

ELECTRIC VEHICLE CHARGING INFRASTRUCTURE IN POLAND AND THE EUROPEAN UNION

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Purpose: The aim of this paper is to evaluate the current status and development of electric vehicle charging infrastructure in Poland, comparing it with the broader context of the European Union and to analyze its potential in reducing urban air pollution and contributing to the decarbonization of the transport sector. The article aims to present the progress in the field of electromobility by examining the number of charging stations and forecasting infrastructure development in Poland compared to the European Union.

Design/methodology/approach: The paper employs a systematic review of the literature and a critical analysis of selected publications to identify the problem and research gap. Research questions were formulated to guide the study, and hypotheses were adopted based on existing data. The analysis includes both Polish and foreign literature, scientific articles, legal acts, websites focused on electromobility, and infrastructure aspects. The descriptive method is used to analyze and present the collected materials. Additionally, the paper reviews legal requirements for charging infrastructure, evaluates the current state of development in Poland and the EU, and presents technical specifications of typical publicly available charging stations.

Findings: The findings indicate that Poland's electric vehicle charging infrastructure is underdeveloped compared to other EU countries, limiting its ability to achieve the climate goals associated with electromobility. There is a significant discrepancy between the growing number of electric vehicles and the insufficient development of charging stations. Despite national plans to increase the number of charging points, the existing infrastructure in Polish cities and along transportation routes remains inadequate. The study highlights the necessity for more strategic investments and legislative support to overcome these limitations and foster the adoption of electric vehicles.

Research limitations/implications: The paper primarily relies on secondary data sources and existing literature, which may not capture real-time developments in electromobility infrastructure. Additionally, data discrepancies between different sources can affect the reliability of findings. Future research should incorporate more empirical data collection and field surveys to validate the conclusions drawn.

Practical implications: The practical implications include recommendations for policymakers to focus on expanding the charging infrastructure, particularly fast charging stations, in urban and rural areas. The paper suggests that integrating charging systems with mobile applications for booking and payment can enhance user experience and adoption rates. It also emphasizes the importance of meeting EU standards and regulations to ensure efficient and widespread deployment of charging stations.

Social implications: The social implications of the study underscore the need for reducing urban air pollution and addressing public health issues associated with vehicle emissions. The transition to electric vehicles can significantly improve air quality, reduce noise levels, and enhance the overall living conditions in cities. The paper stresses the importance of developing infrastructure that is accessible to all residents, promoting equitable growth and environmental sustainability.

Originality/value: This paper contributes to the existing body of research by providing a comprehensive analysis of the development and future prospects of electric vehicle charging infrastructure in Poland, comparing it to the EU. It offers valuable insights into the challenges and opportunities associated with electromobility, and proposes actionable strategies to accelerate the transition to low-emission transport. The study's originality lies in its critical evaluation of policies and infrastructure development plans, providing a foundation for further research in the field.

Keywords: Electric Vehicle Charging Infrastructure, Electromobility, Sustainable Transport Solutions, Charging Stations, EU Policy, Spatial Inequality in Infrastructure, EU Climate Goals.

Category of the paper: Research paper.

1. Introduction

Road transport plays a significant role in the land transport system, especially in the context of cities but at the same time it brings numerous social, economic, and environmental challenges. These include climate change, air pollution, noise, and traffic jams.

Currently, nearly 95% of global transportation relies on liquid fuels derived from fossil sources (Leach et al., 2020). The energy and transport sectors are responsible for 70% of global greenhouse gas emissions (Duan et al., 2016; IEA, 2021; Leach et al., 2020).

In 2021, according to data from the European Environment Agency (EEA, 2023), the total greenhouse gas emissions from the 27 European Union countries amounted to 3,311 million tons of CO₂. The transport sector had the largest share of emissions, which accounted for 24% of total greenhouse gas emissions in the EU, and 17.6% in Poland (Fig. 1 and 2).

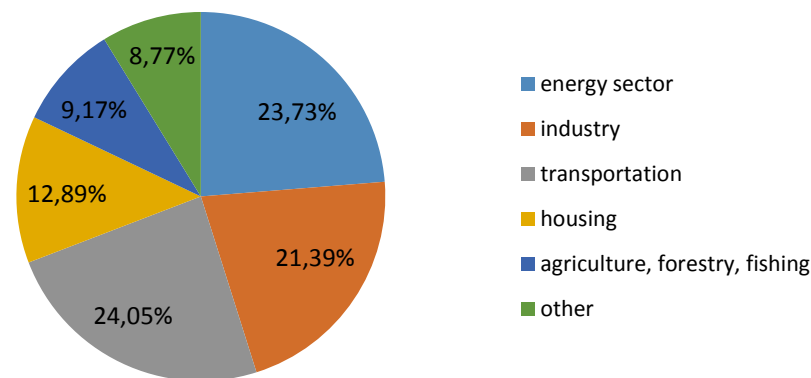


Figure 1. CO2 emissions by sector in the EU-27 in 2021.

Source: own study based on the (EEA, 2023).

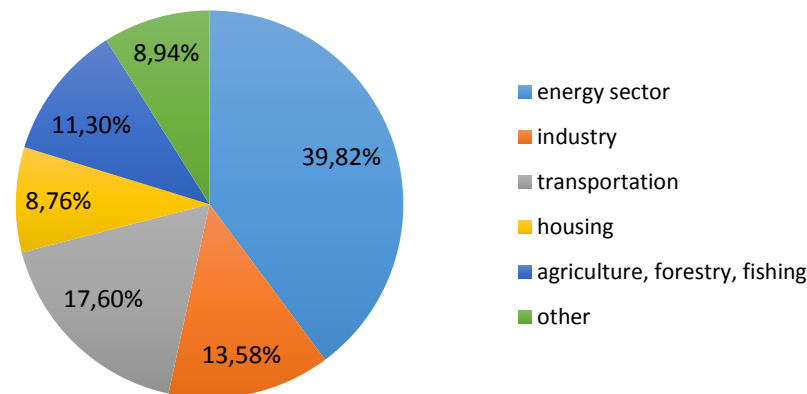


Figure 2. CO2 emissions by sector in Poland in 2021.

Source: own study based on the (EEA, 2023).

According to information available from the European Economic Area, between 1990 and 2017, emissions from the transport sector in Poland increased by as much as 206%, which is a significantly higher value than the European Union average of 28%. The highest levels of emissions occur locally in cities (Huo et al., 2015). Air pollution is also one of the major challenges in Poland, as it contributes to approximately 93,000 premature deaths per year (IEA, 2021). According to IQAir data from 2019, out of the one hundred European cities most polluted with PM_{2.5} particles, twenty-nine are located in Poland (IQAir, 2019). The environmental impact of transport is not limited to atmospheric emissions resulting from the combustion of conventional fuels—it also includes the release of harmful substances into soil and water, as well as noise generation.

To achieve decarbonization goals in line with the Paris Agreement, it is crucial to immediately implement more energy-efficient and energy-saving technologies and fuels (IEA, 2017, 2019). A notable suggestion for complying with this implementation are autonomic

vehicles, as they are oftentimes electric, meaning they contribute to mitigating the effects of climate change, including reducing CO₂ emissions, and additionally they improve air quality and reduce noise levels. The introduction of autonomous vehicles into the transportation system is only a matter of time. However, it is a gradual process, similar to the previous electrification of vehicles (Wasilewski et al., 2023, p. 174).

In recent years, there has been a growing interest in smart city solutions on the European market. According to data from Statzon.com (2023), the global smart city solutions market reached a value of €1024 billion in 2021, and it is projected to grow fivefold by 2030. This growth is mainly driven by the need for environmental protection and the efficient management and use of electricity (Tundys, Wiśniewski, 2023).

Global sales of electric vehicle increased by 41% since 2019, and the market share of electric vehicles worldwide reached a record high of 4.6% in 2020 (Virta, 2021). The number of newly registered vehicles with non-traditional propulsion systems is also steadily increasing. According to the International Energy Agency (IEA), in the European Union in 2020, the number of new electric vehicle registrations more than doubled to 1.4 million, accounting for 10% of all cars sold (IEA, 2022).

The transition to low-emission mobility - in addition to the technological and economic aspects - is also a major political and organizational challenge. This goal can be achieved by addressing key issues, such as the development of a sufficiently dense and efficient network of charging stations. This infrastructure plays a crucial role in promoting the success of the electric vehicle market by eliminating range anxiety and building consumer confidence in electric vehicles.

The priority seems to be the development of a publicly accessible charging network for electric vehicles throughout the EU, which is necessary to achieve the goals of the European Green Deal and the expected significant development of electromobility. In order to implement the indicated objectives, it is crucial to provide users of electric vehicles with charging options, especially fast charging stations located at distances that will make travelling across the EU countries by electric car as easy and accessible as possible.

2. Materials and methods

The aim of this paper is to evaluate the current state of electric vehicle charging infrastructure in Poland and to examine its impact on the potential for implementing electromobility as a strategy to reduce road transport emissions. This paper compares Poland's situation with that of other European Union countries, identifies the main barriers and challenges, and outlines the necessary actions for achieving a sustainable transformation in transportation. The following research questions were formulated:

1. To what extent can the development of electromobility contribute to reducing urban air pollution?
2. How does Poland's electric vehicle charging infrastructure compare to that of other European Union countries?
3. What infrastructural, energy, and institutional factors limit the implementation of low-emission transport strategies in Poland?
4. Considering the current state of infrastructure and energy conditions, is it feasible to achieve the climate goals associated with the development of electromobility?

A systematic review of the literature and a critical analysis of selected publications have made it possible to identify the problem and the research gap. The following research hypotheses were adopted:

- H1: Growing emissions from road transport, particularly in urban areas, caused by the increasing number of vehicles, should be minimized through investment in electromobility promoting zero emissions.
- H2: Poland's electric vehicle charging infrastructure is considered underdeveloped compared to other countries in the European Union.
- H3: Insufficient infrastructure and the energy crisis mean that achieving the assumed goals regarding emission reduction and implementation of electromobility in cities may be impossible.

In addition to presenting the current level of infrastructure development in the country, the authors assess the factors influencing the development of electromobility. They also criticize the Polish charging infrastructure development plan in relation to the assumptions of strategic documents at the Polish and EU level.

The study uses a review of Polish and foreign literature, scientific articles, legal acts, websites in the field of electromobility, infrastructure aspects and concepts that focus on the availability, expansion and density of electric vehicle infrastructure. The descriptive method was used to analyze and present the collected materials.

3. Legal requirements for charging infrastructure

Protection of air quality and actions related to the reduction of greenhouse gas emissions from transport are a priority of the climate and energy policy of the European Union authorities. The implementation of alternative fuels and the development of the related infrastructure are the key elements of the Polish and European climate and energy policy. In response to the growing challenges related to the decarbonization of the transport sector, both the European Union and Poland have developed a set of strategic documents and legal acts aimed at systematic support for the energy transformation in the area of mobility (see Table 1).

Table 1.*List of the most important EU and Polish documents)*

EU strategic documents	Polish strategic documents
• European strategy for low-emission mobility (2016) • Action plan on alternative fuels Infrastructure (2017) • The European Green Deal (2019) • Strategy for sustainable and smart mobility • “Fit for 55” package (2021) • “Hydrogen strategy for a climate-neutral Europe” (2020)	• Electromobility development plan in Poland – “Energy for the future” • National policy framework for the development of alternative fuels infrastructure • Sustainable Transport Development Strategy until 2030 • National energy and climate plan for 2021-2030 • Polish energy policy until 2040 • National Recovery and Resilience Plan • Polish Hydrogen Strategy
EU legal acts	Polish legal acts
• RED II Directive • RED III Directive • EU Taxonomy • AFIR Regulation – Alternative Fuels Infrastructure Regulation • LDV and HDV Regulations (Light Duty Vehicles and Heavy Duty Vehicles) • FuelEU Maritime Regulation (maritime transport) + REFuelEU Regulation • EU ETS Directive (introducing EU ETS BRT)	• Act on electromobility and alternative fuels • Act on bio-components and liquid biofuels • Act on renewable energy sources • Act on monitoring and controlling fuel quality • Energy Law Act

Source: Ministry of Climate and Environment (2025). National framework for the development of alternative fuels infrastructure policy (version of January 10, 2025).

The EU and Polish strategic documents and legal acts clearly indicate the development of electromobility and charging infrastructure as key elements of the transformation of transport towards zero emissions. Within the European Green Deal (European Commission, 2019) and the “Fit for 55” package (European Commission, 2021a), special emphasis was placed on the implementation of electric vehicles and ensuring their efficient power supply through an extensive and publicly available network of charging stations. The AFIR Regulation (European Parliament & Council, 2023) establishes uniform requirements in this area, obligating member states to provide a minimum number of charging points along the main transport corridors. Poland, in pursuing its own electromobility development strategy (“Energy for the Future”; Ministry of Energy, 2017) and the Act on Electromobility and Alternative Fuels (Journal of Laws 2022, item 1083), aims to increase the number of electric vehicles on the roads and expand the infrastructure, particularly in cities and along major transportation routes. These investments are also supported by funds from the National Recovery Plan (Chancellery of the Prime Minister, 2021) and the Energy Policy of Poland until 2040 (Ministry of Climate and Environment, 2021). Energy transformation in the transport sector requires a change in the types of propulsion systems used in new vehicles and the replacement of the liquid and gas fuel distribution infrastructure with an infrastructure for the distribution of electricity.

Polish implementation programs foresee that by 2030, there will be 600,000 electric vehicles in Poland. In line with this goal, the Act on Electromobility outlines regulations that impose certain obligations on public entities and multi-family housing units located in

municipalities with more than 50,000 residents, requiring the establishment of designated control points (Sendek-Matysiak, Szumska, 2018). Municipalities are also required to build charging points for electric vehicles. Additionally, commercial facilities are obligated to ensure that at least 20% of parking spaces are equipped with charging infrastructure (Wieczorek-Hodyra, 2025).

Table 2 presents the guidelines for the minimal distribution of publicly accessible charging stations, demographic specifications, and transport energy supply in various municipalities across Poland.

Table 2.

Requirements regarding the number of charging points in local government units in Poland

Characteristics of the municipality	Required number of electric vehicle charging points
• Population > 1 000 000. • Number of registered motor vehicles $\geq 600\,000$. • Motorization rate (number of registered vehicles per 1000 residents) ≥ 700.	1000
• Number of residents > 300 000. • Number of registered motor vehicles $\geq 200\,000$. • Motorization rate ≥ 500.	210
• Population > 150 000. • Number of registered motor vehicles $\geq 95\,000$. • Motorization rate ≥ 400.	100

Source: own study based on the Act of 11 January 2018 on electromobility and alternative fuels (consolidated text: Journal of Laws 2023, item 875).

Taking into account the number of residents and vehicles, and in accordance with the guidelines included in the Act on Electromobility and Alternative Fuels, it follows that the public charging points need to be established according to the decision makers only in 32 out of 2477 communes in Poland (Sendek-Matysiak, Łosiewicz, 2021). The data for analysis is presented in Table 3.

Table 3.

Minimum number of public charging points in accordance with the Act of 11 January 2018 on electromobility and solid fuels

Voivodeship	Municipality	Number of stations	Voivodeship	Municipality	Number of stations
Zachodniopomorskie	Szczecin	210	Kujawsko-Pomorskie	Bydgoszcz Toruń	100 100
Lubuskie	Zielona Góra Gorzów Wlkp.	60 60	Łódzkie	Łódź	210
Dolnośląskie	Wrocław	210	Śląskie	Bytom Częstochowa Dąbrowa Górnicza Gliwice Katowice Ruda Śląska Rybnik Sosnowiec Tychy Zabrze	60 100 60 100 100 60 60 100 60 60

Cont. table 3.

Pomorskie	Gdańsk Gdynia	210 100	Podlaskie	Białystok	100
Wielkopolskie	Poznań Kalisz	210 60	Mazowieckie	Płock Radom Warszawa	60 100 1000
Opolskie	Opole	60	Świętokrzyskie	Kielce	100
Warmińsko- Mazurskie	Olsztyn	60	Małopolskie	Kraków	210
Lubelskie	Lublin	100	Podkarpackie	Rzeszów	100

Source: own study based on: Sendek-Matysiak, Łosiewicz, 2021, p. 222.

The electromobility market is a rapidly growing segment in recent years, which now requires the creation of new solutions and products. A key element in the development of electromobility is to provide users with convenient and optimal conditions for charging vehicles. To this end, it is necessary to deploy charging stations in high-traffic areas, such as city centers, residential areas and transportation hubs. Equally important is their reliability and round-the-clock availability, which influences users' sense of security and comfort. In addition, the integration of charging systems with mobile applications that allow booking and payment significantly improves the quality of service.

The technical specifications for the charging station also include recommendations for user-friendliness. Each station should have visible instructions on how to use the device. This can take the form of a clear interface with a display containing guidelines for the charging process. It is essential that this interface is also adapted to the needs of people with disabilities.

According to research by Jochem et al. (2024), ease of use and clarity of mobile applications play a crucial role in shaping positive experiences for users of public charging stations. Users expect interfaces to be intuitive, fast, and uniform, regardless of the infrastructure operator (Wang et al., 2020). The diverse interface standards in individual European Union member states create difficulties in navigating and operating the stations, particularly in a cross-border context (Zhou et al., 2023).

Wang et al. (2025) analyzed the feedback from over 17,000 reviews of charging stations. The authors identified 12 key aspects that impact user satisfaction. These include, among others, equipment reliability, charger availability, ease of use, charging time, location, pricing, level of customer service, safety, cleanliness of the surroundings, technical condition of the infrastructure, availability of amenities (e.g., toilets, shelter), and the availability of information. It was found that negative experiences, especially those related to failures and lack of availability, have a stronger impact on ratings than positive aspects. Stations that combined a good location with hassle-free operation and a clear interface were rated particularly highly.

An important element of user satisfaction is also the availability of real-time information – for example, regarding the status of socket occupancy, waiting times, or malfunctions (Yang et al., 2024). Insufficient data updates in applications result in low user trust in the system (Arora et al., 2025). Furthermore, the lack of standardization of payment processes – the necessity to create multiple accounts or install separate applications – is one of the main

barriers indicated by EV drivers in the EU (European Commission, 2023). In response to these challenges, the European Commission is promoting the development of open payment systems and service interoperability (AFIR, 2023).

Increasingly important are automatic vehicle recognition and “plug & charge” payment features, which enable users to start a charging session without additional actions at the terminal (The Verge, 2024). The implementation of such technologies significantly enhances convenience and reduces the need for interaction with an app or screen (Kahlenborn et al., 2024). Research indicates that the availability of this option can increase overall satisfaction by up to 20% (ChargeLab, 2024). To achieve a high level of public acceptance and trust, charging infrastructure must be not only technically reliable but also accessible, intuitive, and universal in use – including for people with limited mobility (Rupprecht Consult, 2022).

The Polish legal system aims to support the development of infrastructure for charging electric vehicles. The planned mechanisms focus on creating clean transport zones in cities and building infrastructure throughout the country. Operators of public charging stations must operate in accordance with applicable regulations and standards to ensure effective, safe and convenient use of the charging infrastructure for all users of electric vehicles (Mańk-Chrulska, Puchała, 2024).

According to the Act on Electromobility and Alternative Fuels, the operator is responsible for the construction, management, safety of use, operation, maintenance and repairs of stations.

The operator of a publicly available charging station is responsible for (UDT, 2022):

- Ensuring the availability and technical efficiency of the charging station, regular inspections and maintenance of charging devices.
- Compliance of the charging station with technical and safety requirements.
- Ensuring easy access to charging stations, including appropriate signage and information for users.
- Ensuring appropriate technical support and customer service, including the ability to contact the operator in the event of problems.
- Providing information on the location, availability and prices of charging in a transparent and easily accessible manner to the Alternative Fuels Infrastructure Register.
- Monitoring energy consumption and collecting data on the charging of electric vehicles.
- Concluding a distribution agreement with the Distribution System Operator (DSO) for the operation of the charging station and the provision of charging services.

In Poland, the President of the Energy Regulatory Office (Energy Regulatory Office, 2024) designated energy companies that sell electricity to the largest number of end users connected to the distribution network in municipalities where they are to act as operators (Energia Obrót SA, Enea SA, Tauron Sprzedaż Sp. z o.o. and PGE Obrót SA). The provision of charging service provider services is carried out by the following companies: Energa-Operator SA,

Tauron Dystrybucja SA, PGE Dystrybucja SA, Innogy Stoen Operator Sp. z o.o. and Enea Operator Sp. z o.o. Despite the designation by the President of the Energy Regulatory Office of the largest energy companies as operators of publicly available charging stations, the largest market share was gained by companies specializing in providing software, such as the European GreenWay, which has about 20% share in the charging station market in Poland (Chmielewski et al., 2023).

The charging service provider offers a service that includes charging vehicles and providing access to the charging station infrastructure. It includes an energy sales contract with the electricity supplier and provides information on prices and terms of providing the charging service on its website. It is worth mentioning that the operator of a public charging station can perform the tasks of a charging service provider.

New guidelines for charging infrastructure have been specified in AFIR (Alternative Fuels Infrastructure Regulation) - a regulation of the Council of the European Union, adopted in July 2023, which replaces the previous Directive 2014/94/EU (AFID). One of the key assumptions of AFIR is the creation of charging zones every 60 kilometers along the main routes of the TEN-T core network for passenger cars and light trucks up to 3.5 tons by the end of 2025 (European Commission, 2021b). Each of these zones should have a power of at least 400 kW, with at least one charging point with a power of at least 150 kW. By the end of 2027, the power of these zones is to increase to 600 kW, with at least two charging points of 150 kW each (European Commission, 2021b). For electric trucks over 3.5 tons, charging hubs are to be located every 120 kilometers along the TEN-T route by the end of 2025.

4. Current state of development of electric vehicle charging infrastructure in Poland and the EU

According to data from the European Automobile Manufacturers Association (ACEA), there are an estimated 1.1 billion cars in the world, in Europe alone – 246.345 million cars (in 2020), and in Poland there were 26.676 million passenger cars registered in 2022 (Korzeniowski, 2022). Taking this data into account, electric cars constitute only 0.23% of the vehicle fleet in Poland (excluding public transport and delivery vehicles, e.g. InPost). In times of crisis convincing people to buy new cars will not be an easy task. In Poland, the average age of a car exceeds 12 years, and the motorization rate is 747 cars per 1000 inhabitants, which is the second highest result in Europe. However, only 25 thousand of the 24.3 million cars registered since 2021 are PHEV (plug-in hybrid electric vehicle) and BEV (battery electric vehicle) vehicles. The current car fleet is outdated and inefficient and this is a significant source of pollution harmful to the health of city residents and excessive greenhouse gas emissions, which is harmful to our planet. Therefore, significant changes in this area are necessary.

One of the desired directions of change is the transition to electric passenger cars. Unfortunately, both Italy and Poland are considered to be countries insufficiently prepared for the introduction of electric vehicles. In 2020, Poland ranked third in Europe in terms of the low number of registered electric vehicles (0.12 EV/1000 residents) (ACEA, 2022).

Construction and density of the charging infrastructure per registered electric vehicle in a given country have a significant impact on the popularity of these vehicles. In Europe, the number of electric vehicle charging stations remains insufficient. The current infrastructure does not yet allow the European Union to fully phase out the sale of new internal combustion engine vehicles in favor of electric ones by 2035.

The number of public charging points in the European Union is constantly growing (Fig. 3). In the second quarter of 2024, a total of 733,431 charging points were available in the U-27, of which 86% were slow alternating current (AC) chargers, and 14% were fast direct current (DC) charging points.

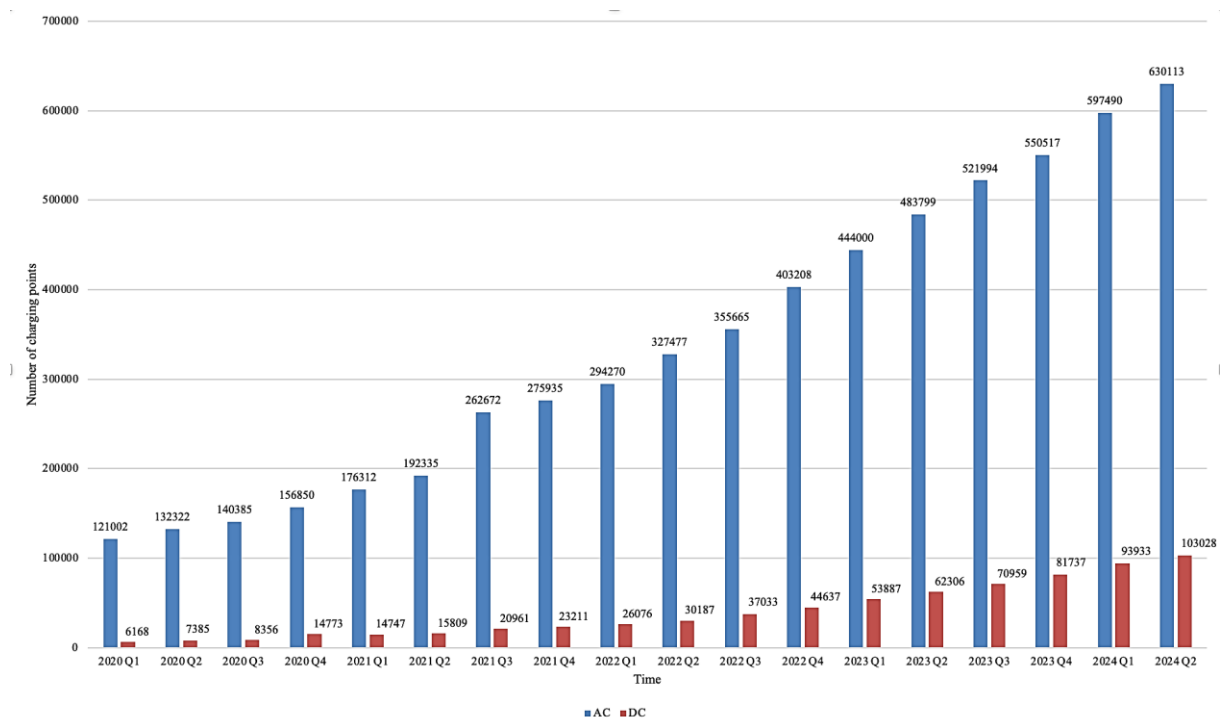


Figure 3. Total number of recharging points, according to the AFIR classification.

Source: EAFO 2024, available at: <https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27/infrastructure>, 12.06.2025.

It is worth noting that the distribution of charging stations across the EU is uneven. Of all publicly available charging points in 2020, almost 69% were concentrated in just two EU countries: the Netherlands (111,821 chargers) and Germany (87,674). The area of both countries is less than 10% of the EU area, the remaining chargers are located in the remaining 90% of the region. The largest number of public charging points in the EU was located in the Netherlands (111,821), Germany (87,674), France (83,317), Italy (37,186) and Spain (34,380). The countries with the least developed electric vehicle charging infrastructure are: Latvia (660),

Lithuania (477), Estonia (300), Cyprus (69) and Malta (13) (ACEA, 2023). Data that also illustrates the development of charging infrastructure was presented by the European Court of Auditors (see Figure 4).

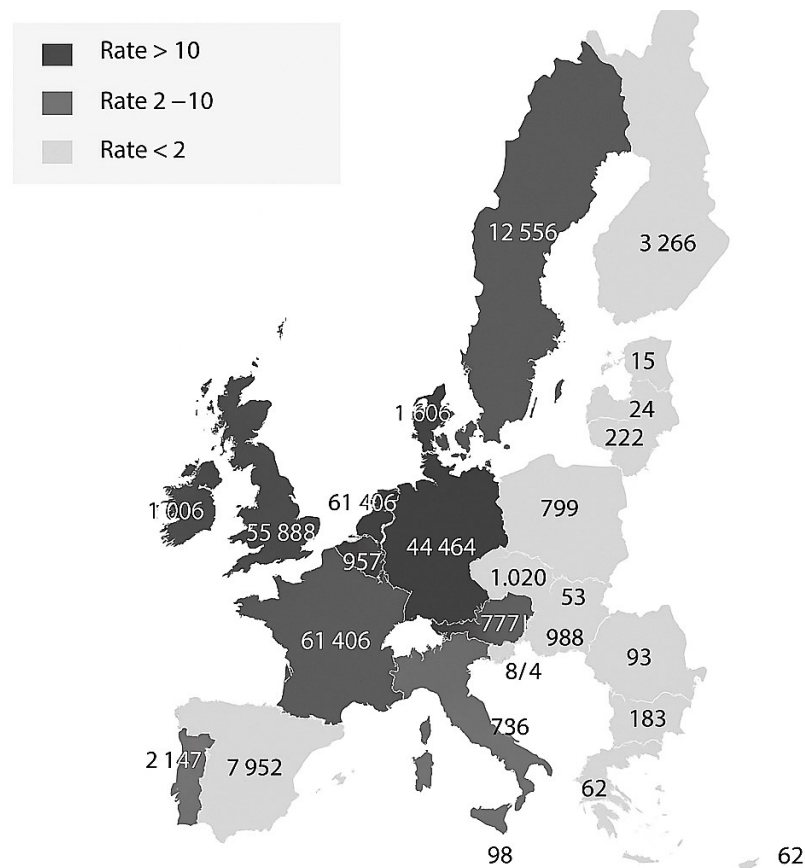


Figure 4. Number of charging points as of September 2020.

Source: European Court of Auditors (2021). Electric vehicle charging infrastructure, p. 25.

The total charging points and data on their distribution in each location. There are differences in solutions in Western European countries (in Germany, Belgium and Great Britain, the density of charging points per 100 km² was above 10 in 2020), and the lowest in Central and Eastern Europe (in countries such as Poland, the Czech Republic, Romania, Bulgaria, Slovakia, this coefficient was below 2) (European Court of Auditors, 2021, p. 25). Uneven distribution of charging infrastructure does not facilitate travel across the EU territory, so that free travel is possible throughout the entire EU area, rather than, as is currently the case, only in selected countries (Komarnicki et al., 2020, p. 4). For better and sustainable development of charging stations, the rules, incentives, and forms of support for market growth should be unified so that they are coherent, understandable and stimulating the development of electromobility. The development of this sector also means stimulating economic growth in the region, increased demand for new green jobs, new professions, and will necessitate new educational systems and training pathways for the workforce.

It is worth pointing that between 2016 and 2022 the growth rate of electric car sales in the European Union was more than three times faster than the rate of building charging points. Electric car sales increased almost 16-fold between 2016 and 2022, while the number of public chargers in the EU increased sixfold during the same period (see Table 4).

Table 4.

Number of charging points and electric cars in the EU-27 in 2016-2022

UE	2016	2017	2018	2019	2020	2021	2022	Change 2022/2016 [%]
Charging points	77038	109896	123727	133947	184392	319978	479396	+522,3%
Electric vehicles	18542	168901	240347	387325	1045893	1744520	1996738	+1584,4%

Source: ACEA, 2023.

The increase in the number of electric vehicles on the roads naturally translates into challenges for infrastructure. According to the Polish EV Outlook 2022 report (PSPA, 2022), the number of electric cars per charging point is increasing (see Figure 5). In 2019, it was 5.6 in Poland. This proportion increased to 7.4 in 2020, to 10.4 in 2021, and to 12 in mid-2022. This carries the risk of low efficiency and capacity of charging devices.

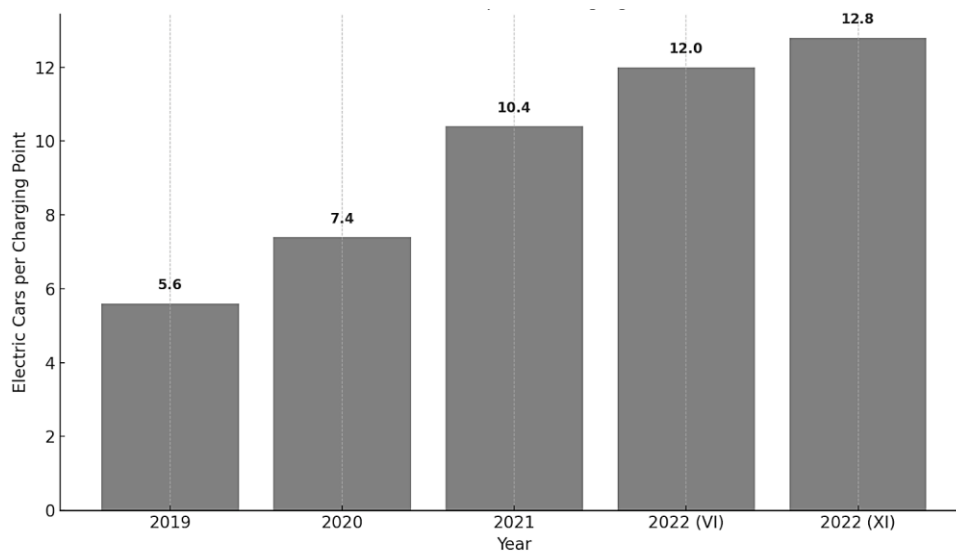


Figure 5. The number of electric cars in Poland per 1 charging point installed in a publicly accessible station.

Source: PSPA, 2022, p. 15.

The increase in the number of publicly available charging points is gaining importance in the light of the European Commission's proposal for a new regulation on infrastructure development for alternative fuels as part of the "Fit for 55" package. The regulation forces member states to achieve specific goals in infrastructure development based on an algorithm that takes into account the number of registered electric vehicles, which will be a challenge for countries such as Poland, which are at an early stage of electromobility development. Undoubtedly, improving the indicator of the optimal ratio of public chargers to vehicles will support the development of electromobility as part of intelligent mobility.

According to the PSPA report (2022), the most popular locations for publicly available charging stations are: public parking lots (41%), shopping malls (17%), hotels (16%), petrol stations (11%) and car showrooms (5%).

In Poland, the largest operators of public charging stations include companies such as GreenWay Polska, PKN Orlen, Tauron, Revnet, EV+, PGE, Innogy, Elocity, GO+, Zepta, Ekoenergetyka, Enea and Ioney.

The largest market share, accounting for over 40% of publicly available charging points according to data from Q4 2022, is held by the leading operators: GreenWay Polska with 1099 charging points at 497 stations (Greenway, 2023) and PKN Orlen with over 1000 charging points at 480 stations (PKN Orlen, 2023). A detailed description of typical, publicly available PKN Orlen and Greenway charging stations is presented in Table 5.

Table 5.
Technical specification of recharging stations in Poland

Operator	PKN Orlen			Greenway	
Producer	ABB Terra CE 54 CJG	Ekoenergetyka AXON EASY	Efacec QC45	ABB Terra Wallbox	Delta Slim 100
Example model graphical view					
EV connectors	CCS2—1 pc. CHAdeMO—1 pc. Type 2 AC—1 pc.	CCS2—1 pc. CHAdeMO—1 pc. Type 2 AC—1 pc (optional)	CCS2—1 pc. CHAdeMO—1 pc. Type 2 AC—1 pc	CCS2—1 pc. CHAdeMO—1 pc.	CCS2—1 pc. CHAdeMO—1 pc. Type 2 AC—1 pc
Output power [kW]	50 kW DC 43 kW AC	60/120/180 kW DC 43 kW AC	50 kW DC 43 kW AC	24 kW DC (peak) 22.5 kW DC (cont.)	00 kW DC 22 kW AC
Output voltage range [V]	150-500 V DC 400 V AC	150-1000 V	50-500 V	150-920 V	200-920 V
Output current [A]	125 A DC 32 A AC 3phase	CCS2 200/250/300 A CHAdeMO 125 A 32 A AC	AC: up to 63 A 3 phase DC: up to 120 A	60 A	CCS2 250 A CHAdeMO 12 A 32 A AC 3phase
Connection Power [kVA or kW]	98 kW	90/156/222 kW	n.a.	n.a.	n.a.
Supply voltage [V]	380-415 V AC AC 3-phase	400 V AC 3-phase	400 V AC +/-10%	400 V AC +/-10%	
Input current [A]	143 A	n.a.	73 A	100 A	203 A
Current type	DC AC 3-phase	DC AC 3-phase	DC AC 3-phase	DC	DC
Peak efficiency	>94%	>94%	>93	>95%	>94%

Cont. table 5.

Size DxWxH [m]	$0.78 \times 0.78 \times 1.9$	$0.98 \times 0.75 \times 2$		$0.3 \times 0.58 \times 0.77$	$0.44 \times 1.62 \times 0.89$
Communication Interface	4G, Ethernet	4G, 5G, Ethernet	3G (GSM/CDMA), LAN, Wi-Fi	GSM/4G modem, Ethernet	Ethernet, Cellular 2G/3G/4G
Load management method	OCCP	OCCP	OCPP	OCCP	OCCP
Authentication method	RFID, NFC, Pincode, App	RFID, NFC	RFID	RFID, NFC, Mifare, Calypso	RFID, NFC
Time to add 100 km (reference battery usage capacity 75 kWh)	~22 min (43 kW) ~19 min (50 kW)	~22 min (43 kW) ~16 min (60 kW) ~8 min (120 kW) ~5.5 min (180 kW)	~22 min (43 kW) ~19 min (50 kW)	~42 min (22.5 kW)	~43 min (22 kW) ~10 min (100 kW)
Charging fee [PLN/kWh]	AC for 50 kW: 1.89 PLN/kWh DC for $x \leq 50$ kW: 2.69 PLN/kWh DC for $50 \text{ kW} < x \leq 125$ kW: 2.89 PLN/kWh DC for $x > 125$ kW: 3.19 PLN/kWh	Energia STANDARD AC: 1.95 PLN/kWh DC for $x \leq 100$ kW: 2.95 PLN/kWh DC for $x > 100$ kW: 3.25 PLN/kWh	Charging fee [PLN/kWh]	AC for 50 kW: 1.89 PLN/kWh DC for $x \leq 50$ kW: 2.69 PLN/kWh DC for $50 \text{ kW} < x \leq 125$ kW: 2.89 PLN/kWh DC for $x > 125$ kW: 3.19 PLN/kWh	Energia STANDARD AC: 1.95 PLN/kWh DC for $x \leq 100$ kW: 2.95 PLN/kWh DC for $x > 100$ kW: 3.25 PLN/kWh
Parking fee [PLN/min]	0.40 PLN/min AC: after 60 min—recharging stations with AC&DC connectors AC: after 720 min—recharging stations with AC connectors only DC: after 45 min	0.40 PLN/min AC: after 600 min (valid from 7:00 to 21:00) DC: after 60 min	Parking fee [PLN/min]	0.40 PLN/min AC: after 60 min—recharging stations with AC&DC connectors AC: after 720 min—recharging stations with AC connectors only DC: after 45 min	0.40 PLN/min AC: after 600 min (valid from 7:00 to 21:00) DC: after 60 min
Cost of charging per 100 km (no parking fee)	29.3 PLN (AC—43 kW) for 22 min 41.7 PLN (DC—50 kW) for 19 min 44.8 PLN (DC—60 kW/120 kW) for 16 min/8 min 49.5 PLN (DC—180 kW) for 5.5 min	30.22 PLN (AC—22 kW) for 43 min 45.72 PLN (DC—50 kW/100 kW) for 19 min/10 min 50.37 PLN (DC— $x > 100$ kW)	Cost of charging per 100 km (no parking fee)	29.3 PLN (AC—43 kW) for 22 min 41.7 PLN (DC—50 kW) for 19 min 44.8 PLN (DC—60 kW/120 kW) for 16 min/8 min 49.5 PLN (DC—180 kW) for 5.5 min	30.22 PLN (AC—22 kW) for 43 min 45.72 PLN (DC—50 kW/100 kW) for 19 min/10 min 50.37 PLN (DC— $x > 100$ kW)

Source: Chmielewski, Piórkowski, Możaryn, Ozana, 2023, p. 4528.

An important aspect of the development of electric vehicle charging infrastructure is their location. The location of the infrastructure is closely linked to the local specificity of the city: access to the distribution network, city spatial plans including the nature of development, reported needs of residents, and state regulations. The analysis of the location of chargers shows that most private users of electric vehicles have the opportunity to charge their vehicles in private garages, private parking spaces or driveways on private properties, equipped with access to electricity, often from their own photovoltaic micro-installation. Chargers are also located in city centers or in private and neighbourhood parking lots. While access to chargers in large cities is no longer as problematic, the need to charge a car on motorways or in rural areas is a bigger problem. The fast charging network being developed along the main communication routes allows moving between the largest Polish cities, but it can be difficult to find a charging station in a rural area and match the type of charger or connector. Table 6 lists the number of vehicles and the number of electric vehicle charging points in particular voivodeships (as of December 2022).

Table 6.

Number of electric vehicles and charging stations in individual voivodeships in Poland in 2022

Voivodeship	Area km ²		Number of Electrically Driven Vehicles			Number of Charging Stations	
		Sum	BEV	PHEV	Sum	AC	DC
Pomorskie	18,31	3885	1874	2011	263	198	65
Zachodniopomorskie	22,892	1893	845	1048	190	164	26
Warmińsko-mazurskie	24,173	836	381	455	139	126	13
Podlaskie	20,187	1214	632	582	52	32	20
Mazowieckie	35,558	18,237	9139	9098	413	326	87
Kujawsko-pomorskie	17,972	1883	805	1078	153	106	47
Wielkopolskie	29,826	6280	3186	3094	158	95	63
Lubuskie	13,988	848	423	425	51	27	24
Łódzkie	18,219	2581	1290	1291	109	44	65
Dolnośląskie	19,947	4089	1996	2093	224	164	60
Opolskie	9412	827	420	407	59	41	18
Śląskie	12,333	5856	2834	3022	323	233	90
Świętokrzyskie	11,711	846	488	358	31	24	7
Małopolskie	15,183	6032	3464	2568	197	126	71
Podkarpackie	17,846	1577	755	822	61	32	29
Lubelskie	25,122	1590	823	767	37	21	16

Source: IEA. Global EV Outlook 2022. Available online: <https://www.iea.org/reports/global-ev-outlook-2022>, 12.06.2025.

Most of the available charging networks are concentrated in four voivodeships: Mazowieckie – 413, Śląskie - 323, Pomorskie - 263 and Dolnośląskie - 224, which constitute almost 50% of the total number of charging stations in Poland. Among the voivodeships with the lowest number of publicly available charging stations are the following voivodeships: Świętokrzyskie (31 stations), Lubelskie (37), Lubuskie (51), Podlaskie (52) and Opolskie (59). This is still too small a number to meet the expectations of potential consumers.

5. Charging infrastructure

Ongoing development and technological progress, especially in the area of electric vehicle charging, requires standardization of terminology. In this regard, the European Union Sustainable Transport Forum (2021) addresses key aspects related to charging infrastructure. The vehicle charging process is a set of activities aimed at transmitting and storing the energy necessary for its propulsion. Currently, it can be carried out in several ways, including by charging using a plug connector, pantograph and wirelessly using electromagnetic induction. The division of electric vehicle charging methods is presented in Figure 6.

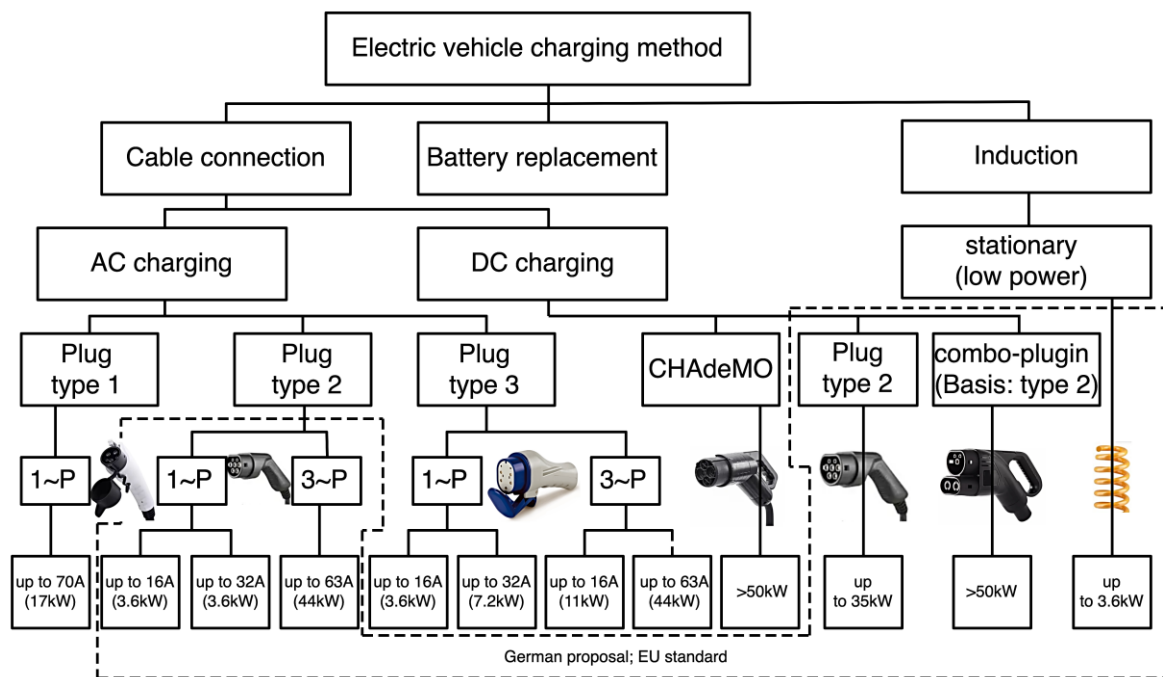


Figure 6. Charging Methods and available power connectors for electric vehicles.

Source: Zajkowski, Seroka, 2017, p. 484.

Charging can be carried out using home and garage installations, as well as charging station infrastructure designed specifically for this purpose.

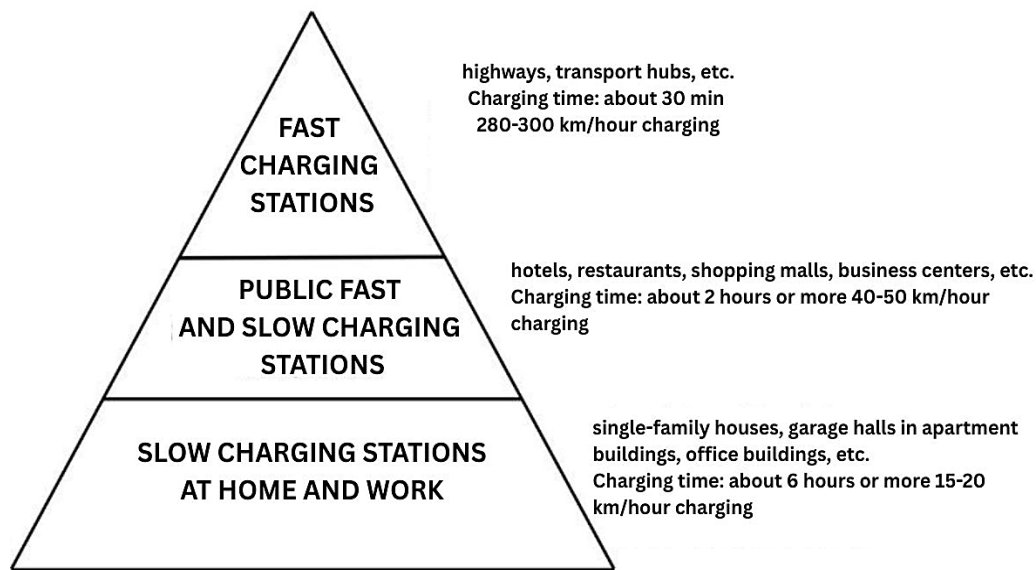


Figure 7. Location of charging stations.

Source: Zawieska, 2019.

Charging station is a dedicated place equipped with one or more devices for charging electric vehicles. The equipment of a charging station includes various components and devices that ensure efficient and safe charging of electric vehicles. Key elements of the charging station equipment include (Zawieska, 2019):

- Chargers (AC or DC).
- Connectors and sockets.
- Charging cables.
- Energy management systems (load distribution and monitoring).
- Payment terminals.
- Communication interfaces (OCPP-Open Charge Point Protocol, Wi-Fi, Ethernet, GSM).
- Safety systems (emergency switches, monitoring).
- Signage and information, including instructions for use and displays showing charging status and cost.
- Additional equipment (roof, lighting, cooling systems).

Charging point, on the other hand, is a single socket or connector at a charging station that allows one electric vehicle to be connected for charging. A charging station can have multiple charging points, which allows for the simultaneous charging of several vehicles. Charging points differ in the type of connector and the power they can deliver to the vehicle. The IEC 61851-1 (International Electrotechnical Commission, 2017) standard defines and classifies power supply methods, including protective installation, communication method and management of the charging system. This standard distinguishes four charging modes for electric vehicles: Mode 1, Mode 2, Mode 3, and Mode 4. The characteristics of wired charging systems for electric vehicles according to the IEC 61851-1 standard are given in Table 7.

Table 7.*Characteristics of electric vehicle conductive charging systems according to IEC 61851-1*

Charging type	Description	Characteristics	Application
Mode 1	Charging with alternating current (AC) using standard household outlets.	No special protective measures. Voltage: up to 250 V (single-phase) or 480 V (three-phase). Current: up to 16 A.	Mainly used for charging at homes or places with publicly accessible sockets. Requires additional protection, e.g., via residual current devices (RCDs).
Mode 2	Alternating current (AC) charging using standard household sockets but with an additional control module (ICCB) integrated in the cable.	The ICCB (In-Cable Control Box) module provides additional safety measures, such as fault detection. Voltage: up to 250 V (single-phase) or 480 V (three-phase). Current: up to 32 A.	Home charging with a higher level of safety compared to Mode 1.
Mode 3	Alternating current (AC) charging using dedicated charging stations.	Charging stations are equipped with specialized sockets as well as communication and control systems. Voltage: up to 690 V (three-phase). Current: up to 250 A.	Public and private charging stations with higher power. Enhanced safety thanks to integrated protection systems.
Mode 4	Direct current (DC) charging using dedicated charging stations.	Fast charging using direct current (DC). Voltage: up to 1000 V. Current: up to 400 A.	Public fast-charging stations, especially along highways and main routes. Designed for rapid recharging of electric vehicles in a short time.

Source: Chmielewski, Piórkowski, Możaryn, Ozana, 2023, p. 4528.

Currently, the most commonly used charging system for electric vehicles worldwide is wired energy transfer. Electric vehicle batteries can be charged using either alternating current (AC) or direct current (DC). Unfortunately, the connectors for stationary electric vehicles vary by geographic region and even model, making it impossible to charge an electric vehicle at any charging point in the world.

The following types of connectors are currently available for charging electric vehicles:

- Type 1 (SAE J1772).
- Type 2 (Mennekes).
- Type 3 (Scame).
- CHAdeMO.
- CCS (Combined Charging System).
- Tesla Supercharger.

Table 8 presents the types of power connectors and their differences depending on the charging system used.

Table 8.*Power connector and charging system used*

Connector type	Type of current	Current voltage	Power	Number of phases	Application	Region	Graphic view
AC – Type 1	Alternating (AC)	Up to 250 V	Up to 7.4 kW	1-phase	Home and public charging	North American, Japan	
AC – Type 2	Alternating (AC)	Up to 480 V	Up to 43 kW	1-phase or 3-phase	Home, public and commercial charging	Europe	
AC – Type 3	Alternating (AC)	Up to 480 V	Up to 22 kW	1-phase or 3-phase	Public charging	Italy	
DC – CHAdeMO	Direct (DC)	Up to 500 V	Up to 50 kW	1-phase	Fast public charging	Japan, world	
CCS Combo 1	Direct (DC)	Up to 1000 V	Up to 350 kW	1-phase	Fast public charging	North America	
CCS Combo 2	Direct (DC)	Up to 1000 V	Up to 350 kW	1-phase	Fast public charging	Europe	
GB/T	Direct (DC)	Up to 750 V	Up to 250 kW	1-phase	Fast public charging in China	China	
ChaoJi DC GB/T 20234 i IEC 62196	Direct (DC)	Up to 1000 V	Up to 500 kW	1-phase	Ultra-fast global charging	Asia (China, Japan, South Korea)	

The Type 1, Type 2, and Type 3 are used for AC charging, as defined in the IEC-62196-2 standard (Chmielewski et al., 2023). The IEC-62196-3 (International Electrotechnical Commission, 2022) standard specifies standards for DC charging connectors. Connectors compliant with this standard are designated in the following configurations: CHAdeMO, CCS Combo 1 (SAE J1772 Combo), CCS Combo 2 (IEC Type 2 Combo), GB/T 20234.3 DC. Currently, work is also being done on the ChaoJi DC standard, combining the GB/T 20234 and IEC 62196 standards.

Source: Benmouna, 2024, p. 33.

6. Summary

Based on the conducted research, it was found that the development of electric vehicles contributes to reducing environmental pressure. Most of the existing studies show that charging infrastructure has a significant positive impact on the adoption of electric vehicles (Dhakal, Min, 2021; Fluchs, 2020; Gota et al., 2019; Klein et al., 2020; Pasaoglu et al., 2016; Sæther, 2022).

The use of battery-powered electric vehicles, charged from a grid where electricity is mainly generated from coal, has the potential benefit of reducing emissions in congested cities. In Poland, where over 80% of electricity is generated from hard coal and lignite, it is difficult to justify the use of electric vehicles in terms of a positive impact on the environment and climate protection. Of course, pollution caused by energy production dominated by coal is high, but it is emitted outside the boundaries of congested cities. Transferring emissions from one place to another is not a way to solve the problem of greenhouse gas emissions on a global scale, but as noted, it has a significant impact on reducing emissions locally in cities (Huo et al., 2015).

An important factor influencing the development of electromobility is the number of electric vehicles charging stations. Although the development of charging stations in Poland has been dynamic, the overall level of charging infrastructure remains insufficient, and the charging time for vehicles is still too long. This is reflected in the low density of charging stations, particularly public charging stations. In addition to the availability of adequate charging infrastructure, the main problem is the lack of fast-charging stations.

A deeper analysis indicates potential problems and shortcomings in the charging infrastructure. The most significant issues include:

1. A disproportionately higher rate of vehicle electrification compared to the slower growth in the number of public charging stations.
2. A low share of fast-charging stations, resulting in longer vehicle charging times.
3. Uneven distribution of public charging stations.

The implementation of electromobility is a complex issue, involving numerous economic, social, and spatial aspects. Some of the key areas that require in-depth research include local factors influencing the purchase of low-emission vehicles and the development of the infrastructure necessary for their charging. To accelerate the adoption of electric vehicles and highlight the benefits of smart electromobility, it is essential to coordinate efforts within a network of organizations. Therefore, supporting initiatives that help cities accelerate the green transition process is crucial. It is obligatory to implement a financial support system and optimize legal regulations. This will speed up the deployment of environmentally friendly solutions, stimulate the economy, and, most importantly, contribute to the sustainability of the transport system. These long-term changes in the transportation sector can have a positive impact on climate change.

In conclusion, the paper verifies all three hypotheses through empirical data and comparative analysis. It emphasizes the urgent need for strategic investments and policy interventions to develop a robust EV charging infrastructure, addressing the energy crisis, and fostering the adoption of electric vehicles for sustainable urban mobility.

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