivering the EU's 2030 Climate Target on the way to climate neutrality, 2021, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2021) 550, Brussels.

Gómez Vilchez J. J., Julea A., Lodi C., Marotta A., 2022, An analysis of trends and policies promoting alternative fuel vessels and their refueling infrastructure in Europe, *Frontiers in Energy Research*, 10, 904500. DOI: 10.3389/fenrg.2022.904500.

Hall D., Xie Y., Minjares R., Lutsey N., Kodjak D., 2021, *Decarbonizing road transport by 2050: Effective policies to accelerate the transition to zero-emission vehicles*, International Council on Clean Transportation.

Helmers E., Dietz J., Weiss M., 2020, Sensitivity Analysis in the Life-Cycle Assessment of Electric vs. Combustion Engine Cars under Approximate Real-World Conditions, *Sustainability*, 12(3), 1241, DOI: 10.3390/su12031241.

Holden E., Gilpin G., Banister D., 2019, Sustainable Mobility at Thirty, *Sustainability*, 11(7), DOI: 10.3390/su11071965.

IEA data, 2022, https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer [access: 30.08.2022].

IPCC, 2022, *Climate Change 2022: Impacts, Adaptation and Vulnerability*, https://www.ipcc.ch/report/ar6/wg2/ [access: 17.09.2022].

Jagiełło A., 2021, *Elektromobilność w kształtowaniu rozwoju drogowego transportu miejskiego w Polsce*, Wydawnictwo Uniwersytetu Gdańskiego, Gdańsk.

Jochem P., Plötz P., Ng W. S., Rothengatter W., 2018, The contribution of electric vehicles to environmental challenges in transport, *Transportation Research, Part D: Transport and Environment*, 64, 1-4, DOI: 10.1016/j.trd.2018.06.022.

Kester J., Noel L., Zarazua de Rubens G., Benjamin K., Sovacool B. K., 2018, Policy mechanisms to accelerate electric vehicle adoption: A qualitative review from the Nordic region, *Renewable and Sustainable Energy Reviews*, 94, 719-731, DOI: 10.1016/j.rser.2018.05.067.

Klecha L., Gianni F., 2018, *Designing for Sustainable Urban Mobility Behaviour: A Systematic Review of the Literature*, Springer, Switzerland, 137149, DOI:10.1007/978-3-319-61322-2_14, https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/2590456/designing_for.pdf?sequence=4 [access: 20.10.2022].

Kolz D., Schwartz M., 2017, Key Factors for the Development of Electro Mobility, *WIT Transactions on Ecology and the Environment*, 224, 225-233, DOI: 10.2495/ESUS170211

Kumar R. R., Kumar A., 2020, Adoption of electric vehicle: A literature review and prospects for sustainability, *Journal of Cleaner Production*, 253, DOI: 10.1016/j.jclepro.2019.119911.

Li L. L., Wang Z., Wang Q., 2020, Do policy mix characteristics matter for electric vehicle adoption? A survey-based exploration, *Transportation Research, Part D: Transport and Environment*, 87, DOI: 10.1016/j.trd.2020.102488.

Liao F., Molin E. J. E., van Wee G. P., 2017, Consumer preferences for electric vehicles: a literature review, *Transport Reviews*, 37(3), 252-275, DOI: 10.1080/01441647.2016.1230794.

Licznik elektromobilności, 2022, https://orpa.pl/licznik-elektromobilnosci-w-styczniu-bez-przelomu-na-polskim-rynku-samochodow-elektrycznych/ [access: 17.08.2022].

Magalhães I., Santos E., 2022, Evaluating the potential of mobility plans for achieving sustainable urban development, *Research in Transportation Business & Management*, 43, DOI: 10.1016/j.rtbm.2021.100743.

Mantouka E. G ., Fafoutellis P., Vlahogianni E. I., Oprea G.-M., 2022, Understanding user perception and feelings for autonomous mobility on demand in the COVID-19 pandemic era, *Transportation Research Interdisciplinary Perspectives*, 16, DOI: 10.1016/j.trip.2022.100692.

Mężyk A., Zamkowska S., 2017, Rozwój polityki transportowej UE dla miast, *Autobusy– Technika, Eksploatacja, Systemy Transportowe*, 6, 1730-1736.

Milakis D., Van Arem B., Vanwee B., 2017, Policy and society related implications of automated driving: a review of literature and directions for future research, *Journal of Intelligent Transportation Systems*, 21, 324-348, DOI: 10.1080/15472450.2017.1291351.

Moćko W., Wojciechowski A., Ornowski M., 2011, Perspektywy rozwoju rynku samochodów elektrycznych w najbliższych latach, *Transport Samochodowy*, 1(31), 56-69.

Moreno A. T., Michalski A., Llorca C., Moeckel R., 2018, Shared autonomous vehicles effect on vehicle-km traveled and average trip duration, *Journal of Advanced Transportation*, 1-16, DOI: 10.1155/2018/8969353.

Motowidlak U., 2020, *Kierunki rozwoju mobilności niskoemisyjnej*, Wydawnictwo Uniwersytetu Łódzkiego, Łódź.

Mouratidis K., 2022, Bike-sharing, car-sharing, e-scooters, and Uber: Who are the shared mobility users and where do they live?, *Sustainable Cities and Society*, 86, 104161, DOI: 10.1016/j.scs.2022.104161.

Netherlands Enterprise Agency, *Electric transport in the Netherlands*, https://english.rvo.nl/information/electric-transport# [access: 11.09.2022].

Philip M., Taylor M. A. P., 2017, Research agenda for low-carbon mobility: Issues for New World Cities, *International Journal of Sustainable Transportation*, 11, 1, Low Carbon Mobility, 49-58, DOI: 10.1080/15568318.2015.1106261.

Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast), 2021, COM(2021) 802, Brussels.

Proposal for a Regulation of the European Parliament and of the Council on the development of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council, 2021, COM(2021) 559, Brussels.

Prussi M., Yugo M., De Prada L., Padella M., Edwards R., 2020, *JEC Well-To-Wheels, Report*, Publications Office of the European Union, Luxembourg.

Rabiega W., Gorzałczyński A., Jeszke R., Mzyk P., Szczepański K., 2021, How Long Will Combustion Vehicles Be Used? Polish, Transport Sector on the Pathway to Climate Neutrality, *Energies*, 14(23), DOI: 10.3390/en14237871.

Ren R., Hu W., Dong J., Sun B., Chen Y., Chen Z., 2020, A Systematic Literature Review of Green and Sustainable Logistics: Bibliometric Analysis, Research Trend and Knowledge Taxonomy, *International Journal of Environmental Research and Public Health*, 17(1), 26, DOI: 10.3390/ijerph17010261.

Renewable energy in Europe 2018: recent growth and knock-on effects, 2018, EEA Report.

Romare M., Dahllöf L., 2017, *Greenhouse Gas Emissions from Lithium-Ion Batteries*, Swedish Environmental Research Institute, Stockholm.

Silvestri L., Forcina A., Silvestri C., Traverso M., 2021, Circularity potential of rare earths for sustainable mobility: Recent developments, challenges and future prospects, *Journal of Cleaner Production*, 292, DOI: 10.1016/j.jclepro.2021.126089.

Smardz J., 2022, *Elektromobilność w Polsce – szanse i potencjalne zagrożenia*, Agencja Rynku Energii, Warszawa.

Spain mobility stimulus – Program to promote electric and sustainable mobility (MOVES Plan), https://www.iea.org/policies/11564-spain-mobility-stimulus-program-to-promote-electric-and-sustainable-mobility-moves-plan [access: 15.10.2022].

State of the art on alternative fuels transport systems in the European Union – 2020 update, 2021, European Commission.

Sustainable and Smart Mobility Strategy – putting European transport on track for the future, 2020, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2020) 789, Brussels.

Šoltés E., Brezina I., Pekár J., 2021, Electromobility and its relationship with the economic development and air pollution in the EU area, *Geografický časopis*, 73, 103-123, DOI: 10.31577/geogrcas.2021.73.2.06.

The first and last mile – the key to sustainable urban transport, 2020, EEA Report No 18/2019.

Ueda M., Hirota T., Hatano A., 2010, Challenges of Widespread Marketplace Acceptance of Electric Vehicles – Towards a Zero-Emission Mobility Society, *SAE Technical Paper*, 1, 2312, DOI: 10.4271/2010-01-2312.

van Loon P., Olsson L., Klintbom P., 2019, *LCA guidelines for electric vehicles*, Swedish Energy Agency, Stockholm.

Vilathgamuwa M., Mishra Y., Yigitcanlar T., Bhaskar A., Wilson C., 2022, Mobile-Energy-as-a-Service (MEaaS): Sustainable Electromobility via Integrated Energy–Transport–Urban Infrastructure, *Sustainability*, 14(5), 2796, DOI: 10.3390/su14052796.

W kierunku zeroemisyjnej mobilności. Raport 2020, 2020, PZPM & ACEA, Warszawa.

Wappelhorst S., 2021a, *On the electrification path: Europe's progress towards clean transportation, Consulting report*, European Alternative Fuels Observatory, https://theicct.org/ publications/electrification-path-europe-mar2021 [access: 15.09.2022].

Wappelhorst S., 2021b, *Small but mighty: The Netherlands' leading role in electric vehicle adoption*, ICCT, https://theicct.org/blog/staff/netherlands-ev-leader-feb2021 [access: 15.09.2022].

Weber J., 2022, *Bewegende Zeiten: Mobilität der Zukunft*, 2020th ed., Springer, Berlin-Heidelberg.

Weber K. M., Rohracher H., 2012, Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework, *Research Policy*, 41(6), 1037-1047, DOI: 10.1016/j.respol.2011.10.015.

White Paper. Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System, 2011, COM(2011) 144 final, Brussels.

Wojewódzka-Król K., Załoga E. (red.), 2016, *Transport. Nowe wyzwania*, PWN, Warszawa.

Wołek M., Wolański M., Bartłomiejczyk M., Wyszomirski O., Grzelec K., Hebel K., 2021, Ensuring Sustainable Development of Urban Public Transport: A Case Study of the Trolleybus System in Gdynia and Sopot (Poland), *Journal of Cleaner Production*, 279, DOI: 10.1016/j.jclepro.2020.123807.

Woo J., Choi H., Ahn J., 2017, Well-to-wheel analysis of greenhouse gas emissions for electric vehicles based on electricity generation mix: a global perspective, *Transportation Research, Part D: Transport and Environment*, 51, 340-350, DOI: 10.1016/j.trd.2017.01.005.

Yu A., Wei Y., Chen W., Peng N., Peng L., 2018, Life cycle environmental impacts and carbon emissions: a case study of electric and gasoline vehicles in China, *Transportation Research, Part D: Transport and Environment*, 65, 409-420, DOI: 10.1016/j.trd.2018.09.009.

Załoga E., 2013, *Trendy w transporcie lądowym Unii Europejskiej*, US, Szczecin.

Zhao X., Ke Y., Zuo J., Xiong W., Wu P., 2020, Evaluation of sustainable transport research in 2000-2019, *Journal of Cleaner Production*, 256(2), 120404, DOI: 10.1016/j.jclepro.2020.120404.

Zuo T., Wei H., Chen N., 2021, Incorporating low-stress bicycling connectivity into expanded transit service coverage, *Transportation Research Record*, 2675(4), DOI: 10.1016/j.cities.2020.102614.

© 2022 Urszula Motowidlak – Open Access Article Covered by Licensed: Attribution 4.0 International (CC BY 4.0)