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Review

Sustainable Development of Operational Infrastructure for Electric Vehicles: A Case Study for Poland

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Abstract: This article overviews Poland's current electric vehicle infrastructure development. It discusses market segmentation and the analysis of charging standards, connectors, and types of charging. The paper focuses on Poland's charging infrastructure, including costs and charging times for popular electric vehicle models in 2022. It highlights the challenges faced by charging operators and the barriers to infrastructure development. The article also presents the outlook for the electric vehicle market in Poland until 2025 and 2030. Furthermore, it examines private charger development, particularly in prosumer households with renewable energy sources. The implementation of smart charging and the potential for vehicle-to-grid technology in Poland are addressed. Lastly, a comparative analysis of incentives for electric vehicle users in Poland and Norway is discussed in the context of achieving 100% zero-emission vehicle sales by 31 December 2035, in Poland.

Keywords: operational infrastructure; battery electric vehicles; recharging station; recharging point; recharging connectors; bi-directional charger; smart charging; prosumer micro-installation; energy aggregator; renewable energy sources

Citation: Chmielewski, A.; Piórkowski, P.; Możaryn, J.; Ozana, S. Sustainable Development of Operational Infrastructure for Electric Vehicles: A Case Study for Poland. *Energies* **2023**, *16*, 4528. https://doi.org/10.3390/en16114528

Academic Editors: Nick Papanikolaou and Anastasios Kyritsis

Received: 6 May 2023
Revised: 26 May 2023
Accepted: 1 June 2023
Published: 5 June 2023

1. Introduction

Civilization progress, human activity, and population growth affect climate change [1]. The degradative impact of humanity [2] is particularly noticeable in the processes of converting other forms of energy into electricity, industrial waste, construction, and agricultural industries.

In order to counteract the progression of climate change, the Paris Agreement [3] was signed by 196 countries responsible jointly for 99.75% of global greenhouse gas emissions (including carbon dioxide—CO_2), which entered into force on 4 November 2016. These countries, signatories to the agreement, committed themselves to maintaining a long-term average temperature increase of no more than 2 °C above the pre-industrial temperature level, aiming for 1.5 °C, and halting and reducing greenhouse gas emissions.

An action plan known as the European Green Deal [4] was created to meet these assumptions. The main goal of this plan is to achieve zero net greenhouse gas emissions in 2050 by developing, among others, sustainable and smart mobility [4].

In 2020, the total emission of greenhouse gases from the 27 countries of the European Union amounted to 3354.12 million tonnes of CO_2 equivalent, according to Eurostat and the European Environment Agency (EEA) [5]. The growing importance of environmental degradation and its harmful effects on human health due to greenhouse gases, toxic smoke, and particulate matter from fossil fuels has caught the attention of scientists [1]. Global warming stands out as a primary concern among these hazards. Consequently, it is crucial to urgently replace traditional fuel vehicles with electric vehicles powered by renewable energy sources [6–9]. At the same time, greenhouse gas emissions from the transport sector accounted for 23.2% in the European Union (including international aviation [10]).

As shown in Figure 1, the transport sector had the second-highest share of emissions after the energy industry sector, which accounted for 23.3% of total EU greenhouse gas emissions. In the transport sector, as shown in Figure 2a, road transport accounted for the largest share of greenhouse gas emissions, accounting for 71.7%. In Europe, passenger vehicles account for 60.6% of total greenhouse gas emissions from road transport, as shown in Figure 2b. Reducing carbon dioxide emissions in road transport can be achieved through the development of purely electric vehicles, such as battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and fuel cell electric vehicles (FCEVs) [11–13].

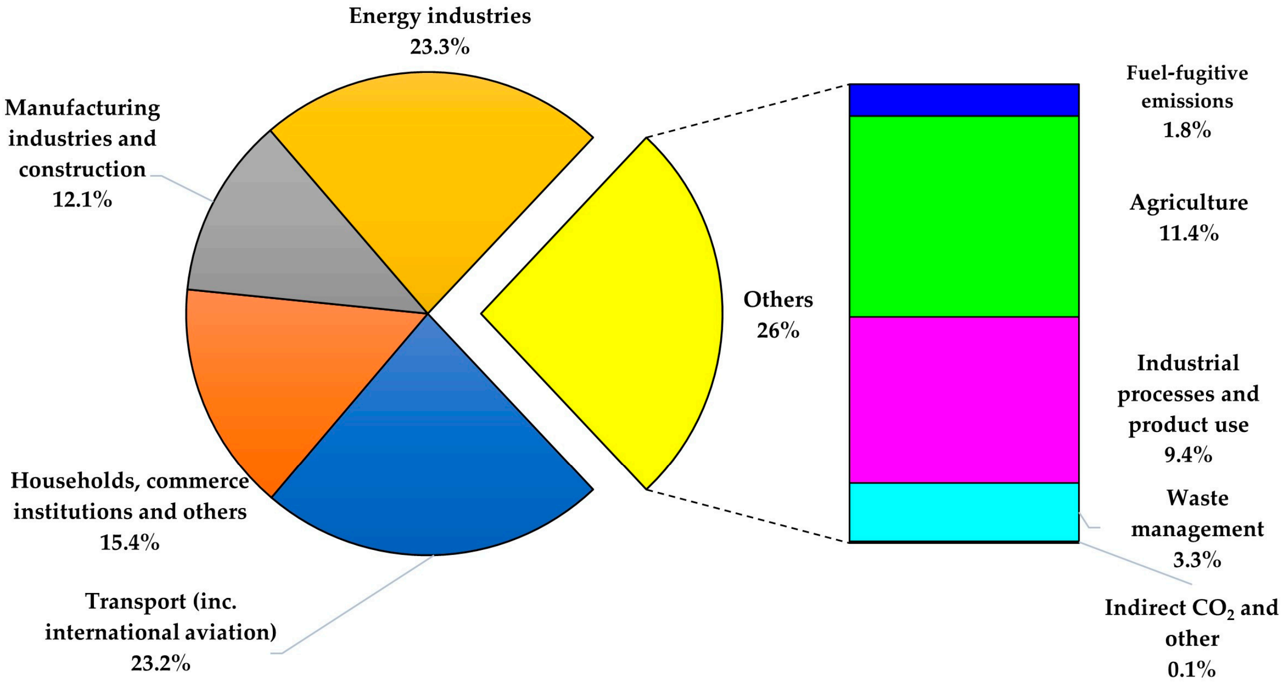
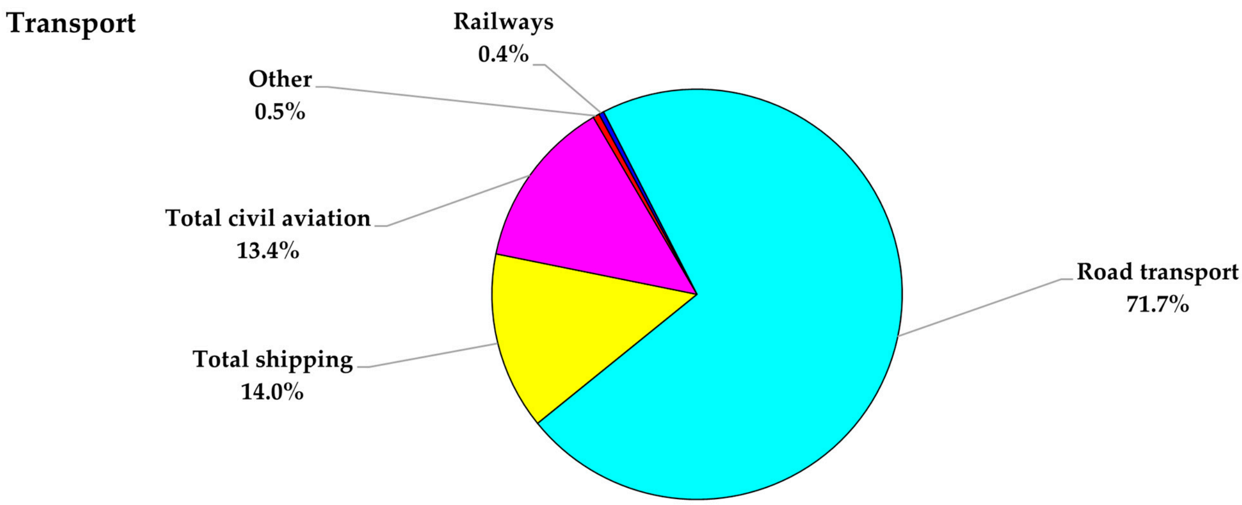
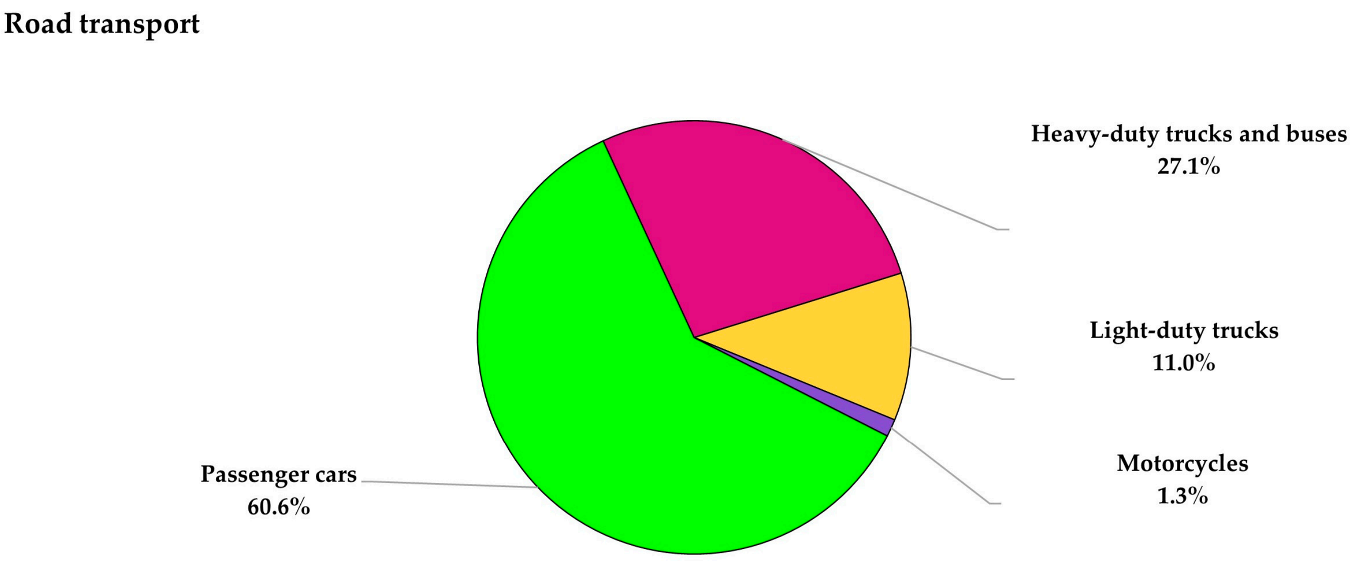


Figure 1. GHG emission by sectors in EU, 2020 [10,14].



(**a**)

Figure 2. *Cont.*



(**b**)

Figure 2. (**a**) Shares of GHG emissions in the European Union transport sector in 2019 transport GHG emissions of EU, (**b**) Shares of GHG emissions in road transport in the European Union in 2019 by type [15].

According to data from the International Energy Agency [16], there are over 16.5 million PHEV and BEV vehicles on the world's roads. The largest share of the electric vehicle market in 2021 was held by China (37.8%—BEV, 9.76%—PHEV) and Europe (18.29%—BEV, 15.24%—PHEV), which is presented in Figure 3. In 2021, China and Europe together accounted for more than 81% of the global electric vehicle market share. In order to ensure the proper functioning of the PHEV and EV markets, it is necessary to develop an appropriate operational infrastructure enabling the recharging of the battery pack in PHEVs and EVs. As shown in Figure 4, there were an average of 15.5 light-duty electric vehicles (LDEVs) per charging point in Europe in 2021.

In the case of China, the number of slow charging stations is 677 thousand, while fast charging stations are 470 thousand. It is worth emphasizing that publicly available fast charging stations in China account for over 82% of all publicly available charging stations worldwide. By 2030, at least 30 million electric vehicles are expected to appear on European roads [5], which will be charged at 3 million publicly available charging points.

Currently, there are 307 thousand slow charging stations in Europe (see Figure 5a) and 49 thousand fast charging stations (see Figure 5b).

In the case of Poland, there is currently an average of 10.3 eLDVs per charging point and 2.5 kW of power from a recharging point (see Figure 4).

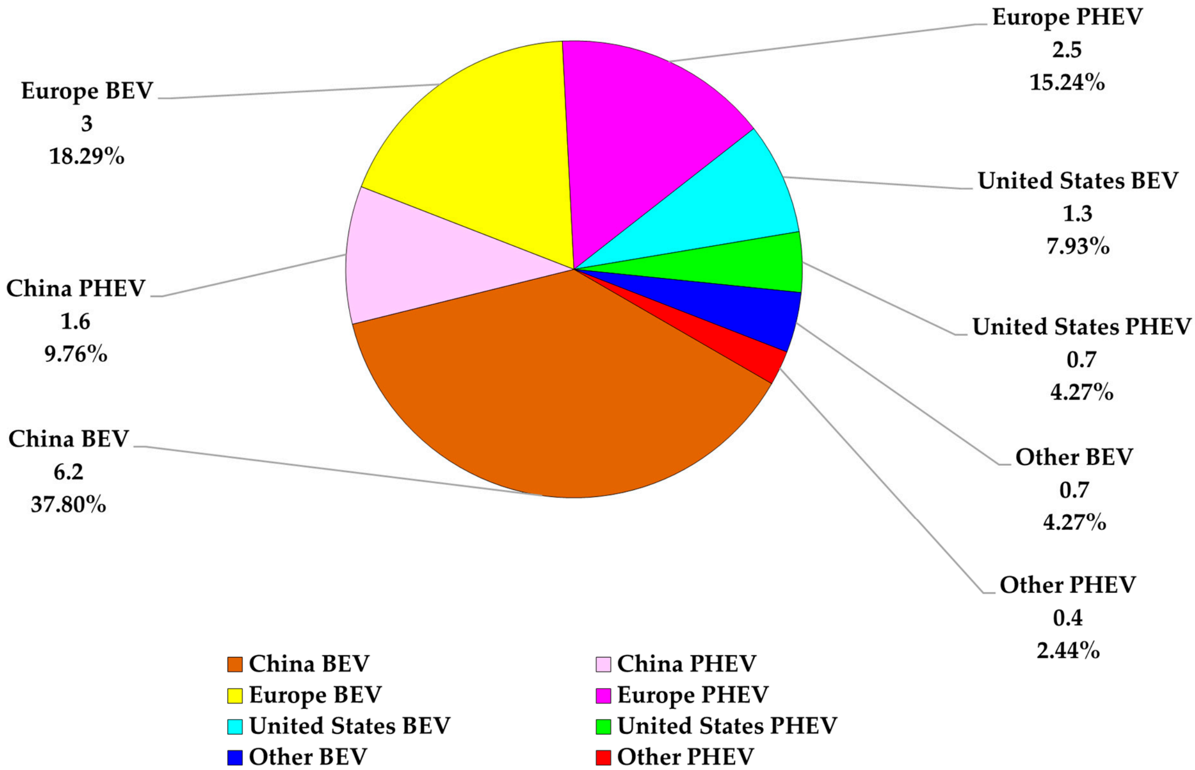


Figure 3. Shares in the global electric light-duty vehicles (LDVs) stock, based on International Energy Agency Global EV Outlook 2022 data [16].

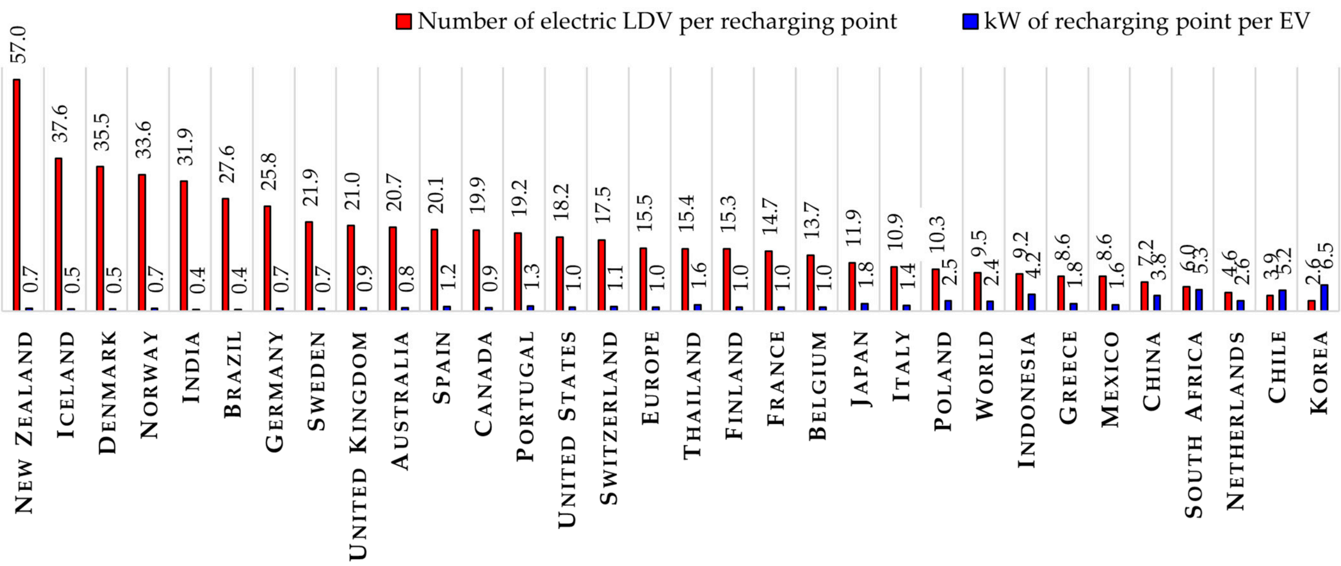
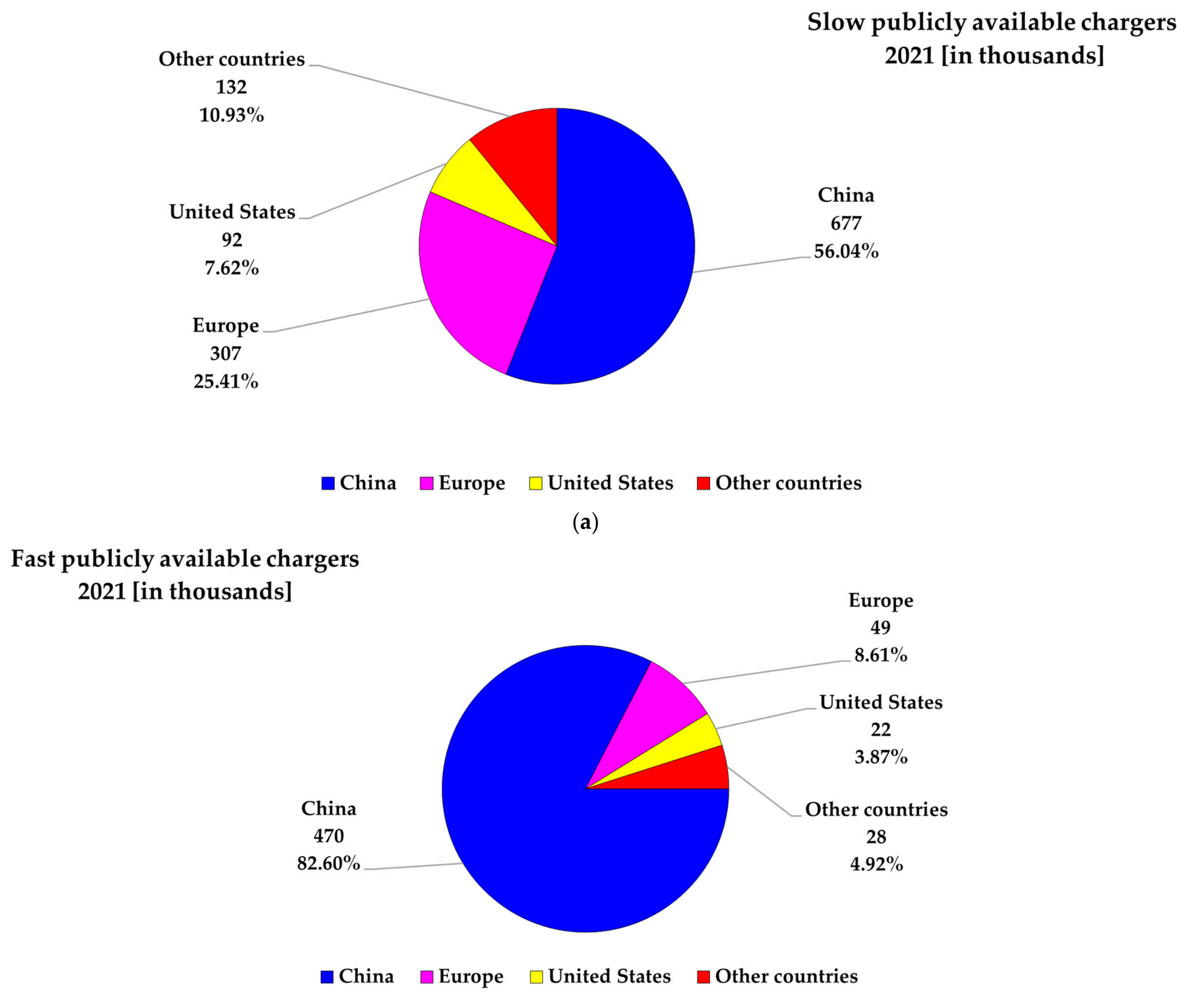


Figure 4. Number of electric light-duty vehicles (LDVs) per charging point and kW of recharging point per EV [16].



(**b**)

Figure 5. Global: (**a**) slow publicly available chargers in 2021, (**b**) fast publicly available chargers in 2021, in thousands [16,17].

Both in Europe and Poland, such an operational infrastructure for charging electric vehicles and the pace of its development are far from sufficient. For this reason, in 2022, the European Commission, as part of the "Fit for 55" package, amended Regulation 2019/631 [18,19] and prepared a draft amendment to Directive 2014/94/EU [20,21] on the development of the Alternative Fuel Infrastructure Regulation (AFIR), which will be replaced by a directly binding regulation that does not require implementation. The most important effects of the introduction of Regulation 2019/631 include the inability to register vehicles other than zero-emission vehicles by 2035 in the European Union, including Poland. In addition, following the assumptions contained in [18–21], European Union State Members will be obliged to develop, among others, a recharging infrastructure and access to public charging stations. This will translate directly into ensuring a significant increase in the power of charging points at the charging station, which is directly related to the development of a fleet of electric vehicles. For each newly registered BEV, it is 1 kW; for PHEVs, it is 0.66 kW. Meeting such requirements in the case of Poland will be possible after eliminating or significantly reducing the key barriers to the development of operational infrastructure, which are presented in this article.

This article is structured as follows: Section 2 presents the architecture of electric vehicle market segmentation. Section 3 describes the current state of operational architecture development for electric vehicles in Poland. In Section 4, the prospective development of EV charging infrastructure in Poland, with particular emphasis on the existing development barriers and ways to reduce them, is presented. Finally, Section 5 offers the synthetic conclusions.

2. Electric Vehicle Market Architecture

One of the foundations for achieving climate neutrality by 2050 for European Union countries, as presented in [22], is the intensification of activities related to electric vehicle market development.

According to Polish nomenclature terminology presented in the Act on Alternative Fuels [23,24], each electric vehicle is a motor vehicle. A motor vehicle is equipped with an engine, except for mopeds and rail vehicles, the construction of which enables it to run at a speed exceeding 25 km/h; this term does not include an agricultural tractor. Taking into account the development of the market and the energy capacity of commercially used battery packs, electric vehicles can be divided into three types: Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV), and Battery Electric Vehicle (BEV).

A HEV is a motor vehicle powered by an internal combustion engine and an electric machine, in which electricity is generated by an internal combustion engine driving an electric machine. Depending on the configuration, between one and several electric machines are used. They are not capable of external charging [25]. In this solution, the batteries are charged during regenerative braking and while driving through the internal combustion engine that drives the electric machine.

A PHEV is a motor vehicle powered by an internal combustion engine and an electric machine that accumulates electricity by connecting to an external power source. PHEV vehicles have the option of purely electric driving up to 100 km, based on data from manufacturers [26,27] following the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) [28].

A BEV is a motor vehicle that uses only electric energy accumulated by connecting to an external power source for propulsion. BEV vehicles have the option of purely electric driving over 600 km and more [26,27], per the WLTP procedure [28]. Lithium-ion cell packages are typical solutions used in electric vehicles to store electricity [29].

Both PHEVs and BEVs use publicly available charging infrastructures (commercial [23,24,30]) and can use home infrastructures as well, such as residential communities/cooperatives [31]. The EV market's segmentation structure is schematically shown in Figure 6.

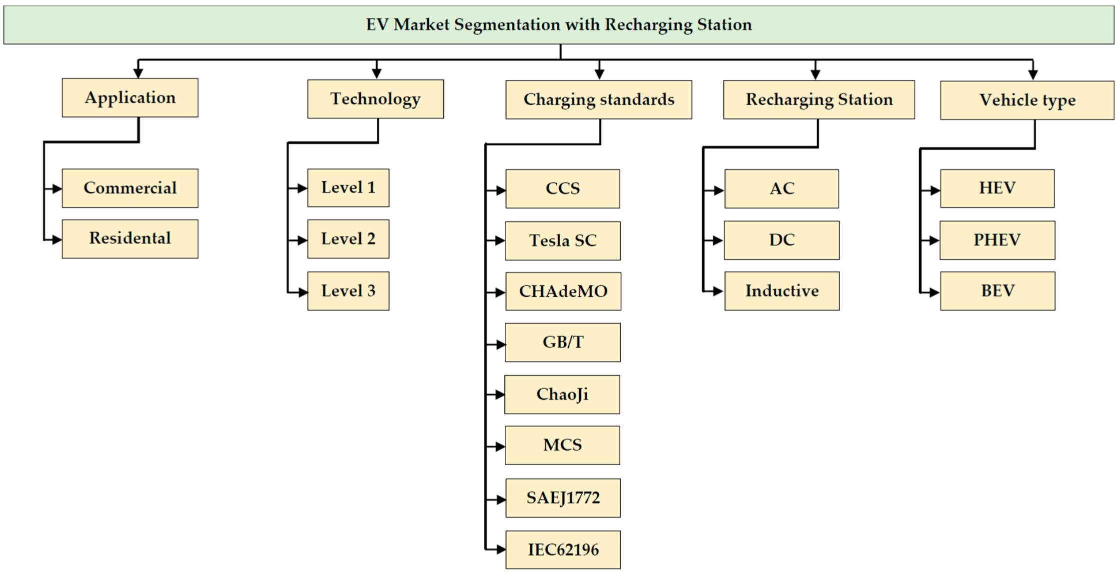


Figure 6. Scheme of the segmentation structure of the electric vehicle market, including recharging stations [32–36].

The ongoing development and technological progress related to the charging of electric vehicles in particular require introducing unification to the vocabulary. Therefore, the European Union Sustainable Transport Forum [37] refers to the key elements related to the charging infrastructure.

The vehicle recharging pool/area/hub consists of at least one or more electric vehicle charging stations equipped with at least one (or more) normal (up to 22 kW) or high-power (above 22 kW) charging point, following the categorization based on AFIR regulation.

According to [24,30,31,37], a recharging station is a construction device that includes at least one recharging point of normal power or a high-power recharging point associated with a building or a free-standing building with at least one recharging point of normal power or high-power. The charging station is equipped with the software used to provide the charging service, along with parking stands, the number of which corresponds to the number of charging points enabling the simultaneous provision of this service, and, if the charging station is connected to the distribution network within the means of the Polish Act of Energy Law [38], along with the installation leading from the charging point to the power connection.

According to the definition presented in [24,30,31], a recharging point is a device that allows charging a single electric vehicle, a hybrid vehicle, or a zero-emission bus, and a place where the battery used to drive this vehicle is replaced or charged. Charging points can be divided into normal-power and high-power charging points. Normal power recharging points are points with a power less than or equal to 22 kW, excluding devices with a power less than or equal to 3.7 kW installed in places other than public charging stations, particularly in residential buildings. A high-power recharging point is a charging point with a power greater than 22 kW.

Each charging point may contain one or more connectors. During the charging process, only one selected connector can be active at one charging point; the operational status (marked in green) is presented in Figure 7.

The two main ways to charge a cell pack in electric vehicles are wired charging and inductive charging. Currently, wired direct current (DC) or alternating current (AC) charging methods are mainly used. Wireless charging technologies are still in the research and pilot implementation phase [38].

Wired charging uses direct contact through a physical connector between the charging point and the electric vehicle's Battery Management System (BMS). According to [39], wired charging is divided into on-board charging and off-board charging, as shown schematically in Figure 8. On-board charging is used for slow charging (domestic, usually single or three-phase AC). In such a solution, the management of the charging process takes place inside the vehicle powertrain. In the case of off-board charging, an external charger is used, and the charging area and charging management are moved outside the vehicle area. Off-board charging is used for fast and ultra-fast charging, usually using publicly available chargers. Currently, according to manufacturers' data [26,27], wired charging is used by all-electric passenger vehicles available for sale on the European market.

Considering the charging architecture, alternating current (AC) and constant current (DC) charging systems can be distinguished, as shown in Figure 9. In AC systems, the charging system is located on the secondary side of the MV-LV distribution transformer. It operates as a common current bus AC, which is connected to the on-board charger of the electric vehicle using AC/DC converters [32,39,40]. As presented in Figure 9a, the AC bus architecture includes different power conversion stages, communicating with different loads and DC sources (e.g., photovoltaic cells).

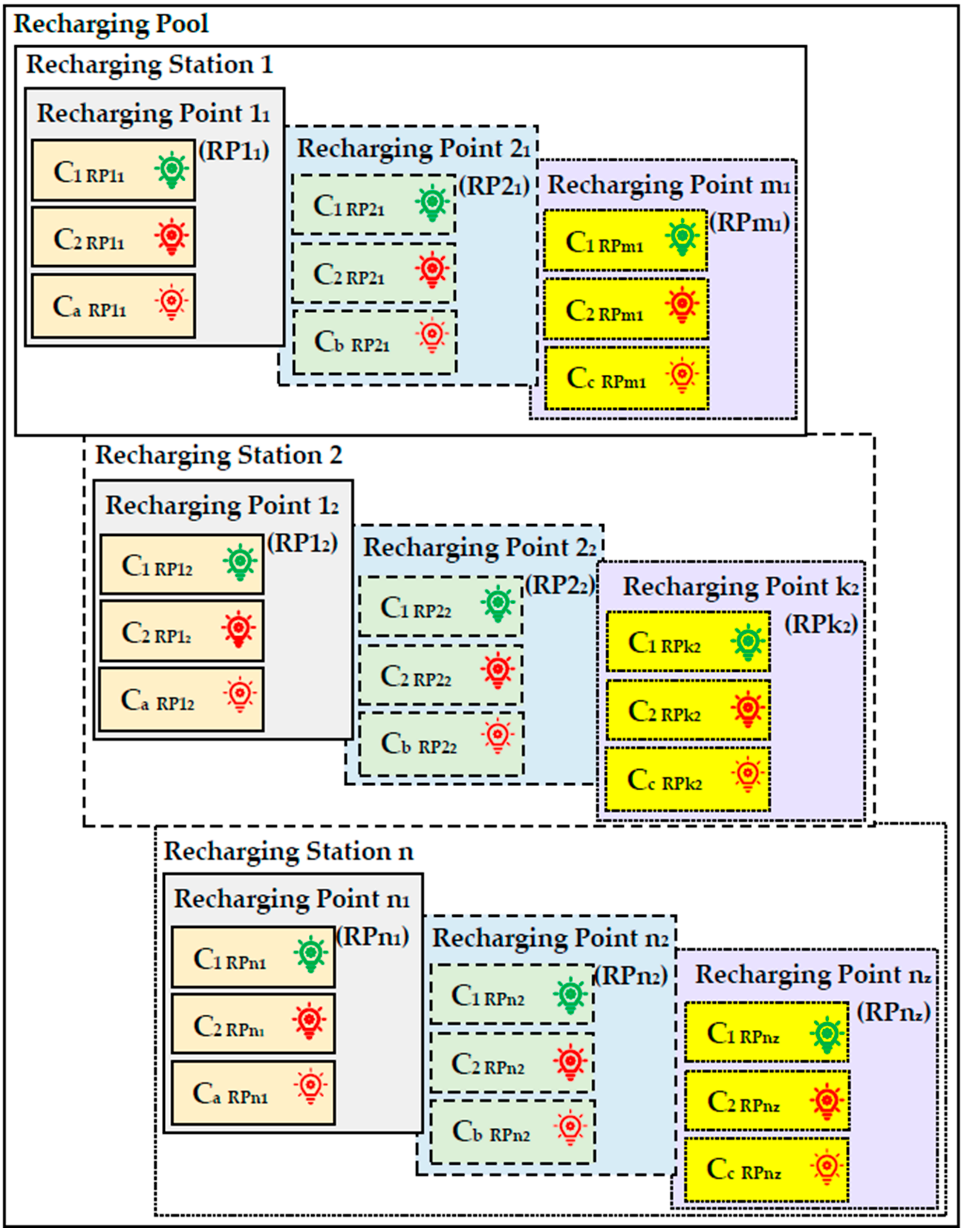


Figure 7. Diagram showing the recharging pool/hub, recharging station, recharging point (RP) and connectors (C_{RP}) with an indication of the active status (green—active, red—inactive) as defined in [24,31,37].

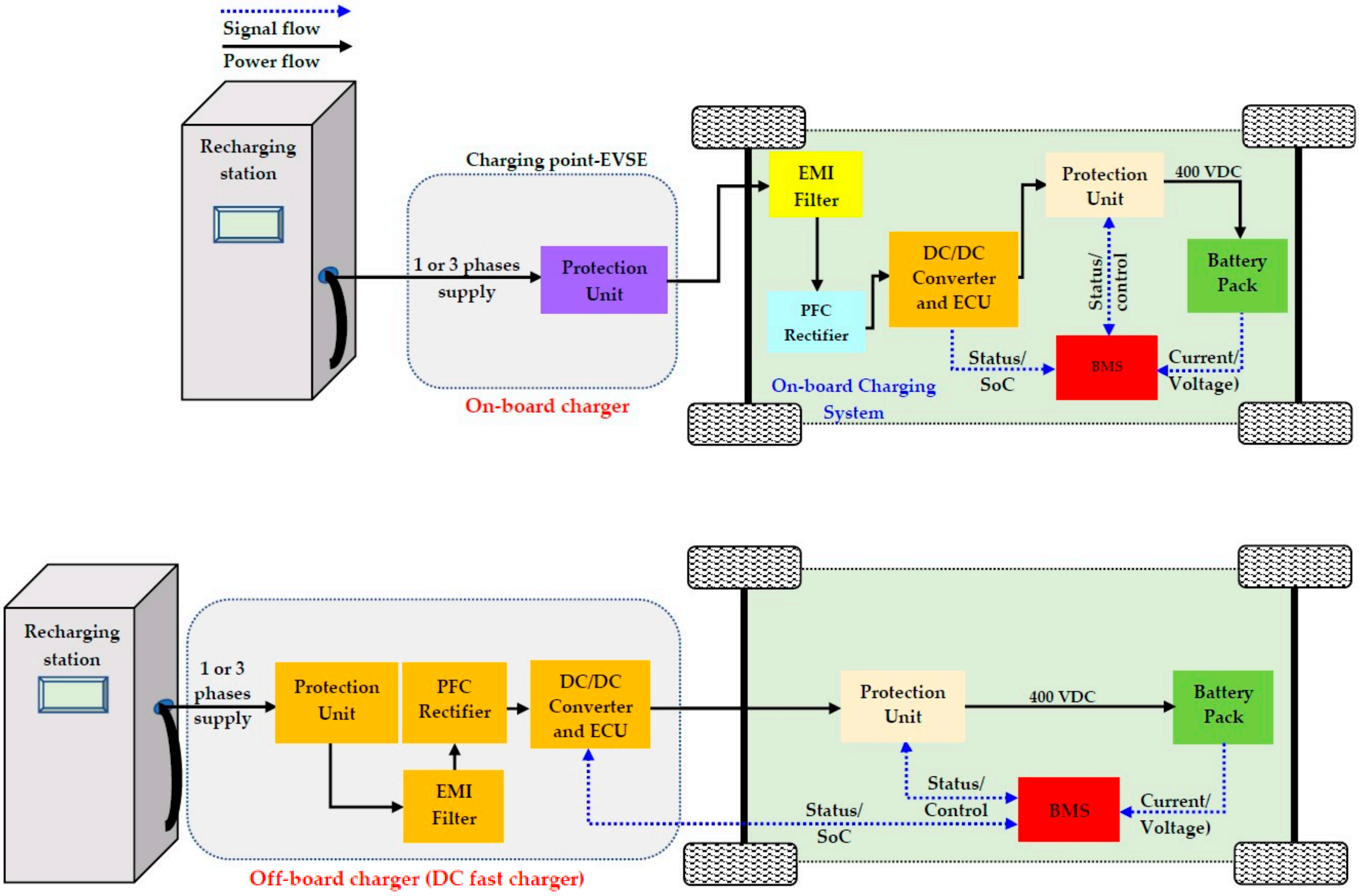


Figure 8. On-board and off-board recharging systems [39,40].

In fast charging (DC) systems, as shown in Figure 9b, the AC/DC converter is located on the common part of the bus by the MV-LV distribution transformer. Usually, in DC charging systems, the common AC bus has a voltage of 400–480 V, which is connected to an off-board, external AC/DC converter [32,40–42]. A power electronic converter enables current rectification, power factor correction (PFC), voltage control, insulation and DC power supply to a port/connector in an electric vehicle. A common DC bus connects all chargers in DC charging systems. It also provides the necessary isolation between the DC bus and the port/connector of the electric vehicle through isolated DC/DC converters. This architecture is usually less expensive and performs better than AC buses [43,44]. However, the development of converters for fast DC charging requires the use of interrupters that ensure adequate protection of the microgrid. This is because after initiating a short-circuit, the DC short-circuit current can quickly increase (up to 100 times the rated current) because there is no natural zero crossing point [45,46].

Wireless charging, known as inductive charging, is being researched and piloted, allowing energy transfer through an electromagnetic field [32]. In such cases, energy is transferred through an electromagnetic field without physical contact between the power source and the vehicle. The main advantage of wireless charging over wired charging is ensuring electrical safety. Unfortunately, wireless charging is less efficient, with significant power losses and lower charging efficiency, as demonstrated in [7,32,33,47]. Besides decreased charging efficiency, the scientific community acknowledges the vital importance of interoperability in wireless charging systems. Interoperability pertains to the ability of output performance to meet predetermined indicators when using different transmitter and receiver devices, with a primary emphasis on their compatibility. If the specified indicators are not met, it indicates a lack of interoperability between the transmitter and receiver [7]. Wireless charging enables the battery pack used in electric vehicles to be automatically charged, typically in three ways. The first way is static wireless charging [32,48], the second way is dynamic wireless charging [49], while the third is quasi-dynamic wireless charging [32].

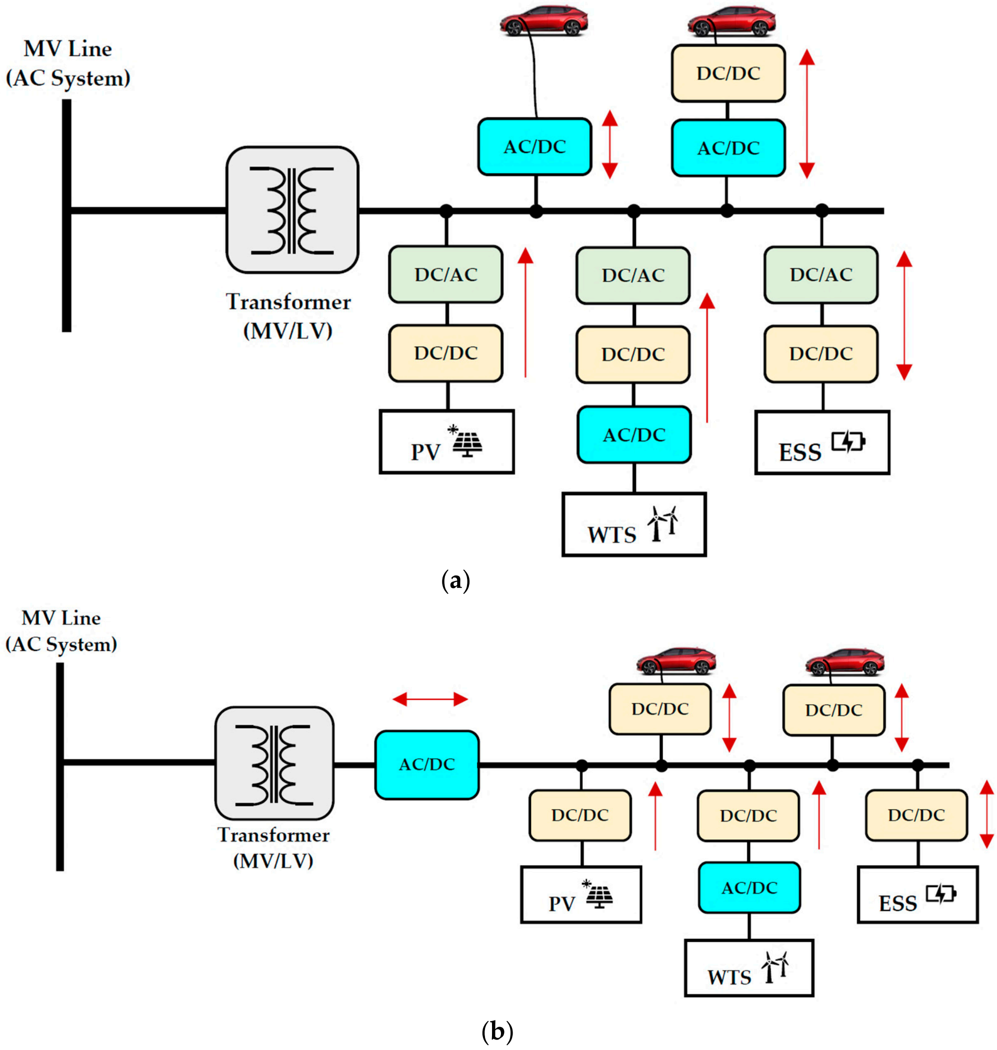


Figure 9. The scheme of EV charging stations integration with power grid: (**a**) AC recharging system, (**b**) DC recharging system [40].

Static charging is usually used in appropriately marked places, e.g., car parks and residential garages [48]. The dynamic charging system allows charging while the vehicle is in motion (e.g., an additional lane [49–52]), extending the range of the electric vehicle. The quasi-dynamic system [48,49] charges the battery pack of an electric vehicle when it stops for a short time (e.g., in a traffic jam, at traffic lights, etc.).

In [53], attention was drawn to the challenges related to the wireless charging infrastructure at the design stage (traffic intensity, external weather conditions such as snow and water, determination of the leakage stream and power losses, size of the air gap) and the maintenance and operation stage (daily load profile, slow zone) [54]. Moreover, in [8], the main challenges related to wireless charging include increasing the efficiency of the charging process, which can be achieved by optimizing the magnetic coupler. In 2017, WiTricity collaborated with Nissan to develop a static wireless charging system. As a result of this cooperation, a modular DRIVE system was developed, which enables charging with a power of 22 kW and more with an electrical efficiency of up to 94% [55]. The Volkswagen Group plans to implement WiTricity's ABT e-Line solution for static wireless charging in their ID.4 electric vehicle model by 2024 [56].

There are three different charging levels for electric vehicles, defined by SAE J1772 [57]. Charging levels are used to categorize the rated power, voltage, and current of the charging system. Table 1 shows the charging levels according to the SAE classification. Level 1 includes charging stations with an output voltage of 120 V/230 V. Usually, the charging time of an electric vehicle battery pack is at least several hours [57–59]. Chargers of this type are connected to the electric vehicle port using the J1772 connector [57,59]. Currently, this type of charger is offered by all manufacturers of electric vehicles; the cost of these devices ranges from 200 USD to 450 USD [60]. To reduce the charging time to a few hours (no more than 10 h), level 2 is used at the charging stations. Typical voltages are 240 V/400 V (USA/Europe) and a charging power of over 19 kW. Level 2 charging stations with the SAEJ1172 connector are used for both slow domestic (from 4 kW to 8 kW) and public charging over 19 kW. The cost of a level 2 charging station ranges from 350 USD (home chargers) to 1300 USD (public chargers) [60,61]. To speed up the charging process of the electric vehicle cell package, level 3 was introduced. The voltage range is from 200 V to 600 V; it is possible to charge with a power value of up to 100 kW. This type of recharging station costs from 10,000 USD up to 50 thousand USD or more depending on configuration [62].

Table 1. Charging power levels according to SAE standard [57,58].

Power Level Types	Charger Location	Application	Energy Supply Interface	Power Level	Charging Time	Vehicle Technology
Level 1—Slow Charging Station (EU: 230 V, US: 120 V):	On Board (1-phase)	Home charging/Office	Convenience Outlet	1.44 kW for 12 A/ 1.92 kW for 16 A/ 3.68 kW for 16 A	11–36 h/4–11 h	PHEV/EV
Level 2—Fast Charging Station (EU:400 V, US: 240 V)	On Board (1-phase or 3-phase)	Private/Public outlets	Dedicated EVSE	From 4 kW for 17 A To 48 kW for 120 A	Up to 10 h	
Level 3—Rapid Charging Station (U_{AC}: 208 V–600 V, U_{DC}: 208 V–600 V)	Off-Board (3-phase)	Commercial	Dedicated EVSE	50 kW for 100 A 100 kW for 200 A	Up to 2 h-50 kW/ up to 1 h-100 kW	

In [63,64], one can also find a classification of DC charging levels for electric vehicles (see Table 2). Level 1, with a voltage range from 200 V to 450 V, enables charging an electric vehicle with a power of up to 36 kW. Level 2 enables charging in the same voltage range, up to 90 kW, while in level 3, it is in the voltage range from 100 V to 600 V, with power up to 240 kW. The costs of chargers using level 3 exceed 50,000 USD [65].

Table 2. Direct current charging power level [63,64].

Power Level (DC)	Charger Location	Application	Energy Supply Interface	Power Level	Charging Time	Vehicle Technology
Level 1 (U_{DC}: 200–450 V)	Off-Board	Commercial	Dedicated EVSE	Up to 36 kW for 80 A	11–36 h/4–11 h	All PHEV/EV
Level 2 ($U_{DC:}$ 200–450 V)	Off-Board	Commercial	Dedicated EVSE	Up to 90 kW for 200 A	Up to 1.5 h	
Level 3 ($U_{DC:}$ 200–600 V)	Off-Board	Commercial	Dedicated EVSE	Up to 240 kW for 400 A	Up to 30 min	

The IEC 61851-1 [66–68] standard defines and categorizes the methods of energy supply, taking into account protective installation, the method of communication, and the control of the charging system. The standard distinguishes four charging modes for electric vehicles: Mode 1, Mode 2, Mode 3, and Mode 4. Mode 1 (Schunko), following IEC 61851-1, is a charging system with an alternating current up to 16 A at a single-phase voltage not exceeding 250 V or three-phase no greater than 480 V. This mode does not ensure communication between the electric vehicle and the charging point; it has no security and protection system. The maximum power obtained with single-phase charging is 3.68 kW or three-phase 6.4 kW. An electric vehicle in Mode 2 is charged using a special cable with a device that monitors and controls the charging process. A residual current device protects the system in the charger. In Mode 2, the maximum AC current is 32 A and the voltage in a single-phase installation should not exceed 250 V or 480 V in a three-phase structure. During the charging process, the functions of the charger can detect and monitor the protective grounding connection. In addition, in this mode, the charger detects the connection with the vehicle and analyses the demand for charging power. Mode 2 is usually used for slow home recharging. Mode 3 uses an electric vehicle's dedicated charger (EVSE) and an on-board charger. Safety is ensured by checking the protective earthing and connection between the charger and the electric vehicle. Type 2 operating mode is supported (Mennekes (Type 2) connector). The maximum charging current in this mode is 250 A, with a voltage in a single-phase installation up to 250 V or 480 V in a three-phase installation.

In Type 2 charging mode, the charger limits the charging current to 32 A in a single-phase or three-phase installation [69]. Communication between the charger and the electric vehicle controller can be carried out using a programmable logic controller (PLC), and the information transfer itself can be carried out using Modbus [70]. During the Mode 4 charging process, an external charger with DC output (off-board) is used. Up to 400 A DC at up to 600 V is supplied directly to the battery pack, and the electric vehicle's on-board charger is bypassed. The charging process is carried out using dedicated connectors, e.g., CCS (Combo 2), along with advanced control and protection functions. The plug-in connection is located on the vehicle side. In this type of charger, the AC/DC converter is stationary. In addition, the charger's power cable is permanently attached to it. Information transfer can be carried out using different buses, e.g., Controller Area Network (CAN), CANopen, FlexRay, Local Interconnect Network (LIN), or Modbus [71].

Currently, in the European Union and Poland, recharging points are categorised based on the assumptions of the AFIR regulation [20,21], which is presented in Table 3. The regulation specifies two categories of charging points: AC—category 1 and DC—category 2. In category 1 AC, three types of charging are specified: Slow AC recharging point (1-phase)—charging power below 7.4 kW, Medium-speed AC recharging point (3-phase)—charging power below 22 kW and Fast AC recharging point (3-phase)—charging power above 22 kW. Charging points with a power of 7.4 kW to 22 kW are called normal power points.

Table 3. Categories of recharging points based on AFIR proposal—Annex III [20,21].

Current Type AC/DC	Category	Subcategory	Maximum Power Output	Definition Based on Art. 2 [21]
AC	AC—Category 1	Slow AC recharging point (1-phase)	$P_{out} < 7.4$ kW	Normal power recharging point
		Medium-speed AC recharging point (3-phase)	7.4 kW $< P_{out} <$ 22 kW	
		Fast AC recharging point (3-phase)	$P_{out} > 22$ kW	High power recharging point
DC	DC—Category 2	Slow DC recharging point	$P_{out} < 50$ kW	
		Fast DC recharging point	50 kW $\leq P_{out} <$ 150 kW	
		Level 1—Ultra-fast DC recharging point	150 kW $\leq P <$ 350 kW	
		Level 2—Ultra-fast DC recharging point	$P \geq 350$ kW	

In category 2 DC, we can distinguish four types of charging: Slow DC recharging point (charging power below 50 kW), Fast DC recharging point (charging power greater than 50 kW, but not exceeding 150 kW), Level 1—Ultra-fast DC recharging point (over 150 kW, up to 350 kW) and Level 2—Ultra-fast DC recharging point (charging power above 350 kW).

Due to different charging powers and standards, electric vehicle manufacturers use different types of connectors for AC and DC charging. The designations Type 1, Type 2, and Type 3 are used for AC charging, defined in the IEC-62196-2 standard [71]. Type 1 is a single-phase connector as specified by J1772/2009. Type 2 is a single or three-phase vehicle connector, according to the Mennekes specification. Type 3 is a single or three-phase AC connector called SCAME. Currently, the Mennekes Type 2 connector is the most popular solution for charging an electric vehicle in Europe, with the maximum value of the charging power equal to 50 kW (see Table 4).

Table 4. Currently used connectors for charging electric vehicles, taking into account the Geographical zone [10,26,27,34,35,64,66–80].

Connector Graphical View	Current Type/Geographical Zone				Maximum Power (the Charger's Technical Maximum Capability) [kW]	Market Solution (Maximum Capability in Public Charging Infrastructure) [kW]
	North America	European Union	Japan & South Korea	China		
 SAE J1772 (Type 1)	AC/DC	AC	AC	-	19.2 kW	7.7 kW (Level 2)
 IEC 62196-2 Mennekes (Type 2)	-	AC	-	-	Up to 50 kW	22 kW–48 kW
 GB/T 20234.2 AC				AC	27.7 kW	22 kW–48 kW
 Tesla Supercharger	AC/DC	AC/DC	-	-	250 kW (Level 3)	up to 150 kW
 CCS (Combo 1)	DC	-	-	-	400 kW (1000 V, 400 A)	150 kW

Table 4. *Cont.*

Connector Graphical View	Current Type/Geographical Zone				Maximum Power (the Charger's Technical Maximum Capability) [kW]	Market Solution (Maximum Capability in Public Charging Infrastructure) [kW]
	North America	European Union	Japan & South Korea	China		
 CHAdeMO	DC	DC	DC	-	400 kW (1000 V, 400 A)	150 kW
 CCS (Combo 2)	-	DC			400 kW (1000 V, 400 A)	350 kW
 GB/T 20234.3 DC	-	-	-	DC	250 kW (1000 V, 250 A)	125 kW
 ChaoJi DC GB/T 20234 and IEC 62196 (planned from 2024)	-	-	DC	DC	900 kW (1500 V, 600 A)	500 kW
 Megawatt Charging System (MCS) IEC 15118-20 (Planned from 2024)	-	DC	-	-	3750 kW (1250 V, 3000 A)	n.a.

For DC charging, the standard IEC-62196-3 [72] applies. Connectors according to this standard are marked in the following configurations: AA, BB, EE, and FF. The AA configuration applies to CHadeMO connectors. They are mainly used in South Korea, Japan, the United States, and Europe. The maximum charging power using these connectors is 150 kW. The BB configuration is mainly used in China, according to GB/T 20234.3. The maximum charging power of solutions available on the market in this configuration is up to 125 kW (see Table 4). The EE configuration is used in Combined Charging Standard (CCS 1) connectors. The FF configuration is used in Combined Charging Standard (CCS 2) connectors. It combines a CCS connector and a type 2 connector and is currently widely used throughout Europe.

According to the assumptions of the AFIR regulation [20,21], in the European Union, including Poland, each public and available charging station should enable charging (see Table 4):

- ✓ In AC 50 kW mode using the IEC 62196-2 Mennekes (Type 2) connector;
- ✓ In DC CCS mode (Combo 2) up to 350 kW and optionally CHAdeMO 2.0 with charging power up to 150 kW.

Currently, work is also underway on the ChaoJi DC GB/T 20234 and IEC 62196 standard [73,74], the implementation of which is planned for 2024 on Asian markets (China, Japan and South Korea), with a charging power range of up to 500 kW [75]. In the European Union, the implementation of the Megawatt Charging System (MCS) for Scania trucks [76,77] with a charging power of up to 3.75 MW [75] is planned in 2024. Due to the construction of electric Heavy-Duty Vehicles (eHDV) with a battery voltage of 800 V appearing on the electric truck market, Directive 2014/94/EU [20,21] of the European Parliament and the Council introduced on 20 March, 2021 a new marking of charging ports and sockets following the EN 17186 standard. The shapes of the sockets and plugs remained unchanged.

3. The Current State of Development of Operational Infrastructure for Electric Vehicles in Poland

Currently, one of the biggest challenges in Europe and in Poland is the development of publicly available, fast and ultra-fast charging stations for electric vehicles. In the case of Poland, in the fourth quarter of 2022, based on data from the European Alternative Fuels Observatory [81], over 70% of the market were AC charging points (2313 pcs.). As shown in Figure 10, nearly 30% were public DC charging points (982 pcs.). The structure of available power is insufficient because the vast majority, almost 92% of AC charging points, have a capacity between 7.36 kW and 22.06 kW (2099 pcs. of medium-speed AC 3-phase recharging points) and below 7.4 kW (27 pcs. of slow AC 1-phase recharging points). Slightly more than 8% were fast AC recharging points above 22 kW in the AC recharging points group, see Figure 11a. Typical connectors used for public AC charging points in Poland are Mennekes (Type 2) connectors (see Table 4) and power level 2 according to the SAE standard (see Table 2).

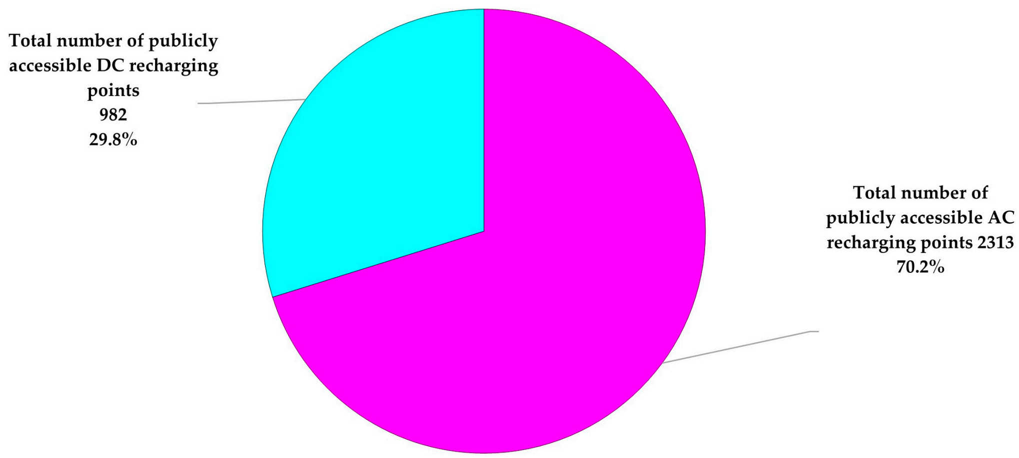


Figure 10. Structure of public charging points in Poland at the end of 2022 based on AFIR power categorization [81].

In the case of DC charging, fast DC charging points account for the largest share of the market (718 pcs., constituting nearly 73.2% of all DC charging points in the power range from 49.95 kW to 150 kW). Slow DC charging points account for 13.5% (133 charging points with a power below 49.95 kW). Level 1—ultra–Fast DC points account for 11.6% of the market (114 pcs with power ranging from 150 to 349 kW). The lowest share, 1.7% on the market, are Level 2—ultra Fast DC points (17 pcs. with power above 349 kW); Ionity launched 16 charging points at Shell facilities. All publicly available DC charging points use the CCS 2 connector and the CHAdeMO 2.0 connector optionally. The presented structure of charging stations in Poland is far from sufficient in the context of the development of electromobility and the assumptions of AFIR [18–20], which are discussed in Section 4.

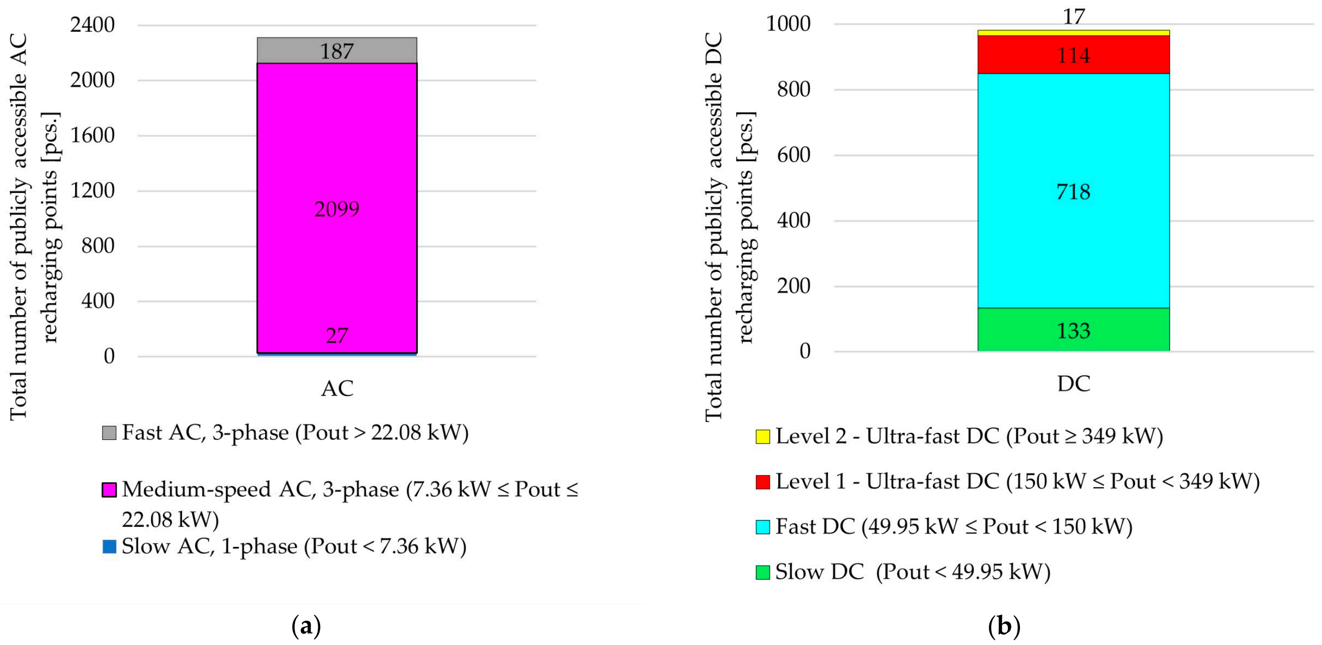


Figure 11. List of power of charging points in Poland: (**a**) AC, (**b**) DC at the end of 2022 based on power categorization according to AFIR [81].

The operator of a public charging station in Poland is responsible for properly functioning a generally available public charging station [23]. The operator of a publicly available charging station is responsible for the construction, management, operational safety, operation, maintenance, and repairs of a publicly available charging station, which is schematically presented in Figure 12. The operator of a publicly available charging station shall ensure that at least one charging service provider operates in the publicly available charging station. In addition, the operator of a generally accessible station is responsible for [30]:

- ✓ Equipping the station with a metering system, enabling the measurement of electricity consumption and transferring measurement data from this system to the station management system.
- ✓ Equipping the station with software that allows it to connect and charge an electric vehicle.
- ✓ Compliance with technical requirements by charging stations.
- ✓ Providing data to the Register of Alternative Fuels Infrastructure on the availability of a charging point and the price for the charging service (on the website [82]).
- ✓ Conclusion of a distribution agreement with the Distribution System Operator (DSO) for the needs of the operation of the charging station and the provision of charging services.

In Poland, the President of the Energy Regulatory Office [83] appointed energy companies that sell electricity to the largest number of end users connected to the distribution network in the commune where they are to act as the operators. The following companies have been appointed to perform the function of the public charging station operator: Energa Obrót S.A., Enea S.A., Tauron Sprzedaż Sp. z.o.o., and PGE Obrot S.A. On the other hand, the following companies have been appointed to perform the services of the charging service provider: Energa-Operator S.A., Tauron Dystrybucja S.A., PGE Dystrybucja S.A., Innogy Stoen Operator Sp. z o.o., and Enea Operator Sp. z o.o., among others. Despite the appointment by the President of the Energy Regulatory Office of the largest energy companies to act as operators of publicly available charging stations, companies specialising in providing software have achieved the largest market share, e.g., GreenWay (approximately ~20% share in the market of charging stations in Poland).

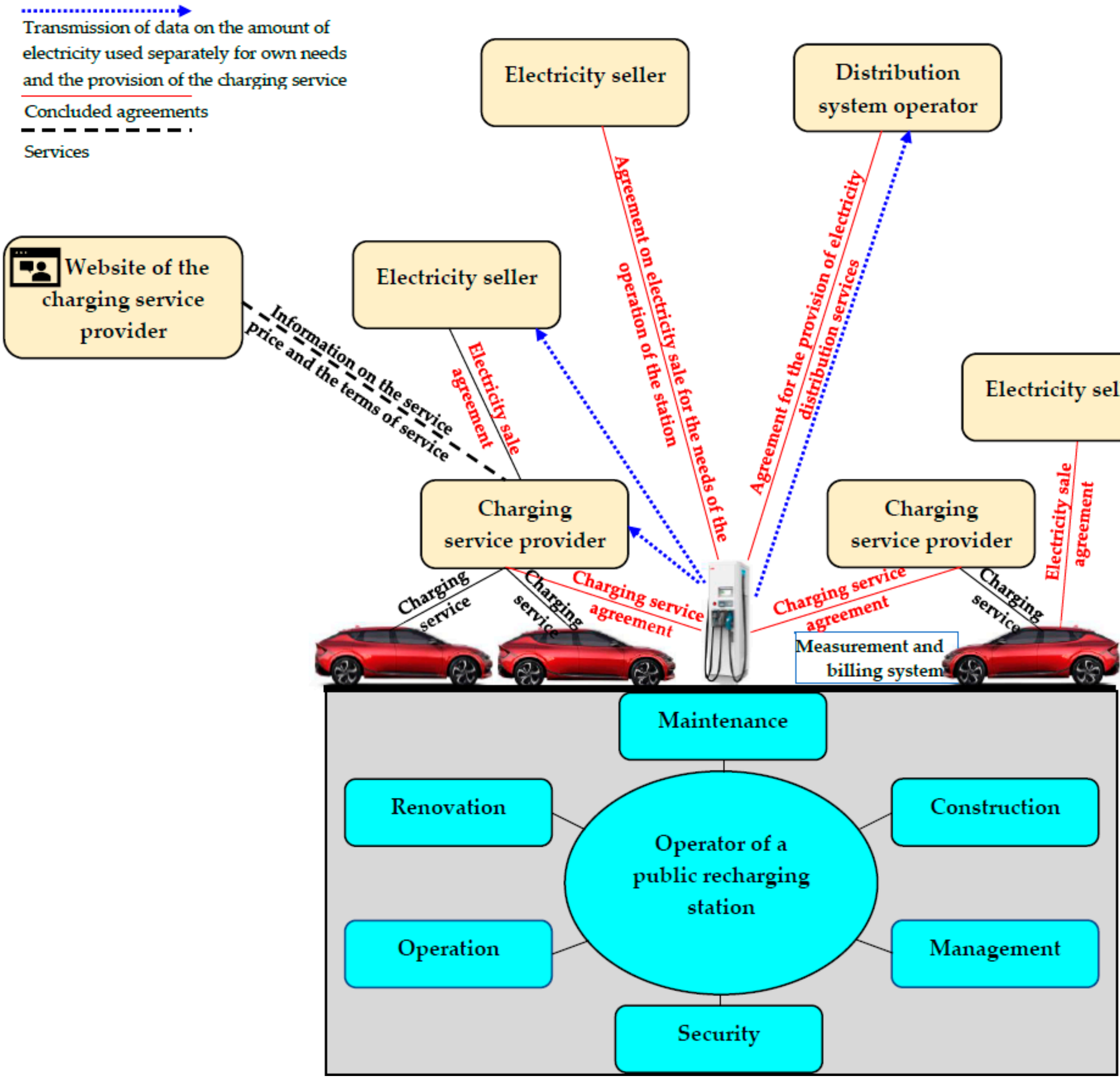


Figure 12. Scheme of connections between entities in the electric vehicle market in Poland [30].

The charging service provider ensures a charging service that includes charging and securing the possibility of using the infrastructure of the charging station, concludes an energy sales contract with the electricity supplier, and provides information on the price of the charging service and the conditions for its provision on its website (see Figure 12). It is worth mentioning that the operator of a public charging station may perform the tasks of the charging service provider.

The most popular locations, according to the data contained in [84,85], for publicly available charging stations are: public parking areas (41%), shopping centres (17%), hotels (16%), petrol stations (11%), and car showrooms (5%).

In Poland, the 14 largest operators of public charging stations include GreenWay Polska, PKN Orlen, Tauron, Revnet, EV+, PGE, Innogy, Elocity, GO+, Zepta, Ekoenergetyka, Enea, and Ionity. The largest market share, accounting for over 40% of the market according to the 4th quarter of 2022, among generally available charging points, belongs to the leading operators, which are: GreenWay Polska (1099 charging points at 497 charging stations [86]) and PKN Orlen (over 1000 charging points at 480 charging stations) [87].

Table 5 summarises typical, generally available PKN Orlen and Greenway charging stations. Currently (according to the price lists for the first quarter of 2023 PKN Orlen [86] and Greenway [87]). The average cost of AC charging with 43 kW power for 155 Wh/km energy consumption for the reference vehicle (Tesla model 3—see Table 6) is approximately PLN 30/100 km.

For fast DC charging up to 100 kW, the charging cost is about PLN 45/100 km—charging time up to several minutes. Above 100 kW, the charging cost increases to PLN 50/100 km with a charging time of up to 10 min (see Table 5). Since the third quarter of 2022, the costs of charging electric vehicles in public charging points in Poland have increased by over 40% [86,87].

Table 5. Technical specification of recharging stations in Poland [86–92].

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.)	100 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 VAC 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%
Size DxWxH [m]	0.78 × 0.78 × 1.9	0.98 × 0.75 × 2		0.3 × 0.58 × 0.77	0.44 × 1.62 × 0.89

Table 5. *Cont.*

Operator	PKN Orlen			Greenway	
Producer	**ABB Terra CE 54 CJG**	**Ekoenergetyka AXON EASY**	**Efacec QC45**	**ABB Terra Wallbox**	**Delta Slim 100**
Weight	325 kg	450–550 kg	600 kg	60 kg	230 kg
Communication Interface	4G, Ethernet	4G, 5G, Ethernet	3G (GSM/CDMA), LAN, Wi-Fi	GSM/4G modem, Ethernet	Ethernet, Cellurlar 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 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	
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)	

Currently, interest in electric vehicles in Poland is growing. In 2022, according to data from the European Alternative Fuels Observatory [81], customers mostly bought brands from the premium segment (see Figure 13), with the largest share in sales being held by Ford Mustang (650 pcs.) and Tesla model 3 (586 pcs.).

In addition, in the case of the Tesla Model 3, the manufacturer declares a range of up to 600 km in the average WLTP cycle. The average energy consumption of electric vehicles ranged from 138 Wh/km (Fiat 500E) to 212 Wh/km (Ford Mustang). The shortest charging time from SoC = 0.2 to SoC = 0.8 is for KIA EV 6 (charging power up to 350 kW) and Tesla model 3 and model Y (charging power up to 250 kW).

In Poland, new zero-emission vehicles of categories M1, N1 and L1e-L7e can receive funding for natural persons not exceeding PLN 18,750, or PLN 27,000 for a person with a large family card. The purchase cost (vehicle price) of a zero-emission vehicle may not exceed PLN 225,000 (this does not apply to someone with a large family card). Subsidies may also be used by, among others, public finance sector units, research institutes, entrepreneurs, associations, foundations, cooperatives, individual farmers, religious organizations and churches, and others [93]. Support can be obtained under the "My Electrician" program, run by the National Fund for Environmental Protection and Water Management from 12 July 2021, to 30 September 2025.

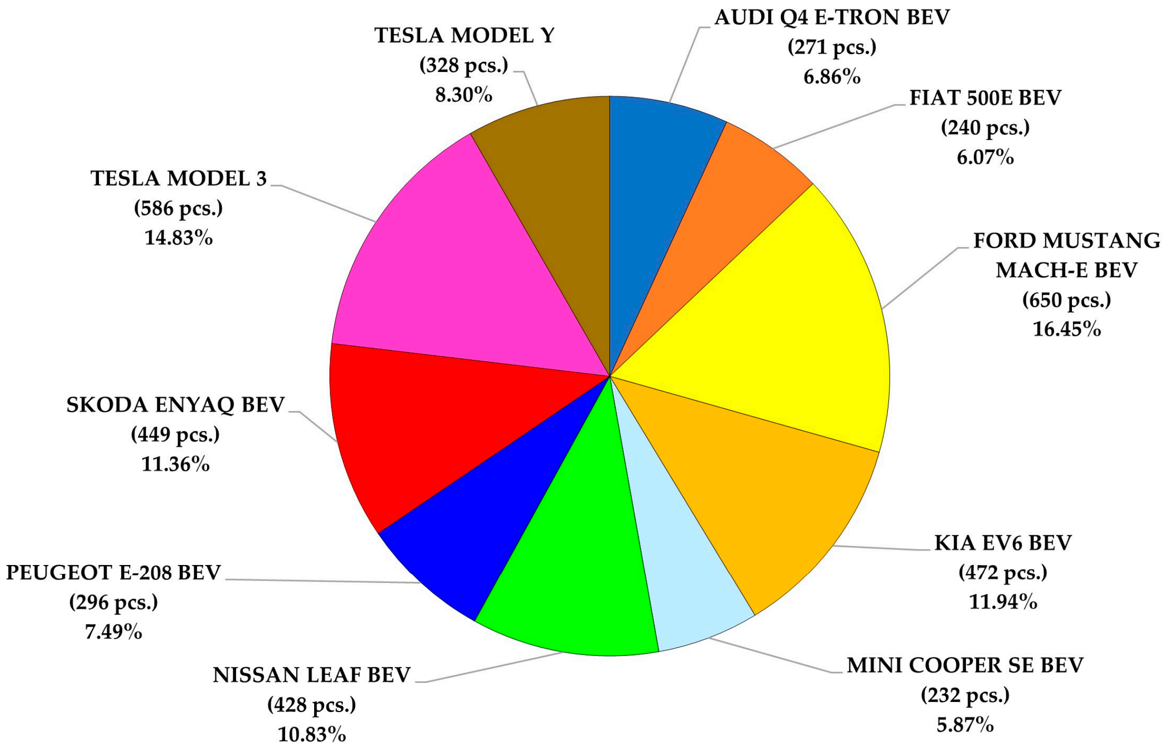


Figure 13. Top 10 best-sold BEV passenger cars in 2022—Poland [81].

Table 6. Summary of the main parameters of TOP 10 electric vehicles sold in Poland in 2022 (exchange rate EUR/PLN = 4.50 from 23 May 2023) [94–103].

No.	Appearance	EV Model	Car Type	Price [Thousands of EUR]	Drive Range $WLTP_m$ [km]	Energy Consumption $WLTP_m$ [Wh/km]	Battery Capacity [kWh]	Battery Usage [kWh]	Duration for a Full Charge (From SOC = 0.2 to SOC = 0.8)	
									AC Level 2 Charging	DC
1		AUDI Q4 e-tron 40	SUV	55.21	520	169	82	76.6	4 h 30 min for 11 kW	~23 min for 135 kW (CCS)
2		FIAT 500E RED FWD	Hatchback	35.67	326	138	42	37.3	2 h 33 min for 11 kW	~26 min for 85 kW (CCS)
3		FORD MUSTANG MACH-E GT	SUV	96.41	490	212	98	91	9 h 27 min for 11 kW	~40 min for 107 kW (CCS)
4		KIA EV6 AWD	SUV	58.87	~506	180	77.4	74	6 h 36 min for 11 kW	~16 min for 350 kW (CCS)
5		MINI COOPER SE	Hatchback	36.64	226–233	152–158	32.6	28.9	2 h 2 min for 11 kW	27 min for 50 kW (CCS)
6		NISSAN LEAF N-Connecta	Hatchback	42.87	385	185	62	59	6 h 27 min for 6.6 kW	59 min for 46 kW (CHAdeMO)
7		PEUGEOT E-208 GT+	Hatchback	40.36	362	159	50	45	3 h 2 min for 11 kW	~24 min for 100 kW (CCS)
8		SKODA ENYAQ 80	SUV	53.91	544	157.7	82	77	4 h 57 min for 11 kW	~29 min for 135 kW (CCS)
9		TESLA MODEL 3 LONG RANGE Dual Motor	Sedan	58.44	547	155	78.1	75	4 h 57 min for 11 kW	~23 min for 250 kW (Supercharging/CCS)
10		TESLA MODEL Y Long Range Dual Motor AWD	SUV	59.22	533	172	78.1	75	4 h 57 min for 11 kW	23 min for 250 kW (Supercharging/CCS)

4. Prospective Development of EV and Charging Infrastructure in Poland

This section presents the prospective development of charging infrastructure for electric vehicles in Poland. Section 4.1 discusses trends in the development of electric vehicles and infrastructure in 2025 and 2030. Barriers to developing electric vehicle charging infrastructure in Poland and possible solutions are discussed in Section 4.2. Section 4.3 presents the potential for developing electric vehicle charging infrastructure in housing cooperatives/communities and detached houses. The prospects for using private chargers in RES micro-installations with energy storage are discussed in Section 4.4. Section 4.5 compares the incentives in Poland and Norway to achieve 100% zero-emission vehicle sales.

4.1. Trends in the Development of Electric Vehicles and Charging Infrastructure in the Perspective of 2025 and 2030

The European Alternative Fuels Observatory [81] and the Polish Alternative Fuels Association [19] forecast that by 2025 there will be over 500,000 electric vehicles on Polish roads, of which BEVs will account for over 290,000, while PHEVs will account for over 220,000 (see Figure 14). With more electric vehicles on the road, the number of charging points (both fast AC and DC) is expected to increase to nearly 42,000 by 2025 (see Figure 15a). This will result in nearly 10 BEVs and 7 PHEVs per public charging point (see Figure 15b).

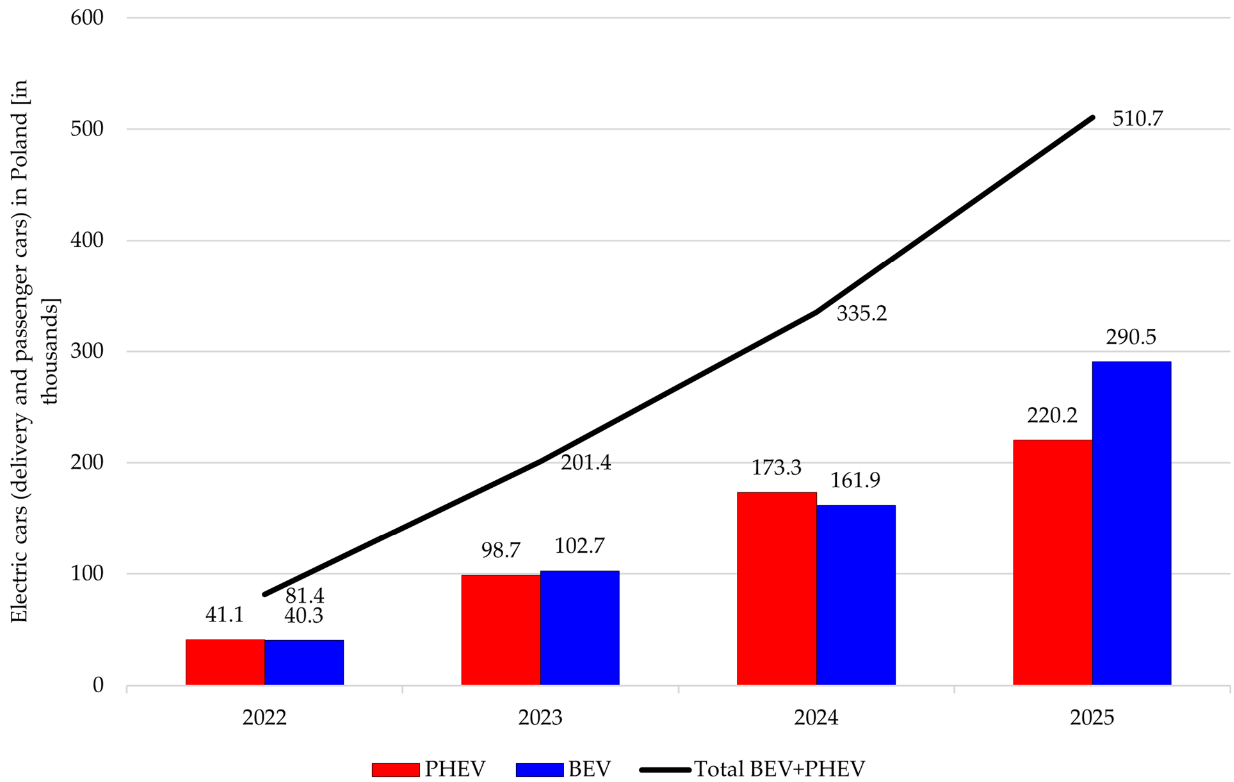
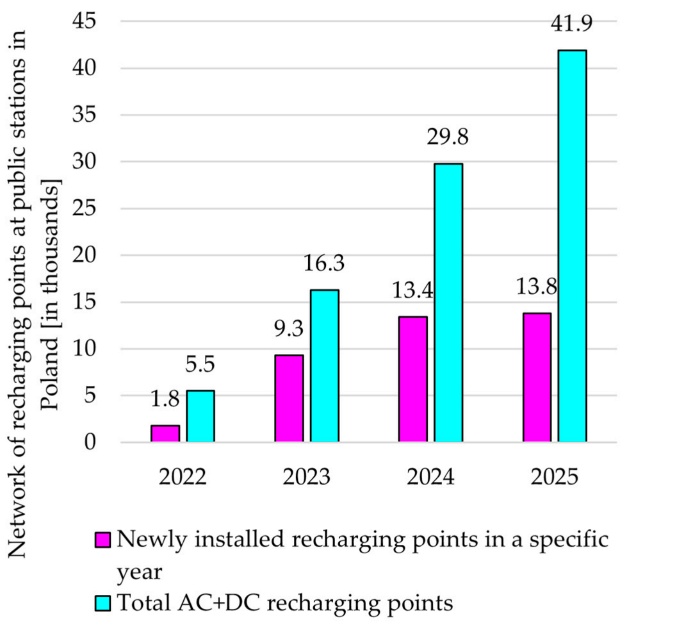
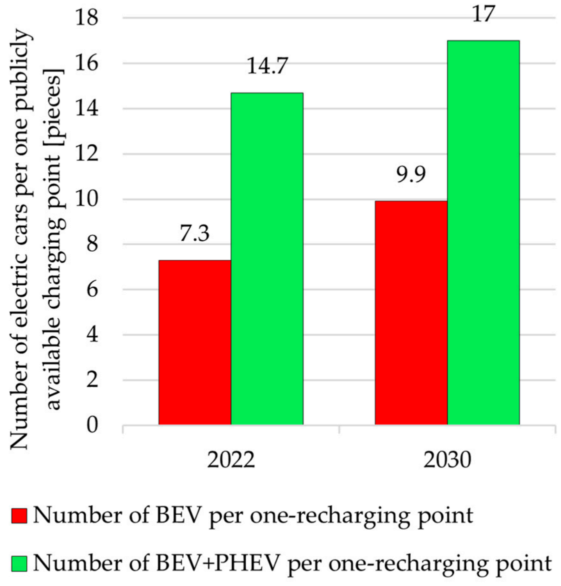


Figure 14. Forecast of the development of the electric vehicle fleet in Poland by 2025, divided into PHEV and BEV [19,81].



(a)



(b)

Figure 15. Diagram of: (**a**) newly installed recharging points in a specific year, (**b**) the number of electric cars per one publicly available charging point [19].

In the case of FCEV vehicles, the dynamics of the development of a hydrogen refuelling infrastructure in Poland is much lower than in the case of electric vehicles. At the end of 2022, according to [81], 115 hydrogen-powered vehicles were registered in Poland. No stationary hydrogen refuelling station is operating in Poland, while several hydrogen refuelling stations are under construction [104]. The main limitations in developing a hydrogen refuelling infrastructure are the high costs of hydrogen production [12,13]. According to analyses conducted by the United States Department of Energy (DOE) [105], in the case of large-scale hydrogen production, counted in tens of tons per day, the cost goal is to achieve a value below USD 2/kg by 2026 in the case of central hydrogen generation installations, and below USD 1.5/kg by 2030 [106]. High operating costs translate directly into interest in FCEV vehicles by drivers. In the case of the Toyota Mirai [107], with an average hydrogen consumption of 0.9 kg/100 km and the cost of hydrogen at the station in Q4 2022 amounting to USD 24.99/kg in Poland [108], it should be stated that the operating costs of FCEV are more than twice as high as at public recharging stations for electric vehicles (see Table 5).

According to AFIR assumptions, a hydrogen refuelling infrastructure that can serve both cars and trucks must be deployed from 2030 in all urban nodes and every 200 km along the TEN-T core network [109], ensuring a dense enough network to allow hydrogen-powered vehicles to circulate across the EU. In the case of Poland, the construction of several dozen hydrogen stations for the normal operating pressure of 70 MPa [107] is expected by 2030.

According to the assumptions of AFIR [18,19], for such a number of electric vehicles on the market in 2025, the installed capacity is supposed to increase from 77 MW (as of the first quarter of 2022) to 435.8 MW in 2025 to reach nearly 1.4 GW of installed power at charging points (an over 18-fold increase compared to 2022).

In addition, AFIR assumes the introduction of electric vehicles on the European Union market, including the Polish market, following [18,19]:

- ✓ The obligation to introduce the smart charging function [64,110–114] (the concept of smart charging is discussed in detail in Section 4.3) to all operators of public charging stations;
- ✓ Automatic authentication with all operators of public charging infrastructure.

- ✓ Supplying DC charging stations with a power of more than 50 kW with payment terminals;
- ✓ Ad-hoc payment with all operators of public charging stations;
- ✓ Introduction of a mechanism for comparing prices and transparency of charging services and presenting/displaying information at publicly available charging stations on charging costs in the format "price per 100 km";
- ✓ The obligation to appropriately mark public charging infrastructure in the Trans-European Transport Network (TEN-T);
- ✓ Expansion of the public charging infrastructure in the TEN-T network [115], so that DC charging points are spaced every 60 km;
- ✓ Increasing the power installed in public charging stations within the TEN-T network from the current level of 19.7 MW to 217.6 MW in 2025 and 665.3 MW in 2030 for electric Light-Duty Vehicles (eLDV) and electric Heavy-Duty Vehicles (eHDV), respectively;
- ✓ Correlating the development of charging infrastructure, charging power at publicly available charging points, and the development of electric vehicles (1 kW was assumed for each newly registered BEV and 0.66 kW for each newly registered PHEV).

This is a major challenge for operators of public charging stations. As shown in [19], currently in Poland, several barriers cause delays in developing the charging infrastructure for electric vehicles. Particular obstacles to development and ways of solving them are presented in Section 4.2.

4.2. Barriers to the Development of Charging Infrastructure for Electric Vehicles in Poland and Selected Solutions

Despite the development of charging infrastructures in Poland, there are still barriers, including lengthy and time-consuming procedures for connecting charging stations to the low-voltage power grid by distribution system operators (DSOs). The most important obstacles, according to [19], taking into account the challenges related to AFIR, include:

- ✓ The waiting time for DSO to build a connection, ranging from 1 to 3 years (on average 1.5 years), see Figure 16.
- ✓ Unfavourable connection conditions for publicly available charging stations include the indicated location of connection points. Indication of connection points to the power grid at a considerable distance from the target location of a publicly available charging station. The consequence of the change of location is increased investment outlays, several times exceeding the outlays for purchasing and installing charging stations.
- ✓ Charging the construction costs of transformer stations and participation in the prices of long connections by operators of publicly available charging stations in a situation where DSOs issue conditions for connecting to the medium voltage power grid. As a result, investments in publicly available charging stations are unprofitable due to the increase in investment outlays.
- ✓ Lack of adaptation of the power grid and energy infrastructure on expressways and highways. The key problem is the failure to ensure the appropriate value of the connection power to expand the already existing and generally available charging infrastructure, e.g., at petrol stations, and passenger service points. In addition, in this context, there is affiliation with the General Directorate for National Roads and Motorways [116] and ownership of infrastructure in passenger service points, limiting the possibility of effective power-grid expansion adapted to the needs of connecting publicly available charging stations.

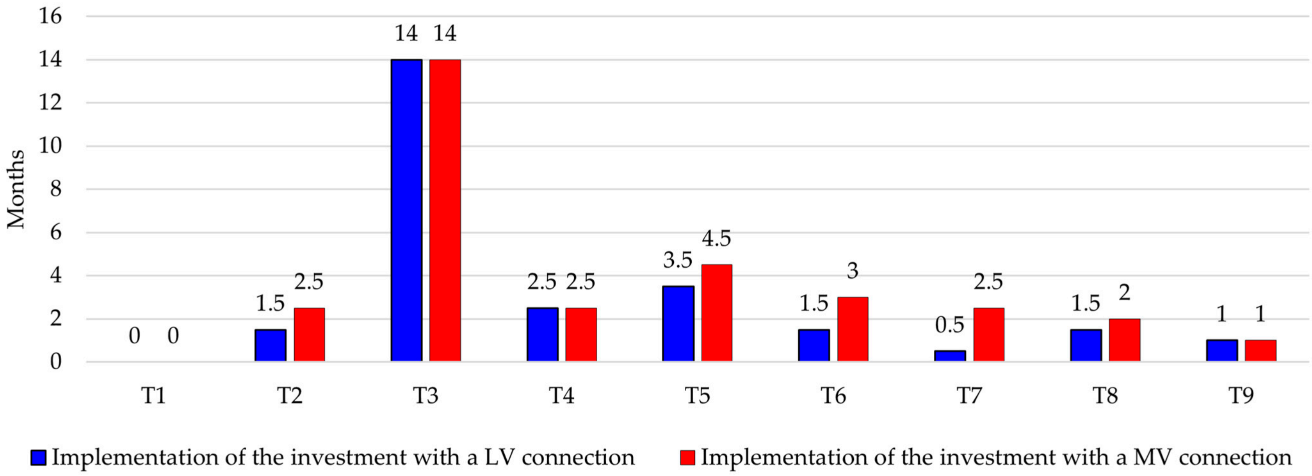


Figure 16. List of components (from T1 to T9) of the lengthiness of the process of building publicly available charging stations for electric cars in Poland, broken down by the implementation of investments with a low and medium voltage connection. Where: T_1—Conclusion of a lease/rental agreement (0—x means immediately); T_2—Submission of an application for the issuance of connection conditions to the DSO and waiting for the conditions to be issued; T_3—Implementation of the agreement on connection to the power grid; T_4—Order and delivery of maps for design purposes; T_5—Preparation of the design of the charging station along with the arrangements industry, including traffic organization arrangements; T_6—Notification of the construction of a charging station (including 21 days of waiting for no objections); T_7—Building a charging station; T_8—Contracting the supply and distribution of electricity and launching a charging station; T_9—Acceptances of the Office of Technical Inspection [19].

Table 7 summarises the main barriers related to developing publicly available charging stations for electric vehicles in Poland and the ways to solve them.

Table 7. List of ways to eliminate barriers related to the development of public charging stations for electric vehicles in Poland [18,19].

Barrier	Elimination Method
Several months of waiting for the construction of the connection by the DSO.	Establishment of legal provisions regarding the possibility of building connections by operators of publicly available charging stations on the terms of the issued connection conditions with the obligation to later repurchase the infrastructure by DSO operators.
There are no binding deadlines for connecting the charging station to the power grid.	1. Making the connection agreements more detailed and specific by indicating the maximum and non-extendable deadline (e.g., 6 or 12 months) along with specifying contractual penalties for failure to meet it 2. In case of exceeding the connection deadline, introducing the possibility of substitute performance at the DSO's cost and risk.
The unprofitability of the investment, additional costs of PLN 200–500 thousand [19], construction of power infrastructure (transformer stations, power lines) due to the DSO issuing conditions for connecting to the low-voltage power grid—specifying the connection power not exceeding 150 kW.	Introduction of legal provisions enabling the selection of the voltage level at which electricity will be supplied by the entity applying for connection to a publicly available charging station.

Table 7. *Cont.*

Barrier	Elimination Method
No requirement to provide information to the operators of publicly available charging stations from the DSO on the possibility of connecting the station in a given location. The result of such an action is the difficulty in determining the decision on the profitability of a given investment.	Introduction of legal provisions imposing a statutory obligation on DSOs to provide information on possible connections to the charging infrastructure, at the request of an entity interested in a given investment, with the obligation to respond within 1–2 months. Information is provided for a fee, and in the event of costs incurred by the DSO, reimbursement of these costs by the applicant.
Lack of ordering the ownership structure of the power infrastructure at the Service Station (SS). The effects of this state of affairs are: the necessity for operators to build charging stations of their own infrastructure, while the owner of the infrastructure—already existing at the SS—is the General Directorate for National Roads and Motorways and the inability to apply the e-tariff when connecting charging stations.	Legal regulation on enabling SS entities (i.e., operators of public charging stations) to transfer to the DSO the elements of the network and infrastructure owned by them (including transformer stations, regardless of the date when they were built).
There is no need to develop plans to expand the power infrastructure in Service Areas (motorways). As a result, the connection power values are not adjusted to the needs related to the development of fast charging stations.	A legal regulation requiring the creation of periodic plans for the construction and expansion of a SS, taking into account the location within the SS area for the charging infrastructure, while maintaining the connection power reserve.
Different fees for connecting the charging station to the medium and low voltage grids applied by DSOs.	Legal regulation concerning standardization of connection fees.

4.3. Potential for the Development of Charging Infrastructure for Electric Vehicles in Housing Cooperatives/Communities and Detached Houses

Currently in Poland, there is great potential for the development of charging infrastructure, especially in the areas of housing cooperatives, municipal buildings, and newly constructed buildings, as pointed out in [31]. For newly constructed buildings and buildings undergoing renovation, regulations regarding the development of charging infrastructure have been introduced by Directive 2018/44 [117], which was implemented into Polish law in the Act on Alternative Fuels [23,24].

In the case of newly constructed residential buildings with more than ten parking spaces, ducts for electrical wires and cables should be included in the electrical installation design so that it is possible to install charging points at all parking spaces, depending on whether the spaces are indoors or outdoors.

For new non-residential buildings with more than 10 parking spaces, at least one charging point and conduits for electrical wires and cables should be provided in the project plan to allow charging for 20% of the parking spaces (1 in 5 parking spaces), depending on whether the stands are inside or outside the building. This requirement does not apply if the owners are Small or Medium Enterprises (SMEs).

For existing non-residential buildings with more than 20 parking spaces, the owner or manager shall install at least one charging point with electrical ducts, wires, and cables so that the installation of charging points covers at least 20% of the parking spaces, depending on whether parking spaces are located inside or outside the building to which they are adjacent. The owner or manager should perform the installation by 1 January 2025.

In the case of existing residential buildings, Poland has no requirements to build a new charging infrastructure for electric vehicles. The exception is when a residential building is subject to reconstruction, in which the cost of works related to the external partitions or technical systems of the building is more than 25% of the value of the building, excluding the value of the land, and the renovation meets the conditions and requirements for new buildings, and when the costs of installing charging points and duct infrastructure do not exceed 7% of the total cost of reconstruction.

In cases where the parking spaces are located inside the building and the reconstruction or renovation includes the car park or the electrical infrastructure of the building, or they are adjacent to the building, or the reconstruction or renovation includes the car park or the electrical infrastructure of the car park, the Act does not specify the minimum number of charging points [23] and is not applicable when it concerns SME entities.

If the building is a monument, entered in the register of monuments or the municipal register of monuments, the installation of a charging point and ducts for electric wires and cables requires the consent of the provincial conservator of monuments in charge of the location of this monument, granted by way of a decision [23].

The infrastructure that can be installed in multi-family residential buildings and garages of these buildings includes:

- ✓ Private chargers that belong to individual residents who use them only for their own needs to charge an electric vehicle.
- ✓ Semi-private chargers that are owned by the building owner and used to charge electric vehicles owned by residents.
- ✓ Public chargers owned by the building owner or the operator of a public charging station (external operator), used to charge electric vehicles belonging to the residents of a given community/housing cooperative and bystanders, not residents of a given community/housing cooperative.

The chargers discussed above may be construction devices permanently attached to the building, the so-called wallbox, or a free-standing construction device, the so-called post. In Poland, private chargers are usually wallboxes (AC charging power ranging from 7.4 kW (single-phase) to 22 kW (three-phase) [118–120]), while semi-private and public chargers are most common posts (three-phase AC charging power up to 22 kW [121]).

In the case of a private charger, the charger user covers the costs associated with its installation and commissioning. In the case of semi-private chargers, their owner and investor will be a housing community or cooperative, or the owner of a building, e.g., a municipal one. Consequently, the costs of commissioning installation and obligations will be charged to the investor. It is worth emphasising that private chargers, regardless of their power, do not require testing by the Office of Technical Inspection before they are put into operation. This test must be carried out for semi-private or public chargers before being put into service.

Currently, charging using a private charger is the most popular in Poland. In the case of a housing association or housing cooperative, to install a private charger, it is necessary to determine a specific power allocation based on the building's electrical installation design and, consequently, the target power of the charger. After positive verification of the connection conditions and exclusion of the conditions for entry in the register of monuments, an application should be submitted to the community board for consent to the installation of the charger along with all the required documents, described in detail in [31]. The administrator commissions an expert opinion, which is aimed at assessing the electrical installation and the parking spaces inside the building or adjacent to it in terms of the admissibility of connecting the charger covered by the application to this installation. The administrator considers the submitted application within 30 days of receiving the expert's opinion. Then, in the case of communities larger than three premises, a simple consent of the management board of the community in the form of a resolution [31,122] is sufficient to obtain a positive consideration of the application for the installation of a charger with a power of less than 11 kW.

When increasing the power of the charger above 11 kW, the consent of 50% of the owners is required [122]. Then, after obtaining permission to install the charger and the private charger, the user can start operation (following the requirements of the operating instructions). In particular, they can perform periodic service and maintenance inspections. Other variants of installing semi-private and public chargers in small communities of up to three apartments are discussed in detail in [31].

In the case of detached buildings, the procedure for installing a private charger is simplified. It includes checking the electrical installation, connection power, and building status, and whether it is under the supervision of a monument conservator (applies to historic detached houses). If the connection capacity is insufficient, the owner applies to the DSO to increase the connection capacity. The next step is to install the private charger and start operation following the requirements of the operating manual.

Currently in Poland, due to significant increases in electricity prices for end users in households [123,124], comprehensive solutions involving hybrid micro-installations of Renewable Energy Sources (RES) [125] with stationary energy storage and a private electric vehicle charger are being implemented. Section 4.4 presents the prospective development of private chargers as elements of RES micro-installations.

4.4. Prospective Use of Private Chargers in RES Micro-Installations with Energy Storage

Currently in Poland, private home chargers are often an integral part of prosumer RES installations. RES include [125] renewable and non-fossil energy sources, using, among others, wind energy, solar energy, aerothermal energy, geothermal energy, hydrothermal energy, hydro-energy, wave, current and tidal energy, energy obtained from biomass, biogas, agricultural biogas, and bioliquids.

According to [125], a prosumer of renewable energy denotes an end user who generates electricity exclusively from renewable energy sources for their own needs in a micro-installation.

A micro-installation is a RES installation with a total installed electrical capacity of a maximum of 50 kW, which is connected to a power grid with a rated voltage below 110 kV or with a combined thermal output of a maximum of 150 kW, in which the total installed electrical power is a maximum of 50 kW.

A hybrid RES installation is a separate set of devices described by means of technical and commercial data, connected to the same distribution or transmission network with a rated voltage not higher than 110 kV, in which electricity is generated only from renewable energy sources, differing in the type and availability characteristics of the electricity produced (e.g., photovoltaic cells and wind or fuel cell generators [125]).

Both the RES micro-installation and the Hybrid RES installation may contain electricity storage, usually a battery module made of single cells with specific parameters of electric capacity and voltage at the terminals [38], enabling electricity storage. The intermittent and unstable nature of renewable energy sources (RES) poses significant challenges to maintaining a stable power system, leading to temporal and spatial differences between energy consumption and availability. Therefore, employing energy storage technology offers an effective solution for achieving stable and efficient utilization of RES [126].

Electricity generated from RES is fed into the low-voltage power grid, which the obligated seller (the energy trading company) must purchase. The settlement takes place with the renewable energy settlement operator [127] based on the information provided by the distribution system operator (DSO). The DSO offers the obliged seller and the renewable energy billing operator, within 10 days after the end of the month, daily data on the amount of electricity generated in the RES installation, determined based on indications from metering and billing devices.

The total balanced amount of electricity introduced to and taken from the power distribution network by the renewable energy prosumer from 1 July 2022 is determined for a given hour using the vector method, according to the following formula:

$$E_{bi}(t) = E_{pr}(t) - E_s(t), \tag{1}$$

where: $E_{bi}(t)$ is the total energy balanced in an hour (t), expressed in kWh, to be settled in a given billing period. A positive value is the amount of electricity taken from the power distribution network in a given hour (t), and a negative value denotes the amount of electricity introduced in a given hour (t) to this power grid. $E_{pr}(t)$ is the sum of the amount of electricity taken from all phases in hour (t) from the low-voltage power grid, expressed in kWh. $E_s(t)$ is the sum of the amount of electricity from all phases introduced in hour (t) to the low-voltage power grid, expressed in kWh.

The obliged seller settles the amount of electricity introduced to and taken from the electricity distribution network with the renewable energy prosumer in the settlement period (e.g., monthly or annually) specified in the comprehensive agreement or the sales agreement based on the following relationship:

$$E_{as}(o) = E_{bip} + (E_{bsp} \cdot C_i) + E_e(o - 1), \quad (2)$$

where: $E_{as}(o)$ is the amount of energy billed as being introduced to or taken from the low-voltage power grid in a given settlement period "(o)", expressed in kWh, and E_{bip} is the sum of the total amount of energy balanced in all hours (t) of the billing period for which the result of the total balancing is positive, marked with the symbol $E_{bi}(t)$ in relation (1), expressed in kWh. E_{bsp} is the sum of the total amount of energy balanced from all hours (t) of the billing period for which the result of the total balancing is negative, marked with the symbol $E_{bi}(t)$ in relation (1), C_i is an appropriate quantitative ratio of 0.8 for micro-installations or small installations with a total installed electrical capacity of 10 kW, or equal to 0.7 for installations with a total installed capacity of more than 10 kW [125]. $E_e(o - 1)$ is the amount of electricity not used by the prosumer of renewable energy in previous billing periods, billed in the current billing period, for which the billing value is negative, expressed in kWh.

If the renewable energy prosumer generated electricity in RES and introduced it to the power distribution network in the period from 1 July 2022 to 30 June 2024, the value of electricity is determined for each calendar month and is the product of:

(a) The sum of the amount of electricity fed into the power grid by a renewable energy prosumer in individual imbalance settlement periods (t) making up a given calendar month, marked in relation (1) with the symbol $E_{bi}(t)$ with negative values.
(b) The monthly market price of electricity determined for a given calendar month.

It is worth adding that from 1 July 2024, the value of electricity is determined for each calendar month. It is the sum of the following products specified for individual imbalance settlement periods (t) in this month:

(c) The amount of electricity fed into the low-voltage power grid by the renewable energy prosumer, marked in relation (1) with the symbol $E_{bi}(t)$ with a negative value.
(d) The market price of electricity, provided that if the value of this price is negative for a given imbalance settlement period (t), then to determine the value of electricity introduced to the grid in period t by a renewable energy prosumer, the price is assumed to be zero.

The entitlement to settlement arises from the date of the first generation of electricity from a renewable energy source and its introduction into the low-voltage power grid and lasts for the next 15 years.

The market price of electricity (MEP), under Regulation (EU) 2019/943 of the European Parliament and of the Council [128], is calculated as the volume-weighted average of electricity prices specified for the Polish bidding area for all trading sessions on a given day in the single-price auction system on day-ahead markets, operated by Towarowa Giełda Energii (TGE) [129] or designated electricity market operators (e.g., Polskie Sieci Elektroenergetyczne—PSE [130,131]). The following relation expresses MEP:

$$MEP_M = \frac{\sum_{t \in T}(E_t \cdot MEP_t)}{\sum_{t \in T} E_t}, \quad (3)$$

where: E_t is the total volume of electricity fed into the power grid in the period of settlement of imbalance t by renewable energy prosumers generating electricity in micro-installations or small installations, connected to the grid of power distribution system operators, having direct connections to the transmission grid and having a concluded agreement for the provision of distribution services with at least 200,000 end customers, expressed in [MWh]. MEP_t is the market price of electricity in the imbalance settlement period "t", where if

MEP_t is negative for a given period "t", then MEP_t equals zero [PLN/MWh] for this period "t". T is the set of imbalance settlement periods in a month.

The procedure of balancing the energy cost generated from prosumer micro-installations described above is called net-billing [132,133]. Currently, balancing the energy accounts from prosumer micro-installations based on net-billing is carried out in many countries where there is a high penetration of RES in the power system, over a dozen or so per cent in the energy generation structure. These countries include, among others, [134–139] Italy, Germany, UK, France, Spain, Belgium, Greece, the United States (especially California, Arizona, Colorado, Hawaii, Kansas, Minnesota, Montana, Nebraska, Nevada, New Mexico, Oregon, Utah, and Washington [139]), Canada, Norway, the Netherlands, India, Ecuador, Philippines, Thailand, Vietnam, and Malaysia.

A private charger used to charge an electric vehicle can act as an additional passive or active element of the structure of a prosumer RES micro-installation [114,140,141]. Currently in Poland, there are mainly passive solutions in which the charger can charge an electric vehicle with energy from RES and/or the power grid, enabling a one-way flow of energy to the electric vehicle's battery pack, schematically presented in Figure 17a.

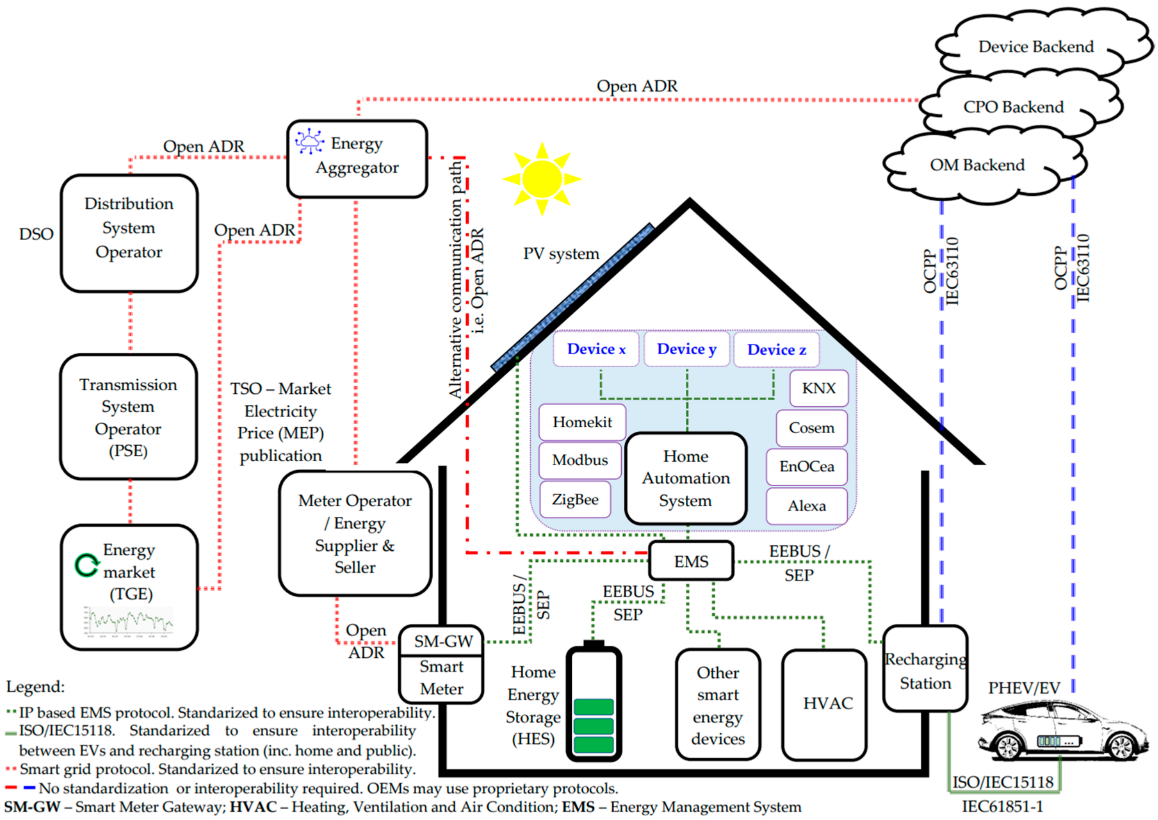
In such a prosumer solution, the Energy-Flow Management System (EMS) can: power a set of receivers that are part of the Home Automation System (HAS), Home Energy Storage (HES) by charging the energy storage; supply the Heating, Ventilation, Air Conditioning (HVAC) system with energy; introduce electricity to the grid through a bi-directional Smart Meter (SM) and an inverter, enabling synchronization of the parameters of the electricity introduced with the parameters of the power grid; and manage the flow of energy to a private charger that enables charging of an electric vehicle.

Usually, communication within the HAS takes place using ZigBee, Modbus, KNX, Alexa, Cosem, Homekit, or EnOCean [114]. The energy supply itself can be prioritized by the attributes and status of the receivers (critical, necessary, can be disconnected). Communication between the ESM and HES can be carried out using voltage lines, and Modbus or CANopen can be used when using a Battery Management System (BMS). The BMS system is necessary if the HES is loaded with pulses with high currents (above 3C). Depending on the HES charge level, the EMS system can determine the energy supply strategy for HVAC devices, the electric vehicle charging point, and a private charger based on information from the energy aggregator (EA) [142]. In Poland, aggregators inform users about the necessary reduction of energy consumption, which the Transmission System Operator introduced—TSO (in Poland—PSE). In addition, they can inform the user about the intervention offered to reduce power consumption (in Poland called IRP [143]), implementing the Smart Grids philosophy [144–158]. It is one of the Demand Side Response (DSR) services, i.e., demand-side management. It is a service thanks to which consumers receive remuneration in exchange for the voluntary and temporary reduction of their power consumption from the power grid. In Poland, IRP services are currently provided by [143]: Enel X Polska Sp. z o.o. (Warsaw, Poland), Enspirion Sp. z o.o. (Gdansk, Poland), Lerta JRM Sp. z o. o. (Poznan, Poland), and Tauron Sprzedaż Sp. z o. o. (Cracow, Poland). The IRP has been in force in Poland since 25 March 2022. The Reduction Facility (ORed) certification process must be carried out for a given facility to be subject to IRP. Distribution System Operators (DSOs) are responsible for this and issue Certificates for OReds, according to the connection point, i.e., where a given ORed is located. Obtaining an active Certificate for ORed is a prerequisite for providing the IRP service by an active electricity consumer (prosumer).

In the case of introducing electricity to the power grid, the amount of electricity introduced is calculated and settled following the procedure described in relations (1)–(3). It is worth noting that MEPh changes at different times. For example, on 9 February 2023, it changed from PLN 540/MWh to PLN 790/MWh, which is shown, for example, in Figure 17b. The average MEPm was PLN 667.59/MWh in February 2023, according to data provided by PSE [130].

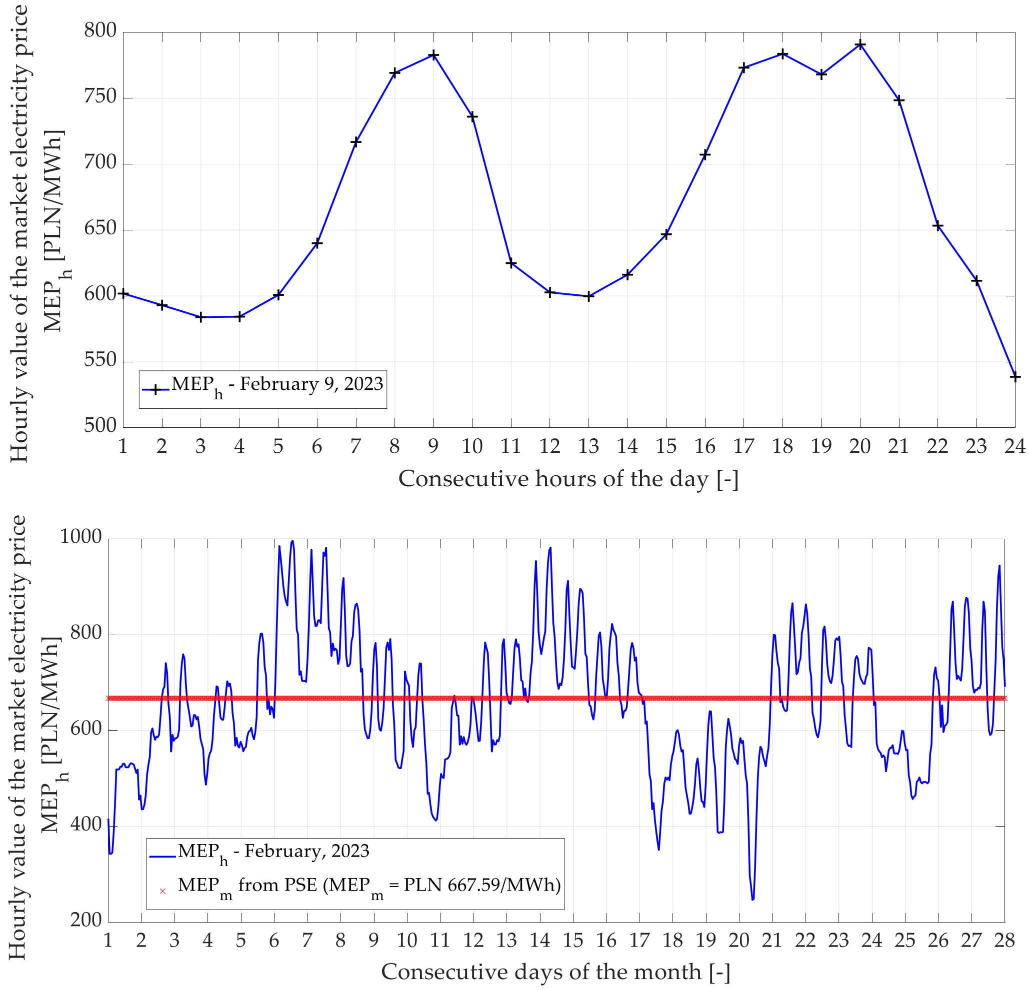
In the discussed case, the charger power can be controlled by costing the daily power demand profile and spreading the load evenly over off-peak hours. Such a solution in the literature is called Smart Charging, known as (V1G). An example of V1G charging characteristics is shown in Figure 17c. V1G allows you to control the charging process of electric cars in such a way as to increase or decrease the charging power, if necessary, depending on the time of day and the MEPh value. Currently, the V1G service can be used in Poland. It is necessary to conclude an appropriate agreement with the DSO. Then, the EA will inform the user about the hours when the demand should be reduced.

Currently, the following wall boxes available on the market enable the implementation of the V1G service: Smappee EV Wall [158], Mye-nergi Zappi V2 [159], Anderson A2 [160], EO Mini PRO 3 [161], ZJ Beny BCP Series [162], Fimer Flexa AC wallbox [163], Ocular IQ Wallbox [164], Enel-x JuiceBox 40 [165] and Tesla Wall Connector [166]. The prices of such chargers range from USD 600 to USD 3000 [158–166], while the charging power ranges from 1.4 kW to 7.4 kW (for single-phase AC installation) and from 7.4 kW to 22 kW for three-phase AC installation.

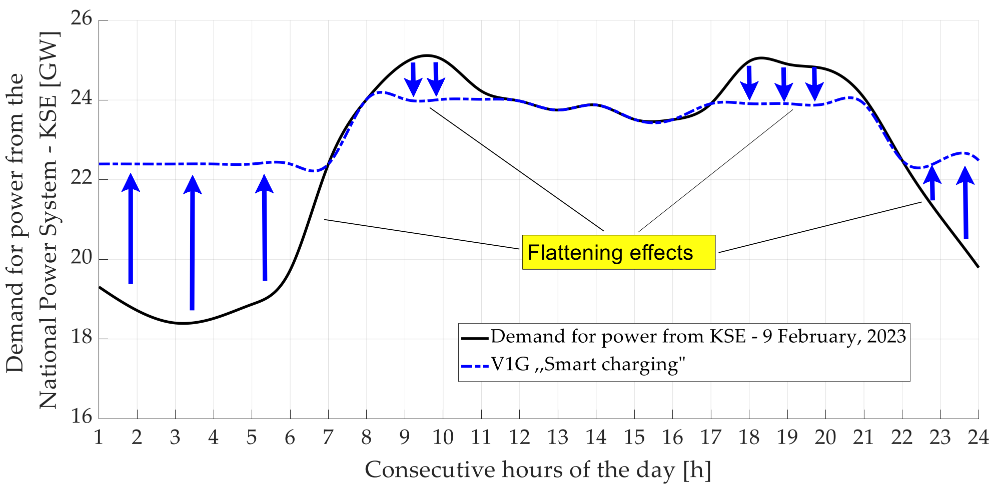


(**a**)

Figure 17. *Cont.*



(**b**)



(**c**)

Figure 17. (**a**) the architecture of a prosumer micro-installation using a net-billing system with energy storage and a private charger [114], (**b**) monthly and daily MEPs from the Polish Power Exchange (in Poland TGE), published by PSE [129,130], (**c**) typical power demand characteristics with a visible effect flattening (blue arrows) due to the implementation of the V1G concept [167–169].

If a bi-directional charger (bi-directional converter) is used, bi-directional energy flow is possible (private charger constituting a bi-directional AC/DC and DC/DC converter at that time, see Figure 18) and it is possible to enter with the use of a bi-directional meter, calculating the amount of electricity consumed and fed into the power grid. In practice, this is implemented through a two-way flow of information between the Energy Aggregator (EA) and the private charger and the data of the electric vehicle (OEM Backend, CPO Backend and Device Backend) [114]. Through communication using the Open Charge Point Protocol (OCPP), EA can obtain information about the status of the charging or energy storage process (e.g., the current SoC level of the package, the amount of energy stored in the cell package inside the vehicle, as well as the reading of specific parameters after confirmation of access via the Vehicle OEM Backend). The Vehicle OEM Backend provides a digital key that protects the vehicle from outside access. EA can affect the energy storage process by providing information to the user on a mobile device, indicating the current situation on the energy market (e.g., instantaneous MEP value). Communication between the user, EA, and the energy market occurs using Open Automated Demand Response (OpenADR), which can occur over high-voltage lines (Power Line Communication—PLC).

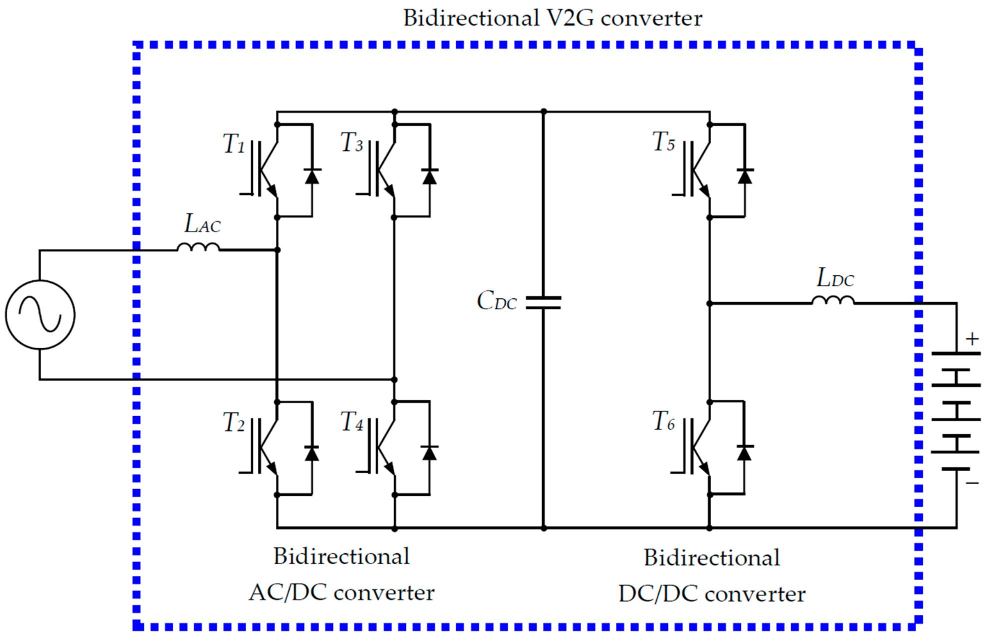


Figure 18. Bi-directional converter system enabling the implementation of the Vehicle to Grid (V2G) concept [144].

Currently in Poland, there are no such solutions in the implementation process using bi-directional chargers. Still, soon they will appear on the market due to the functionalities offered by manufacturers of electric vehicles and chargers. From 2024, ABB plans to introduce bi-directional wall boxes to the Polish market, implementing the V2G concept [157], one of the Vehicle to Everything (V2X) variants.

The term V2X [167] serves as an overarching term defining various cases of energy use through intelligent control of the charging and discharging process using the information on the state of the power grid, information on MEP, information on the amount of energy produced from RES, and the current user demand home workers.

The most common types of V2X are: Vehicle to Grid (V2G), Vehicle to Home (V2H), and Vehicle to Load (V2L). As mentioned, V2G enables power grid support services through a bi-directional private charger converter. Currently, the V2G service on the market is offered by the electric Nissan Leaf (ZE1) [169] and PHEV vehicles, e.g., Mitsubishi Outlander and Eclipse [170]. Currently, the V2G service is available, e.g., at the European Technical Centre in Cranfield as part of a joint project with Nissan, E.ON, and Virta, as a result of which 20 chargers for charging electric vehicles were installed [171].

V2H makes it possible to supply energy to selected or all household receivers. It is worth emphasizing here [167] that the energy from the vehicle can power the house for several consecutive days [172]. Currently, since 2022, the implementation of V2H is possible thanks to Nissan Leaf ZE1 [169], Mitsubishi Outlander, and Eclipse [170] as well as Ford F-150 Lightning [173].

V2L can be used to power selected non-household devices or to charge other electric vehicles. In such cases, this solution is called Vehicle to Vehicle (V2V) [167]. Implementing V2L and V2V is currently possible with the Ford F-150 Lightning [173]. The maximum value of the load power is 9.6 kW. In addition, the implementation of the V2L concept is possible thanks to: Hyundai Ioniq 5 [174] up to 3.6 kW, KIA EV6 [175] up to 3.6 kW, BYD Atto 3 [176] up to 3.2 kW, BYD Han EV [177] up to 3.2 kW, and MG ZS EV [178] up to 2.2 kW.

In Poland, since 2022, support has been provided for purchasing energy flow management systems in prosumer households, billed based on net billing. As part of the "My current 5.0" edition 2023 [179], it is possible to obtain support for the energy flow management system for up to 3000 households. It is worth mentioning that bi-directional chargers enabling the implementation of the V2G or V2H concept can be elements of this system. The total support under the "My current 5.0" program is PLN 58,000 with the possible division of funding into PV micro-installation (without additional elements) up to PLN 6000/coupled with another subsidised device of up to PLN 7000 for heat storage up to 5000 PLN and electricity storage up to 16,000 PLN.

Developing two-way chargers with balanced financial support for prosumer micro-installations opens up new possibilities for controlling the flow of electricity in Polish households.

4.5. Comparison of Incentives in Poland and Norway to Achieve 100% Zero-Emission Vehicle Sales

Norway began to introduce the first facilities related to the development of electromobility after 1990 [180–185]. Exemplary incentives currently operating in Norway and are dedicated to EV users are presented in Table 8. In 2022, there were 598,712 [186,187] electric vehicles on the roads in Norway, which accounted for 79.3% of newly registered vehicles.

Table 8. Incentives for EV users—a comparison of the current state in Poland and in Norway [23,24,30,84,85,115,180–188].

<table>
<tr><th>Poland</th><th>Norway</th></tr>
<tr><td>1. Excise tax exemption for fully electric (BEV) and hydrogen-powered passenger cars (FCEV)
2. A write-off for the wear and tear of a BEV passenger car is a tax-deductible cost up to a value not exceeding EUR 30,000 (other vehicles up to EUR 20,000).</td><td>No tax on the purchase and import of electric vehicles (valid from 1990 to 2022). From 2023, a car weight-based purchase tax on all new electric vehicles.</td></tr>
<tr><td rowspan="3">Co-financing from the "My Electrician" program from 22 November 2021, to 30 September 2025, for the purchase of a new electric vehicle for:
1. individual persons in category M1: (a) up to PLN 18,750, the price of a new vehicle may not exceed PLN 225,000, (b) families with a "large family" card up to PLN 27,000 without the price limit of a new vehicle.
2. entities other than natural persons (leasing is also allowed), for vehicles in the following categories: (a) N1: subsidy up to 20% of eligible costs, but not more than PLN 50,000 or subsidy up to 30% of eligible costs, but maximum PLN 70,000 in the case of declaration of average annual mileage above 20,000 km, (b) L1e-L7e: subsidy up to 30% of eligible costs, but maximum PLN 4000.</td><td>25% VAT exemption on purchase (valid from 2001 to 2022). Since 2023, Norway has introduced 25% VAT on the purchase price of at least NOK 500,000</td></tr>
<tr><td>25% reduced tax on company cars (valid from 2000 to 2008). 50% reduction in company car tax (valid from 2009 to 2017). Reducing the tax on company cars to 40% (valid from 2018 to 2021) and 20% since 2022.</td></tr>
<tr><td>Exemption from 25% VAT on leasing (valid since 2015).</td></tr>
</table>

Table 8. *Cont.*

Poland	Norway
1. Exemption from tolls for travel on public roads until 31 August 2028 for zero-emission buses of the public collective transport operator, providing public utility transport, are exempt from tolls for travel on national roads. 2. Other electric vehicles are not exempt from road tax and other tolls (e.g., motorway tolls).	Exemption from annual road tax (applicable from 1996 to 2021). Reduced road tax from 2021. Full road tax since 2022.
No discounts.	No tolls on toll roads (valid from 1997 to 2017).
No discounts.	No fees on ferries (valid from 2009 to 2017).
No discounts.	Maximum 50% of the total amount on toll roads (valid from 2018 to 2022). Since 2023 it has increased to 70%.
BEVs are exempt from paying for parking on public roads in the paid parking zone (except for designated places at public charging stations)—effective since 2018.	Free city parking (valid from 1999 to 2017).
Possibility of moving electric vehicles on bus lanes until 1 January 2026. Possibility of entering the clean transport zone	Access to bus lanes (valid from 2005). New rules allow local authorities to restrict access to only electric vehicles carrying one or more passengers (valid from 2016).
Regulation 2023/851 assumes 100% registration of zero-emission vehicles (electric or e-fuel [189]) among new vehicles in the European Union from January 2036. From 01.2036, according to the data in [188], there will be a ban on registration for combustion vehicles powered by fossil fuels derived from crude oil processing, including: petrol, diesel, LPG, etc.	The Norwegian Parliament has decided on a national target that all new cars sold by 2025 should be emission-free (electric or hydrogen, valid since 2017).
The Act of 2 December 2021 amending the Act on electromobility and alternative fuels and certain other acts, specifying, among others, procedures for installing charging points in multi-family buildings: cooperatives and housing associations (valid since 2022).	Established Charging Law for people living in apartment buildings (valid since 2017).
Share of BEV in the fleet of vehicles used by the chief and central state administration bodies (from 1 January 2020 to 31 December 2022 at least 10%, from 1 January 2023 to 31 December 2024 at least 10%, from 1 January 2025 at least 50%).	From 2022, cars must be ZEV for public procurement. Since 2025, the same applies to city buses.

In 2025, according to the assumptions of the EV development policy, Norway will be the first country in the world to achieve 100% zero-emission vehicle sales, as shown schematically in Figure 19. In the case of Poland and other European Union countries, per Regulation 2023/851 [188], from 1 January 2036, it will have to achieve 100% zero-emission vehicles among newly registered vehicles. It means that from 1 January, 2036, it will not be possible to register vehicles with internal combustion engines powered by fossil fuels derived from crude oil processing (e.g., gasoline, diesel oil, LPG and others), which is schematically shown in Figure 19.

Achieving these goals in Poland will involve reducing potential barriers related to the development of charging infrastructure, which must be eliminated by 2035 (see Section 4.2).

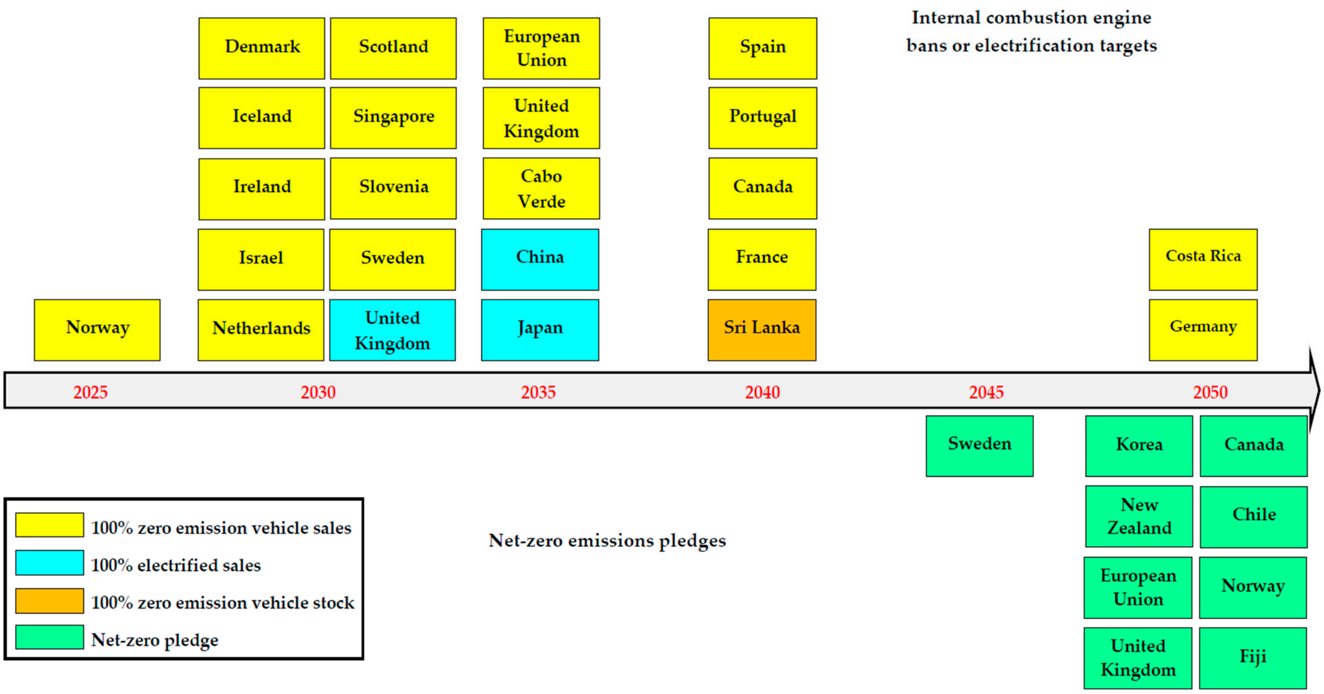


Figure 19. Declared and planned 100% emission vehicle sales, Internal combustion engine bans or electrification targets, net-zero emissions pledges for selected countries based on EU 2019/631 regulation [18], EU 2023/851 regulation [188] and IEA data [190].

5. Conclusions

The article presents the current state of the development of operational infrastructure for electric vehicles in Poland. It discusses market segmentation and a synthetic classification of charging standards, types and modes of charging, types of connectors currently used, and those that will soon appear on the market. The paper analyses the current state of development of the charging infrastructure in Poland in the context of the AFIR regulation. The current status of developing the charging infrastructure in Poland for 2022 is being discussed, as well as the possibility of implementing the Vehicle to Grid concept in Poland and comparing incentives for users of electric vehicles implemented in Poland and Norway in terms of achieving 100% zero-emission vehicle sales by December 31, 2035, in Poland.

Looking forward to 2035, the most important challenges for Poland in terms of the development of charging infrastructure for electric vehicles include:

- Increasing the number of high-power recharging points above 150 kW (Ultra-Fast DC Level 1 and Level 2) at public charging stations in Poland, so that the AFIR goals are met (1 kW for each newly registered BEV and 0.66 kW for each PHEV).
- Location of high-power recharging points above 150 kW (Ultra-Fast DC Level 1 and Level 2) in the TENT-T network every 60 km.
- Informing users about the charging cost in the PLN/20 kWh format will be a substitute for the PLN/100 km price for most electric passenger vehicles.
- Implementation of the “smart charging” functionality in the law for all operators at all publicly available charging stations.
- Equipping all public DC charging stations with payment terminals.
- Introducing the obligation to inform users about the current status and availability of charging points in a given location (displaying the availability status and the price on the pylon, e.g., in the “▲HP-DC × 3” format, i.e., three high power charging points available over 150 kW.

As far as the elimination of strategic barriers to the development of electric vehicle charging infrastructure for low and medium-voltage connections in Poland is concerned, the following could be viewed as possible solutions:

- Introducing a provision in the law concerning the maximum duration of the contract for connecting the charging station to the low and medium-voltage power grid, not exceeding six months.
- Introduction of legal provisions imposing a statutory obligation on DSOs to provide information on possible connections to the charging infrastructure, at the request of an entity interested in a given investment, with the obligation to respond within 1–2 months. Information is provided for a fee, and in the event of costs incurred by the DSO, reimbursement of these costs by the applicant.

Implementation of additional incentives for electric vehicle private users into legal acts (a lesson from Norway for Poland):

- 50% off tolls on toll roads by 2035.
- 50% discount on ferry fares until 2035.

A very important issue is the development of zero-emission eHDV heavy transport, some of which will be implemented as battery-powered trucks. In parallel with the development of this type of truck, the 350 kW+ high-power charging infrastructure, as well as the MCS standard, will have to be developed. The requirements of the AFIR define it. This issue is very important, as over 30% of European freight transport is carried out by Polish transport companies. Despite this, only a dozen electric trucks are currently registered in Poland, and charging hubs are only being planned. It is also important that the limitation be the charger's power and the provision of an appropriately sized driveway for a truck under the charger. These problems are extremely significant, which is why they will be the material of our next research, when electric trucks will appear on Polish roads in greater numbers and when it will be possible to conclude their actual operation.

Author Contributions: Conceptualization: A.C.; Data curation, A.C.; Formal analysis, A.C.; Investigation, A.C.; Methodology, A.C.; Software, A.C.; Supervision, A.C.; Visualization, A.C.; Writing—original draft, A.C.; Writing—review & editing, A.C., P.P., J.M. and S.O. All authors have read and agreed to the published version of the manuscript.

Funding: Studies were funded by ENERGYTECH-1 project granted by Warsaw University of Technology under the program Excellence Initiative: Research University (ID-UB), No. 504/04496/1155/45.010700.

Data Availability Statement: Data will be made available on request.

Conflicts of Interest: The authors declare no conflict of interest.

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