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Electromobility in Poland as a challenge for modern transport

Elektromobilność w Polsce jako wyzwanie dla współczesnego transportu

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Abstract. The article discusses the issues related to the development of electromobility in Poland and its significance for the functioning of road transport. These are the elements that create a research niche, which also includes the spatial distribution of charging stations in Poland. The main research problem was formulated in the form of the following question: how did electromobility develop in Poland in the years 2019-2023 and what are the main determinants of this development? The aim of the research was therefore to assess the development of electromobility in Poland in the indicated period and to identify its main determinants. The authors put forward the following working hypothesis: the development of electromobility in Poland in 2019-2023 was limited, despite the increase in the number of electric vehicles and government regulatory support as well as the growing general interest in electromobility. The main determinant limiting this development is the spatial distribution of charging stations throughout the country. The innovativeness of the research lies in proving (based on theoretical research methods) that the use of electric vehicles is currently justified only in large cities with developed infrastructure, where almost half of all chargers in the country are located. The expansion plans for the charging infrastructure along the TEN-T network, according to the authors, may serve as a fundamental incentive for the increased importance of electric vehicles in car transportation.
Keywords: transport, electromobility, electric vehicles, electric vehicle charging stations, alternative fuels

Abstrakt. W artykule przedstawiono zagadnienia związane z rozwojem elektromobilności w Polsce oraz jej znaczeniem dla funkcjonowania transportu samochodowego. Są to elementy tworzące niszą badawczą, która objęła także rozmieszczenie przestrzenne stacji ładowania na terenie Polski. Główny problem badawczy ujęto

w formie następującego pytania: Jak rozwijała się elektromobilność w Polsce w latach 2019-2023 oraz jakie są główne determinanty tego rozwoju? Cel badań stanowiło zatem dokonanie oceny rozwoju elektromobilności w Polsce we wskazanym okresie oraz zidentyfikowanie jego głównych determinantów. Autorzy przyjęli następującą hipotezę roboczą: Rozwój elektromobilności w Polsce w latach 2019-2023 był ograniczony, mimo że towarzyszył mu wzrost liczby pojazdów elektrycznych i rządowe wsparcie regulacyjne, a także rosnące ogólne zainteresowanie elektromobilnością. Głównym determinantem ograniczającym ten rozwój jest przestrzenne rozmieszczenie stacji ładowania na terenie całego kraju. Innowacyjność badań polega na ty, aby udowodnić (w oparciu o teoretyczne metody badawcze), iż wykorzystanie pojazdów elektrycznych jest obecnie uzasadnione jedynie w dużych miastach z rozwiniętą infrastrukturą, w których zlokalizowana jest niemal połowa wszystkich ładowarek w kraju. Plany rozbudowy infrastruktury ładowania wzdłuż sieci TEN-T, zdaniem autorów, mogą stanowić fundamentalną zachętę do wzrostu znaczenia pojazdów elektrycznych w transporcie samochodowym
Słowa kluczowe: transport, elektromobilność, pojazdy elektryczne, stacje ładowania pojazdów elektrycznych, paliwa alternatywne

Introduction

Transport plays a crucial role in the dynamic development of the modern world. Transport needs occur in almost every socio-economic area and determine proper functioning of any community. Currently, most modes of transportation rely on burning hydrocarbon fuels, which results in exhaust emissions. Despite the use of increasingly advanced technical solutions, combustion vehicles permanently deteriorate air quality. This is related to the dynamic growth in the number of vehicles and increased transportation activity and noticeable in urban areas characterized by transportation congestion (Małek and Taccani, 2021, p. 63). Depleting oil reserves resolve the search for alternative sources of energy and fuels, which use will also contribute to reduce environmental pollution caused by transport. Reducing oil dependence followed by limiting CO_2 emissions will restore natural climate balance (Brodacki and Polaszczyk, 2018, p. 105). The estimated transport fuel consumption exceeds more than half of the global fossil fuels amount and is responsible for 25% of total CO_2 emissions. Popularizing the idea of electromobility may become an opportunity to reduce the amount of emitted air and noise pollution (Adamczyk et al., 2023, p. 2). The planned expansion of vehicle charging infrastructure along the TNN-T network may become a factor influencing the dynamic development of electromobility in Poland. This may be a fundamental incentive to increase the importance of electric vehicles in road transport.

The main research problem was formulated in the form of the following question: how did electromobility develop in Poland in the years 2019-2023 and what are the main determinants of this development? The aim of the research was therefore to assess the development of electromobility in Poland in the indicated period and to identify its main determinants. The authors put forward the following working hypothesis: the development of electromobility in Poland in 2019-2023 was limited, despite the increase in the number of electric vehicles and government regulatory support as well as the growing general interest in electromobility. The main determinant limiting this development is the spatial distribution of charging stations throughout the country. Poland has implemented a number of organizational and legal changes related to electromobility and the use of alternative fuels, and the growing number of electric vehicles and infrastructure points related to this process is causing continuous progress of the previously mentioned means of transport. However, the conducted analysis shows an urgent need to develop public battery charging infrastructure, especially in small towns and on major transportation routes. Actions and changes like this may determine the development of electromobility in Poland.

Theoretical research methods were used in the work, including, among others, comparative analysis of the efficiency and infrastructure distribution for replenishing electric energy in vehicles in relation to the rate of increasing number of electric vehicles. The innovativeness of the research lies in proving that the use of electric vehicles is currently justified only in large cities with developed infrastructure, where almost half of all chargers in the country are located.

Literature review

Electromobility has become the subject of interest for researchers due to its significance, which is reflected in the literature on the subject (Grzesiak and Sulich, 2023, p. 1-2; Mpousdra et al., 2018, p. 19-30; Xu and He, 2017, p. 83-96; Konstantinu and Gkritza, 2021, p. 5-22). In the monograph *Electric Car*, A. Węglarz and M. Pleśniak (2011, p. 6) present the origins of using electric energy as a source of propulsion for motor vehicles, dated back to the first half of the 19th century. The authors referred to technical details and existing limitations regarding the implementation of such solutions. Subject literature citing the principles of electric vehicles' operation refers to the presentation of existing technical solutions of the drives used and methods of charging batteries. In the publication titled *E-mobility: visions and development scenarios*, authors present the advantages of electric drives over internal combustion engines (Gajewski et al., 2017, p. 5). They highlighted electric engine's high energy efficiency and limited impact on the natural environment, due to their emission-free combustion and minimal noise levels. J. Zawieska's study *Development of the electromobility market in Poland* (2019a, pp. 9-36) refers to the increasing number of electric cars in Poland over the last few years. The lack of studies presenting the progress of electromobility in Poland over the past few years is caused by the current nature of the issue, making it an ongoing matter. There are several expert studies by Polish Alternative Fuels Association and other reports containing quantitative data on electric vehicles and charging points, which served as a source of scientific information for the authors.

A very valuable publication is W. Stahl (2018) *V2G and G2V Solutions as a Way of Utilizing Electric Vehicles to Change the Shape of the Daily Load Curve in the Power System*, which presents the possibilities of utilizing electric vehicles as mobile energy storage units. The widespread use of such a solution would constitute a key element of the national electrical system based mainly on renewable sources of electrical energy. Important complementary elements to bibliography are EU and national legal acts. Some important ones include: Directive of the European Parliament and the Council on the development of alternative fuels infrastructure and the Electromobility and Alternative Fuels Act. These documents should be recognized as the basis for taking actions in the development of necessary technical infrastructure.

Aspects of electromobility development in Poland

Electricity use as a power source for vehicles is a basic idea of electromobility. This term refers to a complex of issues related to electric cars used for individual and public transportation. The concept of electromobility also cover a set of hardware and charging infrastructure, which includes devices used to transfer energy to batteries using various technologies (Kowalski and Depta, 2019, p. 69; Munkácsy et al., 2024, p. 6).

The idea of non-emission vehicles, known today as zero-emission vehicles, dates back to the 1830s. Electric motor invented by Thomas Davenport in 1834 initiated the process of electromobility, which resulted in construction of the first street electric vehicle just two years later. A breakthrough event in development of electric vehicle drives was invention of the lead-acid battery in 1859 and the car generator in 1871 (Węglarz and Pleśniak, 2011, p. 6). Electromobility as a concept refers to the idea of e-mobility encompassing the development of energy storage technologies and the widespread dissemination of electric vehicles, including those powered solely by batteries (BEV), hybrids (plug-in hybrids - PHEV), and those utilizing hydrogen fuel cells, which also generate electrical energy (Gajewski et al., 2017, p. 5). Electromobility does not only cover passenger vehicles, but also vehicles such as those indicated in figure 1, which play a very significant role in transportation.

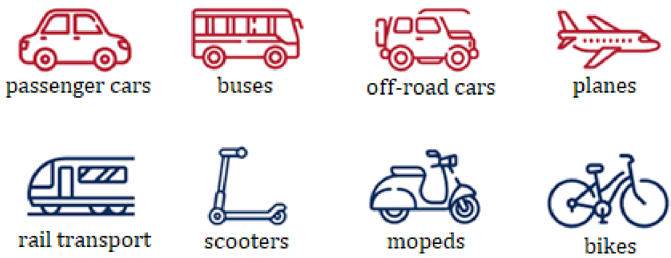


Fig. 1. Electrically powered vehicles
Source: Polish Investment & Trade Agency, 2022

Changes in the area of vehicle power sources mainly result from the depletion of fossil fuel resources, the shortages of which may appear in the second half of the 21st century at the current rate of extraction. Other limitations are based on the ecological conditions related to the impact of transportation on the natural environment, as well as the difficulty to overcome design deficiencies of combustion engines. Most of the energy supplied to vehicles, that is 65%, is lost in the combustion process in the form of thermal energy (Polakowski, 2017, p. 153). Modern electric motors have efficiency exceeding 90%, which can be considered as a significant argument in favour of e-mobility (Nemś, 2012).

Precedingly presented problems serve as inspiration for searching for solutions that minimize the negative impacts of transportation on the natural environment and promote balanced development. This contributed to the creation of national legal regulations providing a platform for the dissemination of electromobility. One of the key documents is the Strategy for Responsible Development (Resolution No. 8 of the Council of Ministers, 2017), which is based on the provisions of the European Parliament directive on the development of alternative fuel infrastructure (Directive 2014/94/EU of the European Parliament and of the Council, 2014). It became the basis for taking action in Poland through the Electric Mobility Development Plan "Energy for the Future", adopted by the Council of Ministers on 16.03.2017, which identified the benefits of popularizing the use of electric vehicles in our country. The document named as National Framework for the Development of Alternative Fuel Infrastructure (2017) represents the implementation of European regulations concerning the conditions for the construction of alternative fuel infrastructure in 32 Polish urban areas. The purpose of the Act on electromobility and alternative fuels (2018) is to stimulate the development of electromobility and promote the use of alternative fuels in the transport sector in Poland (Ministry of Climate and Environment of the Republic of Poland, 2023). Government estimates that by 2025, there will be 1 million electric vehicles on the roads in electricity powered car section, making Poland follow global and European trends in the field of electromobility. Offered solutions are also aimed at stabilizing the energy system and positively impacting the protection of the natural environment and the country's economy. The number of electric vehicles increased in the first quarter of 2023 by 84% comparing to a similar period in 2022 (Bytniewska, 2023). According to the Polish Alternative Fuels Association data, as of the end of August 2023, there were 107,946 electric vehicles registered in Poland, of which 82,955 were passenger cars, and 4,787 were lorries and vans. It is noticeable, that motorbike and mopeds make up less than 17% of all electric vehicles. The presence of 78 hydrogen-powered vehicles in Poland was related to the increasing number of refuelling points for this fuel, of which there were 11 in 2021, however only two, located in Warsaw and Gdańsk, allowed passenger cars refuelling (European Leasing Fund, 2021). Table 1 presents the changes in the number of registered electric vehicles in Poland, classified by their types, from 2019 to 2023.

Table 1. Number of registered electric vehicles in Poland

Month and year	Passenger car			Lorries and vans	Buses above 3,5 t	Motorbikes and mopeds	Micro cars and others	Hydrogen po-wered vehicles FCEV	Sum of all vehicles
	PHEV	BEV	Sum						
VII 2023	40690	42265	82955	4778	946	18290	771	206	107946
VI 2023	39452	40780	80232	4459	906	17888	751	204	104440
V 2023	38012	38671	76683	4188	885	17452	738	180	100126
IV 2023	36668	37027	73695	3942	865	17097	712	179	96490
III 2023	33864	33263	67127	3588	842	16503	670	177	88907
II 2023	32783	33902	66685	3578	846	16602	643	176	88530
I 2023	32555	31146	63701	3396	837	16416	625	126	85101
XII 2022	30135	31249	61570	3135	821	16274	611	125	82536
XII 2021	19206	18795	38001	1657	651	10650	441	78	51478
XII 2020	8834	10041	18875	839	430	8941	367	0	29452
XII 2019	3546	5091	8637	519	224	6239	211	0	15830

Source: own study based on Polish Alternative Fuels Association, 2023

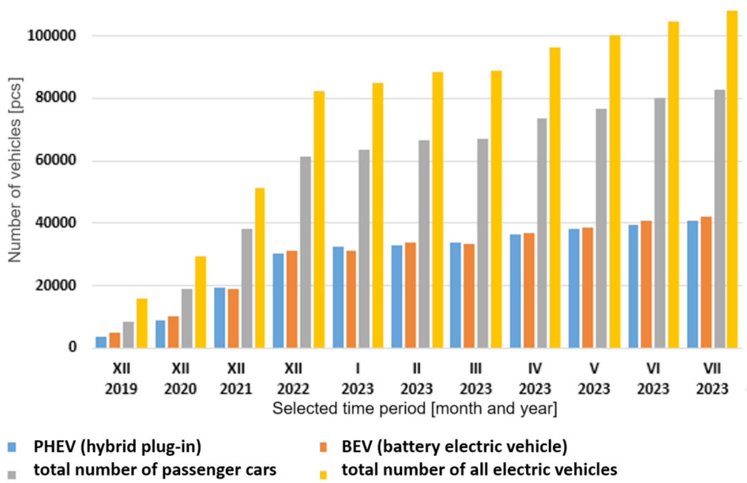


Fig. 2. Changes in the number of electric vehicles in Poland
Source: Own study based on Polish Alternative Fuels Association, 2023

Based on the data presented, the most dynamic growth is observed in the number of electric passenger cars. However, motorbikes and mopeds make up a significant group of electric vehicles subject to registration. The smallest share is made up by lorries, delivery vans, and buses used in commercial transport. Figure 2 presents graphically the changes in the number of electric vehicles in Poland from 2019 to 2023.

There is a noticeable growth in the total number of electric vehicles, which increased by 92116 units since 2019. Following current trend, it will take approximately 21 years to reach assumed level of 1 million electric vehicles, which coincides with the estimation of the Polish Alternative Fuels Association and Frost & Sullivan, which set the target number of electric vehicles in Poland by 2025 at level of 300 thousand units (Zawieska, 2019a, p. 12). However, considering global trends in the development of electromobility and the continuing downward trend in battery prices, as well as the need to limit emissions of harmful particles and gases from exhaust fumes, we can expect a more dynamic development of this type of transport in Poland. Another important aspect of sustainable development is the ability to use partially used batteries that are no longer suitable for use in vehicles as storage for green energy generated in home installations (TOR Team of Economic Advisors, 2017, p. 18).

It should be emphasized that the development of electromobility brings Poland a number of opportunities for comprehensive economic and social development, as well as the resulting benefits in the area of environmental protection (Gądek-Hawlena and Bęben, 2023, p. 172).

Energy replening infrastructure for vehicles

The Charging infrastructure for electric vehicles consists of chargers used to replenish electrical energy in the batteries of electric vehicles (Efthymiou et al., 2017, p. 2). These devices can be installed in garages of residential multi-family buildings and in parking lots belonging to these buildings or may be owned by operators of publicly accessible charging stations. According to the Act on electromobility and alternative fuels, charging point is a device enabling the charging of a single electric vehicle, hybrid vehicle or zero-emission bus, and a place where the battery used to power the vehicle is exchanged or charged. They are divided into charging points with normal power, where it is less than or equal to 22 kW, excluding devices with power less than or equal to 3.7 kW installed in places other than public charging stations, especially in residential buildings, and high power above 22 kW. The charging station is a construction device or a freestanding building with at least one charging point installed [Announcement of the Marshal of the Sejm of the Republic of Poland, 2020].

Due to technological reasons, we distinguish two basic groups of charging stations, powered by alternating current (AC) and powered by direct current (DC). From the perspective of the charging point's power and the associated delivery time of energy to the battery, the following types are known:

- slow (AC) with power up to 7 kW,
- fast (AC) with power 7-43 kW,
- rapid (DC) with power 41-145 kW,
- ultra-rapid (DC) with power 150-350 kW (Zawieska, 2019b, p. 67).

Figure 3 shows an example of a slow charger installed in a garage attached to a house.

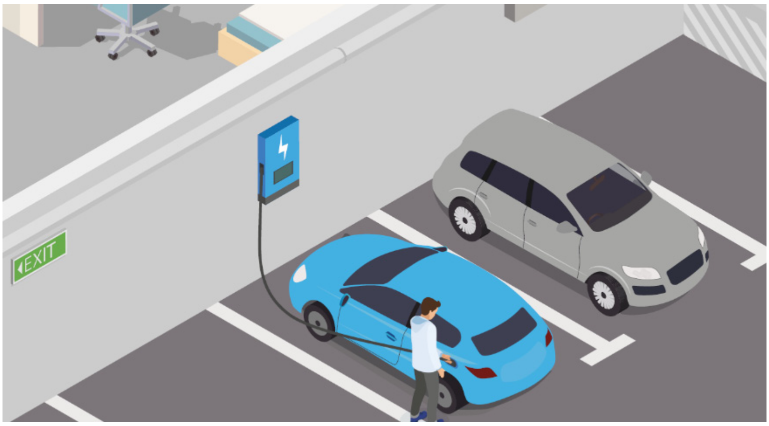


Fig. 3. Charger in a residential building
Source: Opoka et al., 2020

The vehicle charging process is a set of activities used to transfer electrical energy in order to accumulate it in the vehicle's battery. This process can be carried out in several ways, the most popular of which are: charging via a plug connector, pantograph and wireless connection basing on electromagnetic induction. The most common method of charging electric vehicles using a plug-in connector involves physical vehicle connection to the charging point using a flexible electrical cable. In terms of design, two basic solutions can be distinguished here. The first when the charging point is equipped with a socket and the cable is equipped in the vehicle or the second with a charging cable that is an integral part of the charging point, which is used primarily at charging points of higher powers (Office of Technical Inspection, 2023). Figure 4 shows a model charging station for electric vehicles.

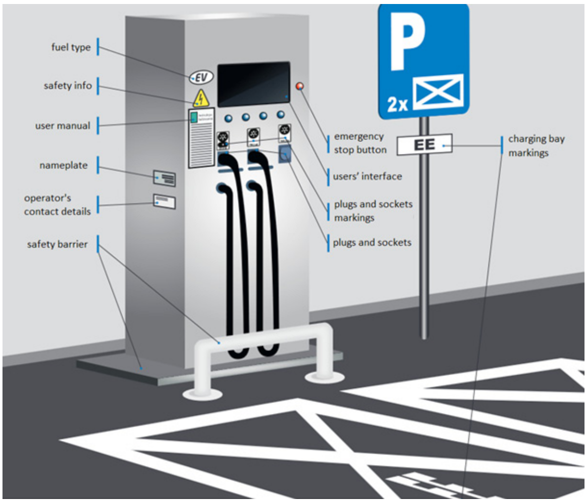


Fig. 4. Model vehicle charging station
Source: Office of Technical Inspection, 2022, p. 9

Pantograph chargers are highly powerful, usually above 50 kW, and are used to quickly charge the batteries of electric buses, usually during short stops at the terminals. Electricity is transmitted via a metallic connection between the pantograph and the rails installed on the roof of the bus or at the charging point. The energy is transmitted in the same way as in the plug-in connector solution, where the correct communication between the point and the vehicle is first carried out, and then voltage is applied to the battery bank poles. The elements of the pantograph poles and rails are not isolated, simply because of their high positioning, away from persons reach (Office of Technical Inspection, 2023). Figure 5 shows pantograph charging solutions.

Fig. 5. Pantograph charger
Source: samochodyelektryczne.com, 2015

Inductive charging enables vehicles to be wirelessly powered with electricity by using the electromagnetic induction phenomenon produced in inductors. The coil placed in a parking spot that is a charging point or in the road lane generates an electromagnetic field. It induces electric current in the coil located in the vehicle, allowing the vehicle to charge even while driving. After the vehicle approaches such a point and the charger circuits are powered, an electromagnetic field is generated, which induces electric current in the nearby coil in the vehicle located nearby. Inductive charging of buses at terminals is a commercialized solution. Figure 6 shows the principle of inductive replenishment of electricity in vehicles.

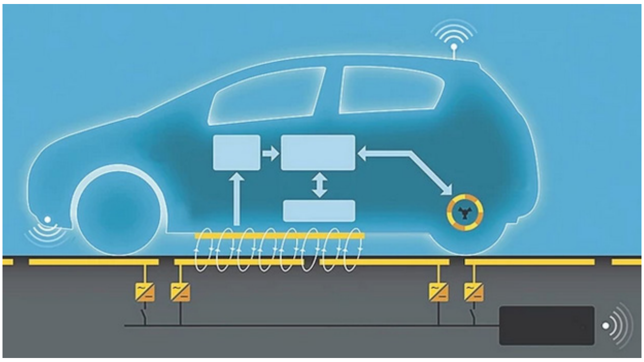
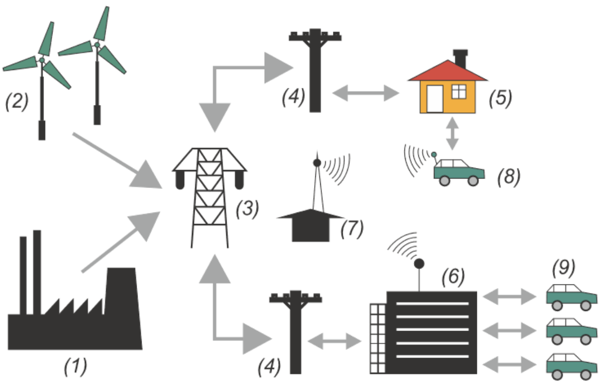


Fig. 6. Inductive charger diagram
Source: Auto-swiat.pl, 2016



(1) base power plants, (2) distributed renewable power plants, (3) high and medium voltage transmission lines, (4) low voltage transmission lines, (5) individual charging stations - houses, (6) group charging stations - parking places, shop centers, offices, (7) The System Operator central office, (8) electrical vehicles with individual communication System Operator, (9) electrical vehicles in grup charging stations - the communication with System Operator is realized by central net.

Fig. 7. Idea of the V2G technology
Source: Guziński et al., 2014, p. 77

One of the vehicles charging technologies is V2G (Vehicle-to-Grid). A vehicle connected to a charger or socket simultaneously serves as an electrical energy storage unit acting as an energy storage for the local power grid. Such a solution allows to balance the daily demand for energy, as well as reduce production in the power system. An additional effect could be the creation of financial benefits for users of electric vehicles for sharing energy. Currently, a commonly used technology is G2V (Grid-to-Vehicle), which allows energy to be transmitted only from the distribution network to the vehicle's battery (Stahl, 2018, p. 69). Figure 7 shows a vehicle connection to the power grid via a V2G charging station scheme.

The type of charger used and its power has the main impact on the time it takes to replenish energy in batteries. There is also a close correlation between battery capacity (which determines the vehicle's traction properties) and the vehicle's range. Figure 8 shows the relationship between the charging time for selected vehicles and the use of different power devices. Chargers with a power of up to 3.7 kW need about 24 hours to replenish energy in the batteries, and rapid or ultra-rapid chargers reduce this time to less than 1 hour (TOR Team of Economic Advisors, 2017, p. 14).

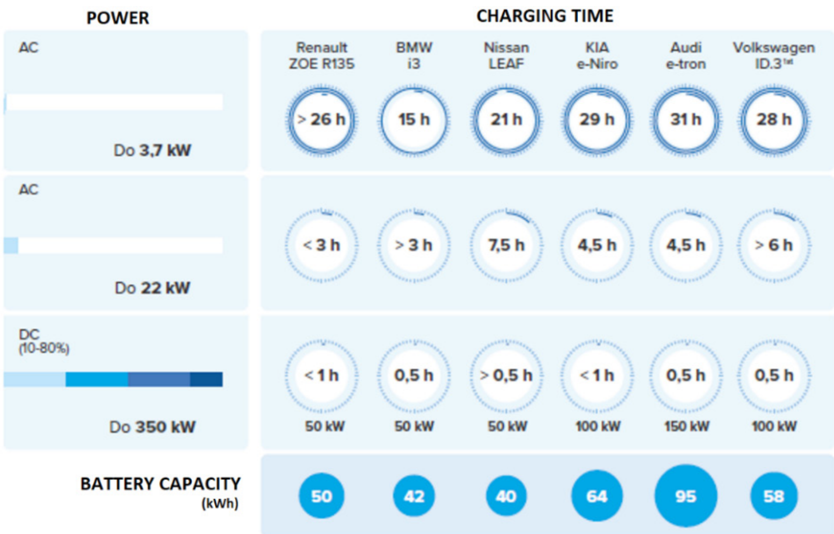


Fig. 8. Estimated battery charging time for selected vehicles
Source: Wiśniewski and Kania, 2020

At the end of August 2021, there were 1631 charging stations in Poland which are; 1120 fast AC charging stations with a power of up to 22 kW and 511 DC rapid ones, of which over 100 are devices with a power of over 50 kW. The total number of charging stations in the analysed period added up to 3178 units (Polish Association of New Mobility, 2021). Table 2 presents increasing number of charging stations and available public charging points in Poland.

Table 2. Number of publicly available charging stations and points in Poland

Month and year	AC Charging stations	**DC charging stations**	**All charging stations**	**Number of charging points**
VII 2023	2013	940	2953	5884
VI 2023	1991	894	2885	5709
V 2023	1967	869	2836	5597
IV 2023	1923	845	2768	5440
III 2023	1884	815	2699	5305
II 2023	1873	807	2680	5266
I 2023	1853	769	2622	5139
XII 2022	1813	752	2565	5016
XII 2021	1120	511	1932	3784
XII 2020	912	425	1364	2641
XII 2019	723	288	1011	1815

Source: Own study based on Polish Alternative Fuels Association, 2023

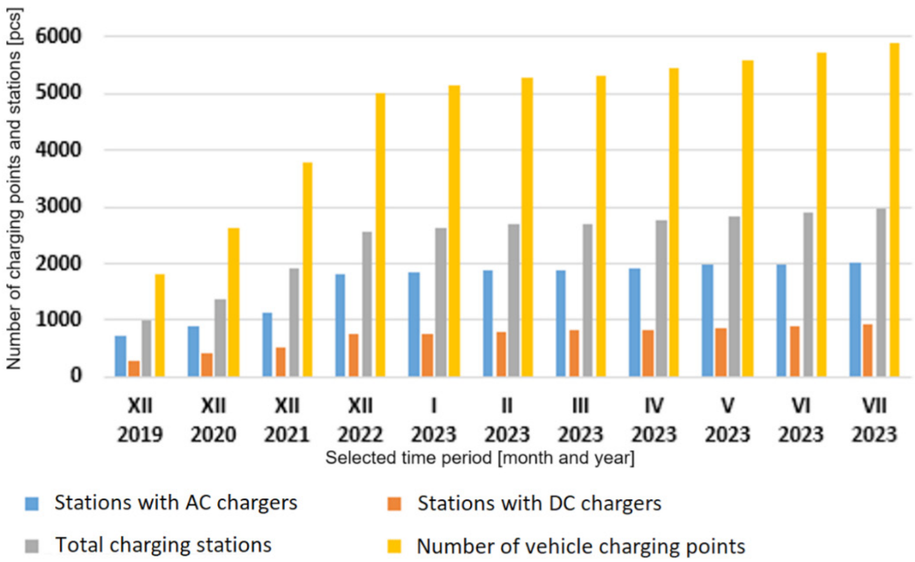


Fig. 9. Changes in the number of publicly available stations and points in Poland
Source: Own study based on Polish Alternative Fuels Association, 2023

Figure 9 graphically presents data relating to changes in the number of slow (AC) and rapid (DC) charging stations, taking into account their sum and number of all existing public charging points in Poland.

The average number of all vehicles per public charging point is currently around 18, which estimates that when charging a vehicle for 1.5 hours a day, it uses their full potential. A number of vehicles use private or company charging stations, however, this indicator shows a lock of places to replenish energy in vehicles. Figure 10 shows changes in vehicle to a charging point in 2019-2023 ratio.

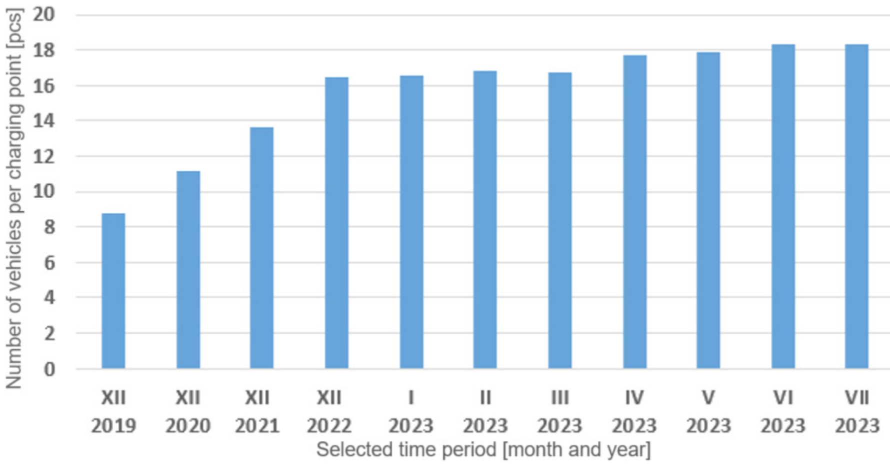


Fig. 10. Number of vehicles per charging point
Source: Own study based on Polish Alternative Fuels Association, 2023

At the end of August 2023, number of publicly available chargers in Poland was as follows: 33% fast direct current (DC) charging stations, 67% slow alternating current (AC) chargers with a capacity of less than or equal to 22 kW. There were 8 all-electric passenger vehicles per charging point. In terms of the distribution of infrastructure across the country, almost half of all existing devices in Poland are located in 15 cities with the highest number of publicly accessible charging stations (Rynekelektryczny.pl, 2024).

Location of battery charging stations in Poland

It becomes extremely important to arrange infrastructure for recharging energy in vehicles in such a way that all users have the opportunity to charge batteries in a convenient place and time for themselves (Fishbone et al., 2017). Figure 11 shows quantities of charging stations with the locations and the time needed to replenish energy to cover a specific distance. The recommended solution is to have many free charging devices for batteries placed in homes and workplaces, which can provide enough energy to charge for a day of using the vehicle in urban conditions. Another, smaller group should contain slow and fast public charging stations where energy can be restored for longer distances, dedicating relatively more time to it. The minimal amount of rapid charging stations should be located on motorways and major intersections, allowing for quick replenishment of energy to cover the distance to the next city or station.

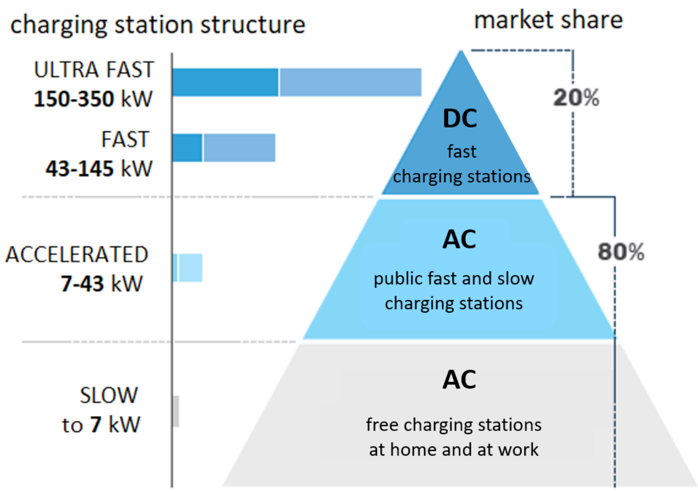


Fig. 11. Charging infrastructure distribution
Source: Own study based on Witkowski and Wiśniewski, 2018, p. 50

The distribution of electric vehicle charging infrastructure in Polish is very uneven. By the end of 2022, 56% of all publicly accessible charging stations were available in 37 cities with a population of over 100,000. Cities with the largest number of stations are: Warsaw (257), Gdańsk (139), Katowice (102), Poznań (81), and Kraków (74). The most of publicly available stations are located in the Masovian, Silesian, Pomeranian, Lower Silesian and Lesser Poland voivodeships. The least of them are located in Świętokrzyskie, Lublin, Podlasie and Lubusz voivodeships. 41% of publicly accessible charging stations in Poland are located in public parking lots, 17% within shopping centres, 16% on hotel premises, and 11% at petrol stations (Polish New Mobility Association, 2023). Figure 12 shows the percentage share of stations located in cities mentioned above in the total number in the voivodeships.

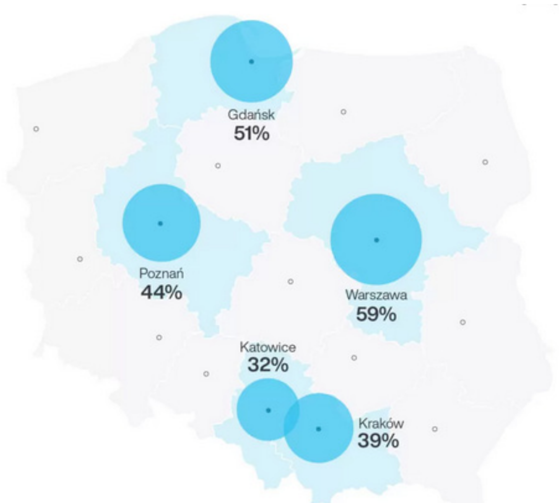


Fig. 12. Density of public chargers in Poland
Source: Polish New Mobility Association, 2023

The main problem is the uneven distribution of public charging facilities in Poland. According to research, the number of available devices is increasing steadily, however, almost half of it is located in 15 cities with the highest number of publicly accessible charging stations. In Warsaw alone, there are more stations than in the Świętokrzyskie, Lublin, Lubusz, Podlaskie, and Podkarpackie voivodeships combined (Rynekelektryczny.pl, 2024). Figure 13 shows the map of the distribution of e-chargers in Poland. Thanks to this solution, drivers can find an available charger in any location in the country.

The Electromobility Act says, there is an obligation to establish an adequate number of electric vehicles charging stations between urban centers to enable smooth movement of electric vehicles with limited range. The longest distance to travel between two voivodeship's capitals in Poland is in the north, between Szczecin and Gdańsk, and it is 359 km. Existing charging infrastructure allows for transportation within large cities. Thanks to its expansion, it will also be possible to travel between cities. Unfortunately, covering the distance between charging stations will not be possible for all vehicles available on the market, as many of them have a range of approximately 200 km. Therefore, in some parts of the country, e.g. Central Pomerania, the infrastructure should be denser to make commuting between voivodeship's cities possible (Polish Investment & Trade Agency, 2022). Figure 14 shows the distances between major cities in Poland with a graphical representation of the size of available battery charging infrastructure.

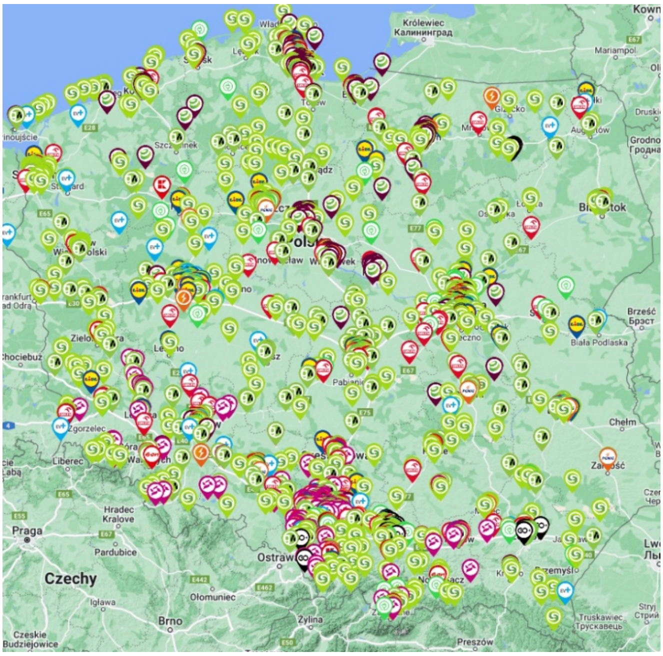


Fig. 13. E-chargers in Poland
Source: Cleanerenergy.pl, 2023

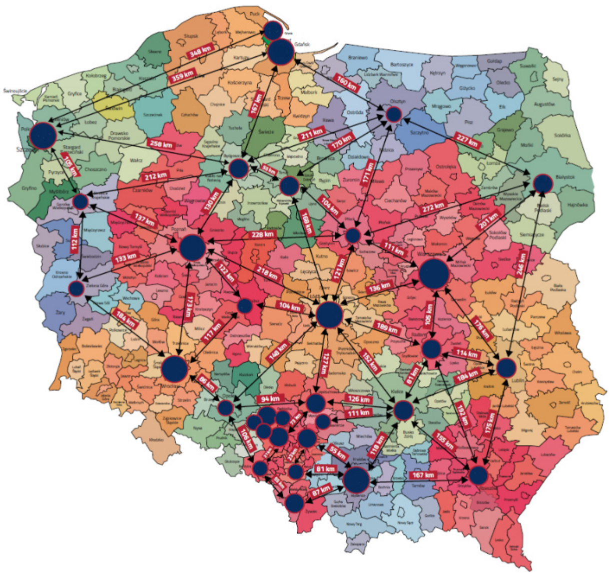


Fig. 14. Distance between cities subject to the Electromobility Act
Source: Polish Investment & Trade Agency, 2022

Among the European Community countries, the largest number of charging points for electric vehicles per 100 kilometres of roads have:

- Netherlands - 47,5 units,
- Luxembourg - 34,5 units,
- Germany - 19,4 units,
- Portugal - 14,9 units,
- Austria - 6,1 units.

Poland is among the 10 EU countries where there is not even 1 charging point for every 100 km of roads (Alternative Fuels Market Observatory, 2021).

Directive 2014/94/EU of the European Parliament and the Council sets out the framework for the development of alternative fuels infrastructure. The Commission's announcement of 9 December 2020 entitled „Strategy for sustainable and smart mobility – European transport on track to the future" highlighted the uneven development of charging and refuelling infrastructure throughout the EU, as well as the lack of interoperability and ease of use. The Regulation of the European Parliament and the Council of the European Union 2023/1804 of 13 September 2023 on the development of alternative fuel infrastructure sets compulsory minimum targets for the development of publicly accessible charging and refuelling infrastructure for vehicles, and repeals Directive 2014/94/EU. Uneven distribution of publicly available charging infrastructure affects the popularization of electric vehicles and hinders connectivity in the EU, affecting the sustainable transformation of transport sector. Mandatory minimum target values for Member States should complement national policy frameworks resulting in the development of publicly available charging infrastructure, ensuring full coverage of charging points along the main EU road networks, enabling easy and seamless travel throughout the European Union. It is also important to consider the possibility of charging batteries used by heavy vehicles, which require a different charging infrastructure than light vehicles. The regulation indicates that currently publicly available infrastructure for this type of vehicles is insufficient in the EU and it is advisable to speed up its development. Infrastructure is planned to be distributed along and within the TEN-T network, providing adequate land coverage to support the expected increase in market share of electric-heavy-duty vehicles (Regulation (EU) 2023/1804 of the European Parliament and of the Council, 2023).

According to the Ministry of Climate and Environment project for optimal placement of charging infrastructure for light and heavy vehicles along roads in the core of TEN-T network, a scenario for the location of charging infrastructure at Service Areas (MOP) located along roads belonging to the core network of the TEN-T has been developed. Requirements of the Alternative Fuels Infrastructue Regulation (AFIR), which came into force on April 13, 2024, state that the distance between charging hubs may be up to 60 km, therefore it is important to define the criteria for selecting the location. The map presented in figure 15 shows possible scenario for expanding the infrastructure in the TEN-T core network by the end of 2025 for the group of heavy commercial vehicles HDV (Heavy Duty Vehicle). Charging stations located at MOPs and up to 3 km from the nearest network road exit (Polish Alternative Fuels Association, 2022).

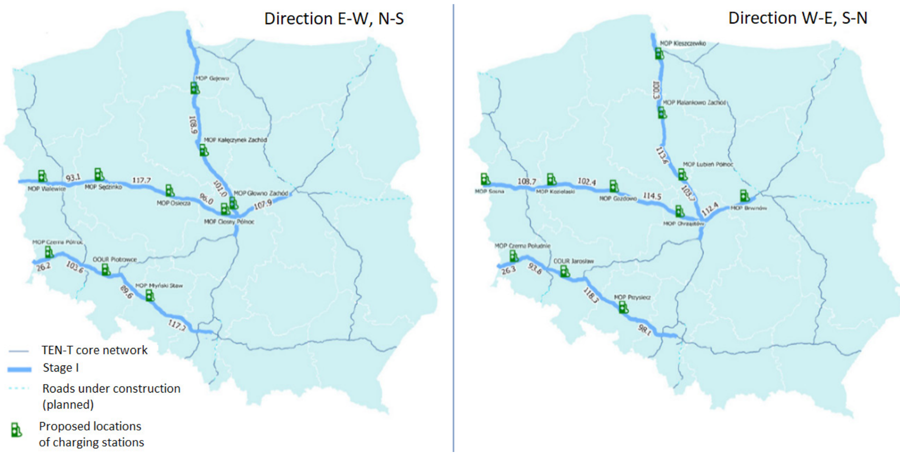


Fig. 15. Development example of charging infrastructure on the TEN-T core network by the end of 2025 for HDV group vehicles

Source: Polish Alternative Fuels Association, 2022

The need to reduce emissions requires manufacturers of new heavy-duty vehicles to comply with regulations setting emissions standards for CO_2 (Regulation (EU) 2019/1242 of the European Parliament and of the Council, 2019; Coppola and Arsenio, 2015, p. 1). Manufacturers are required to reduce the intensity of emissions from newly registered heavy vehicles by 15% in 2025 and 30% in 2030 compared to emissions from heavy vehicles registered between July 1, 2019, and June 30, 2020. The regulation is also intended to ensure a smooth transition to emission-free mobility. Quickening factor for reduction of emissions from the heavy-duty transport sector will also be the upcoming new European emission standard - Euro 7, which will significantly affect the scope of emission reduction in heavy-duty vehicles and buses (Villeneuve et al., 2020, p. 78). Previously mentioned AFIR regulation project regarding the development of alternative fuel infrastructure will impact the expansion of charging station networks, including those designated for zero-emission heavy transport (Miniszewski et al., 2023).

Discussion

The popularization of electric vehicles is still hampered by the uneven distribution of publicly available charging infrastructure. Another problem is the limited possibilities of charging batteries by heavy vehicles. The lack of appropriate density of charging infrastructure in Poland constitutes a significant obstacle in covering distances between provincial cities. Although the number of such infrastructure is increasing, this growth is uneven in relation to the country's territory. A situation is occurring in which most publicly available charging stations operate in large cities with over 100,000 inhabitants. This is a fundamental barrier in the process of ensuring the possibility of free movement of electric vehicles. Meanwhile, the popularization of the idea of electromobility is becoming a necessity in conditions of increased transport activity and striving to achieve climate neutrality. The organizational and legal projects undertaken by Poland in the field of electromobility are seen as an opportunity to reduce the amount of air pollution and noise emitted by means of transport. Achieving these goals requires the urgent development of publicly available infrastructure for charging batteries – both on main communication routes and in small towns. The dynamics accompanying the implementation of EU requirements provokes the continuous updating of data on the development of electromobility in Poland. The content available in the literature on the subject only fragmentarily describes the content presented in this article. It should be noted, however, that the scientific literature on electric vehicles and their infrastructure is constantly being updated, and the pace of change forces the emergence of ever newer research and solutions. The authors of the text not only analyze issues related to the development of electromobility in Poland but also identify challenges for modern transport in this area – they do not focus on the development of the national charging infrastructure itself, but on its limitations, which is a kind of innovation.

Conclusions

In summary, the aim of the article was to present the current state of the development of electromobility in Poland in terms of the number of electric vehicles and the potential for meeting needs of recharging electric energy through existing infrastructure. The discussion of normative-economic conditions of implementing and developing electromobility in the country, in relation to EU requirements and the dynamics of infrastructure development for vehicle charging, highlights the transportation capabilities of electric vehicles in Poland. The presentation of the spatial distribution of charging stations throughout the country shows the existing transport limitations of electric vehicles, the current use of which is justified only in large cities with developed infrastructure. The scenarios of locating charging stations within European transportation routes, in connection with the development of local infrastructure, may serve as a stimulus for the dynamic growth of the number of electric vehicles used for commercial purposes.

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