Distribution grids and electromobility

Planning and development

www.forum-energii.eu

Forum Energii is a think tank active in the energy sector. Our mission is to forge the foundation for an efficient, safe, clean and innovative energy sector based on data and analysis.

AUTHORS
Paweł Czyżak, Adrianna Wrona - Instrat Foundation

COOPERATION
Michał Borkowski
Joanna Maćkowiak-Pandera, Klaudia Wojciechowska - Forum Energii
Marek Mańko, Bartosz Wieczorek - Price4Wheels
Jacek Mizak - Electric Vehicles Promotion Foundation

GRAPHICS PREPARED BY
Karol Koszniec

PHOTO
Unsplash.com

DATE OF PUBLICATION
November 2021

The analysis was prepared as part of the Int-E-Grid Polish-German project implemented by Forum Energii together with the Electric Vehicles Promotion Foundation and Agora Verkehrswende. Details on the project can be found at https://www.int-e-grid.eu. The project is supported by the European Climate Initiative (EUKI).

The overarching goal of EUKI is to foster climate cooperation within the European Union to reduce greenhouse gas emissions. EUKI is an instrument to finance projects by the German Environment Ministry (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, BMUB). EUKI is supported by the German International Cooperation Society (Deutsche Gesellschaft für Internationale Zusammenarbeit, GIZ). The opinions contained in this publication are solely those of the authors.

Fundacja Promocji Pojazdów Elektrycznych
Electric Vehicles Promotion Foundation
Forum Energii
Analizy i dialog
Agora Verkehrswende
INT-E-GRID
Powering Electromobility in Poland and Germany
Supported by:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
based on a decision of the German Bundestag
European Climate Initiative EUKI

TABLE OF CONTENTS

NOVEMBER 2021

Introduction

Electrification of transport is the future - not only because we need to protect the climate and air, and we want to use new, innovative technologies. Thanks to electrification of transport, we can invest several tens of billions of zlotys a year in the country's modern economic sector - at the same time reducing expenditure on imported fuel. The end of the combustion engine in transport will occur already in the mid-30s.

In the following years, Poland will have large financial resources available for investment in electrification of transport. However, efficient development of electric vehicles will require well-planned and wisely developed grid infrastructure, which until now has not been adapted to handle such a large scale of new equipment. The new grid architecture must take into account how the electric car is used. The second key element is easily accessible charging stations for such vehicles.

What does the expansion of electromobility mean for the energy system? How will grids cope with the rapid development of this field and how to plan their future growth? Can the grid in smaller towns cope with greater fluctuations in power supply?

We offer you an analysis that focuses precisely on the challenges for distribution networks associated with the development of electric transport. We hope you enjoy reading it.

Dr. Joanna Maćkowiak-Pandera
Forum Energii CEO

Main conclusions

The European Green Deal has set out a road map for achieving climate neutrality by the European Union, setting an ambitious target of 90% of greenhouse gas emission reductions (GHG) for the transport sector by 2050. The electrification of this sector is one of the most effective and fastest methods of transport decarbonisation.

The development of electromobility will proceed rapidly, although it is conditioned by many factors (from economic incentives to the development of car charging infrastructure). It is important that Poland starts preparing for electrification of transport in a thoughtful way - this would allow to minimise costs and maximise benefits for the economy and society. In the study, we analysed several scenarios for the development of electromobility and the impact of their implementation on national distribution grids.

The development and modernisation of distribution grids is a key element for road transport electrification. The process of integrating electromobility with the grid must be wisely planned over time. The results of the analysis show that by 2050 the cost of adjusting the grid will amount to PLN 2.5 billion in the base scenario (moderate development[1]) and approximately PLN 11.8 billion in the alternative scenario (more ambitious[2]). In the latter case, costs may be reduced by PLN 5.8 billion (49%) if flexible charging (smart charging) is applied.

Investment costs in distribution grids related to transport electrification are relatively low. Considering the annual basis, they represent a fraction of the investment costs currently incurred by DSOs and required by increasing capacity of renewable energy sources, the need to upgrade and cable MV and LV grids, and the implementation of smart meters. The costs of expansion and modernisation of distribution grids should therefore not be a barrier for the development of electromobility in Poland.

However, it is important that electromobility is well planned and included in DSOs' investment plans. The scale of necessary grid investments depends on the specifics of the area concerned:

- In rural areas, even almost complete electrification of transport does not require significant investment in low and medium voltage grids. The implementation of standard planned upgrades and investments related to the expected development of RES will be fully sufficient for handling the increased demand for power from the electric vehicle sector;
- In small and medium-sized towns, the increase in the number of electric vehicles and the increased demand for energy to charge them may require additional investments in grids, in particular the increase in main power supply stations' (GPZ) capacity and the potential increase in the permissible load capacity of the low voltage lines. The implementation of flexible charging makes it possible to avoid investments in the low voltage grid, even in the alternative scenario;
- In the case of large towns and cities, it is already anticipated that electricity demand will increase due to the development of electromobility and the planned public transport electrification programmes. These changes may require investments in order to increase the load capacity of medium and low voltage lines. The use of flexible charging makes it possible to significantly reduce the scale of investments required.
- The biggest costs are definitely linked to the development of high power charging infrastructure for expressways and motorways. This is mainly due to the distance of charging stations from main power supply stations. Dynamic development of electromobility will require additional medium-voltage line circuits, expansion of transformer stations and increased capacity of the main power supply station.

1 2030: 680 thousand light electric vehicles, 18.5 thousand heavy urban vehicles and 113 heavy road vehicles. 2050: 3.93 million light electric vehicles, 107 thousand heavy urban vehicles and 143 thousand heavy road vehicles.

2 2030: 3 million light electric cars, 82 thousand heavy urban vehicles and approximately 500 heavy road vehicles; 2050: 16.5 million light electric vehicles, 450 thousand heavy urban vehicles and 600 thousand heavy road vehicles.

In the short term, the development of photovoltaic installations should primarily be taken into account in the design of the low voltage grid, as their dynamic development poses a greater challenge for the grid than the development of electromobility. Investments related to the development of RES may be sufficient in many areas of the country (especially in rural regions) in terms of adapting the grid to electromobility development. At the same time, the development of electromobility can contribute to reducing investments necessary to adapt distribution grids to the rapid development of RES - increasing local energy consumption in households reduces the amount of energy returned to the grid by prosumers.

The implementation of the scenarios for the development of electromobility discussed in this study along with the decarbonisation of the energy mix will allow for the reduction of GHG emissions from transport by up to two-thirds by 2050. This is a lot, but still not enough, given the objective of climate neutrality. Therefore, in addition to electrification, greater changes will be necessary – the development of public transport, bicycle transport, etc.

Recommendations for DSOs:

- DSOs should urgently prepare plans for modernisation of distribution grids considering the development of electromobility and RES micro-installations. The plans require including specific RES and EV development objectives which should be updated each year.
- DSOs should regularly monitor the state of distribution grids and make the results available to public according to selected indicators.
- The installation of smart energy meters should be accelerated nationwide.
- By 2050, the capacity of most of small and medium town main power supply stations will have to be increased. The stations' reconstruction should involve implementing transformers with highest possible capacity (e.g. 63 MVA).
- When converting overhead lines into cable lines in medium towns the increased demand, resulting from the development of electromobility, should already be taken into account in order to avoid further costs in the future.
- In larger cities, we recommend a gradual increase in the load capacity of the most important sections of the 400 V grid in order to foster the development of electromobility.
- We recommend considering the extension of the grid and new power supply points at the planned expressways and motorways (including the planned locations of rest areas) – as well as the modernisation of the existing ones (e.g. construction of the third lane of A2 motorway at the Pruszków-Stryków section).

Recommendations for public administration:

- It is important to include specific (ambitious) objectives for the development of electromobility and the development of RES in national strategic documentation. This will avoid future problems with integration of RES microinstallations and EV with the grid.
- Including electric vehicle users in balancing the energy system will allow to reduce grid costs. However, it is important to introduce flexible charging and dynamic tariffs for energy consumers, hence creating appropriate economic and regulatory conditions will be crucial. We recommend pilot projects related to dynamic tariffs to verify their effects on the behaviour of electricity consumers.
- Local authorities should be encouraged to actively participate in planning the development of electromobility, including creating plans for charging infrastructure development. Considering the familiarity of the region and citizens' needs, the local authorities should prepare a strategic electromobility development plan for their region.
- In order to stimulate the development of the EV vehicle market in Poland, we recommend making sure that the currently introduced and planned incentive schemes for the purchase of electric vehicles and the charging infrastructure for individual users as well as business units will enable the achievement of the objectives pursued. This is particularly important in the context of the Fit for 55 legislative package published in July 2021, which will require a strong increase in ambition for the decarbonisation of road transport.
- Due to the fact that the influence of heavy urban vehicles on peak grid load is relatively low, the electrification and development of public transport means in Polish cities should be prioritised.

1. Introduction

Road transport is one of the most emissive sectors of the global economy. In the European Union, it is responsible for approximately 22% of greenhouse gas emissions and 17% in Poland (approx. 64.6 million tonnes of CO_2eq).[3] In addition, transport is the last sector from which emissions are constantly increasing. In Poland, they have increased by 250% since 1990 and by 85% since 2005 (30 million tonnes of CO_2eq)[4]. The European Green Deal requires achieving climate neutrality by 2050 and a 90% of reduction in transport emissions. In order to achieve this objective, the EU introduces increasingly demanding vehicle emission standards and focuses on the electrification of the sector. This means a dynamic development of electromobility in many European countries, including Poland, in the coming years.

In planning its development, two key elements need to be distinguished: vehicles and infrastructure, and it is the infrastructure that constitutes a specific base and driving force for this development. However, designing background facilities, which would be suitably adapted to the increased electric vehicle fleet (EV), constitutes a major organisational and technical challenge. This requires a strategically planned expansion of the charging infrastructure, taking into account the increased demand for capacity and electricity as well as adapting distribution grids to the dispersed nature of the charging system.

It is necessary to properly integrate the charging infrastructure into the power grid, which has not yet been adapted to such a broad range of new equipment. The development of electromobility will therefore require investments in the distribution grid, and understanding the grid's technical issues and weaknesses is crucial for determining the optimal direction of these investments.

Objective of the study and approach

The main objective of this publication is to estimate the impact of electromobility on distribution grids, in particular to determine the extent of the necessary scope of upgrading the grid infrastructure resulting from the increased capacity demand.

The costs of these investments will depend on:

- the size of the electric vehicle fleet,
- local grid conditions.

That is why two development scenarios are analysed – the baseline and the alternative scenario – for 2030 and 2050. In addition, the calculations were divided into categories corresponding to the structure of population distribution in Poland and the impact of electromobility development on:

- grids in rural areas,
- small and medium-sized towns,
- large cities,
- charging stations located along motorways and expressways.

The conclusions of the following analysis are mainly aimed at Distribution System Operators (DSOs) to draw their attention to the directions of necessary grid investments which would not only make further development of electromobility in Poland possible, but also make it safe for the grid and economically justified. On the other hand, this publication offers a number of recommendations to the public administration, the aid of which may prove necessary in order to accelerate the development of the sector, especially at its initial stage.

3 Eurostat database, http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do
4 as above

2. Diagnosis of the electromobility sector situation in Poland

2.1. Current condition: legal framework and current state of the market

One of the key documents shaping the process of electromobility development in Poland is the *Strategy for Responsible Development (SRD)*[5] up to 2020 (including perspective up to 2030) of 2017. As part of this strategy, *the Electromobility Development Plan* was established, which aims to create conditions for the implementation of electromobility in Poland, inter alia, through the development of charging infrastructure and the stabilisation of the power grid by appropriate integration of vehicles with the grid [6].

Further strategic documents are documents forming part of the so-called *Clean Transport Package*, which are presented in the table below.

Tab. 1. Strategic documents shaping the development of electromobility in Poland

Strategic documents shaping the development of electromobility in Poland (the so-called Clean Transport Package)	
Electromobility Development Plan in Poland	Adopted by the Council of Ministers on 16 March 2017
National framework for development of alternative fuel infrastructure policy	Adopted by the Council of Ministers on 29 March 2017
Act on Electromobility and Alternative Fuels	Act of 11 January 2018; entered into force on 22 February 2018. On 20 November 2020, a draft Act amending the Act on Electromobility and Alternative Fuels was published, and its subsequent version, following the consultation in February 2021, aimed at modifying the legal framework previously established by the Act of 2018. The draft amendment of this act includes, among other things, the industry's demands for sustainable development, including solutions facilitating the installation of charging infrastructure in multi-family residential buildings, as well as including and simplifying connection procedures for publicly available electric vehicle charging stations.
Act of 6 June 2018 amending the Act on Biocomponents and Liquid Biofuels introducing the Low Emission Transport Fund (LETF)	The Act was adopted on 10 July 2018. In July 2020, LETF was liquidated and its tasks and resources accumulated so far were taken over by the National Fund for Environmental Protection and Water Management, which is now to be responsible for financing the development of electromobility in Poland.

Source: Own study.

As part of *the National Policy for the Development of Alternative Fuel Infrastructure*, the government anticipates that by 2025 1 million EV will be used in Poland.

The document identified 50 thousand electric vehicles and 6 thousand publicly available charging points with normal charging power and 400 high power charging points as the objective for 2020[7]. Below are the categories of vehicles and charging points for electric cars.

5 Ministry of Funds and Regional Policy, Strategy *for Responsible Development up to 2020 (including perspective up to 2030)*, 2020, https://www.gov.pl/web/fundusze-regiony/informe-o-strategii-na-rzecz-odpowiedzialnego-rozwoju

6 Zawieska J., *Development of electromobility market in Poland* [in:], Electromobility in Poland in view of European and global trends [Rozwój Rynku Elektromobilności w Polsce [in:], Elektromobilność w Polsce na tle tendencji europejskich i światowej], ed. J. Gajewski, W. Paprocki, J. Pieriegud, Warsaw 2019, Publication of the European Financial Congress, 2019, p. 9, https://www.efcongress.com/wp-content/uploads/2020/02/publikacje09__Elektromobilno%C5%9B%C4%87-w-Polsce-na-tle-tendencji-europejskich-i-globalnych.pdf

7 Ministry of State Assets, *National Framework for the Development of Alternative Fuels Infrastructure Policy* [Krajowe ramy polityki rozwoju infrastruktury paliw alternatywnych], 2017, https://www.gov.pl/web/aktywa-panstwowe/rzad-przyjal-Krajowe-ramy-polityki-rozwoju-infrastruktury-paliw-alternatywych-3

Categories of electric vehicles (EV)

BEV (Battery electric vehicle) - a motor vehicle using only electric energy accumulated through connection to an external power supply

PHEV (Plug in hybrid electric vehicle) – a combustion and electric vehicle in which electricity is accumulated through connecting to an external power supply

Source: National framework for the development of alternative fuels infrastructure policy.

Tab. 2. EV charging infrastructure

EV charging infrastructure		
Charging point	A device capable of charging a single electric vehicle, a hybrid vehicle and a zero-emission bus, as well as a place where the battery used for vehicle propulsion is replaced or charged.	
Normal power charging point	Charging point with capacity less than or equal to 22 kW, excluding equipment with capacity less than or equal to 3,7 kW installed in places other than publicly available charging stations, in particular in residential buildings.	
High power charging point	Charging point with a capacity exceeding 22 kW.	
Charging station	a) a construction facility comprising a charging point of normal power or a high power charging point and associated with a structure; b) stand-alone structure with at least one normal power or high power charging point installed.	Provided with software enabling the provision of charging services together with a parking space and an installation leading from the charging point to the power connection.
Publicly available charging station	Charging station available under equal treatment for each user of an electric vehicle and a hybrid vehicle	

Source: Act of 11 January 2018 on Electromobility and Alternative Fuels.

One of the overarching objectives of the *Act on Electromobility* of 2018 was to address the lack of public EV charging infrastructure in agglomerations, densely populated areas and on trans-European transport corridors, inter alia, by creating appropriate regulatory conditions. The Act contains a number of incentives for the broader adaptation of electric vehicles, i.e. the abolition of excise duties on electric cars or their exemption from parking charges and the obligation for state institutions to use electric cars[8].

In 2018, the Polish government established the Low Emission Transport Fund, which was supposed to provide financial support for various initiatives related to the implementation of the plans specified in the strategic documents described above. The areas of activity were to cover, inter alia, the production of transport means, investments in clean public transport by local authorities, investments in charging infrastructure or even education on the use of alternative fuels in transportation[9]. Unfortunately, due to the numerous delays in the introduction of legal regulations, the fund did not fulfil its role. No direct surcharge system has been put in place for the acquisition of electric cars or for the development of charging infrastructure[10].

In August 2020, LETF was liquidated and its tasks and the funds accumulated so far were taken over by the National Fund for Environmental Protection and Water Management (NFEPWM), which is now to be responsible for financing the development of electromobility in Poland.

8 Journal of Laws, *Act of 11 January 2018 on Electromobility and Alternative Fuels Journal of Laws of 2018, item 317*, https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20180000317

9 Ministry of Climate and Environment, *Low Emission Transport Fund*, 2018, https://www.gov.pl/web/klimat/fundusz-niskoemisgo-transport

10 Supreme Audit Office, *Information on audit results: Electromobility development support* [Wsparcie rozwoju elektromobilności], 2020, https://www.nik.gov.pl/plik/id,23045,vp,25751.pdf

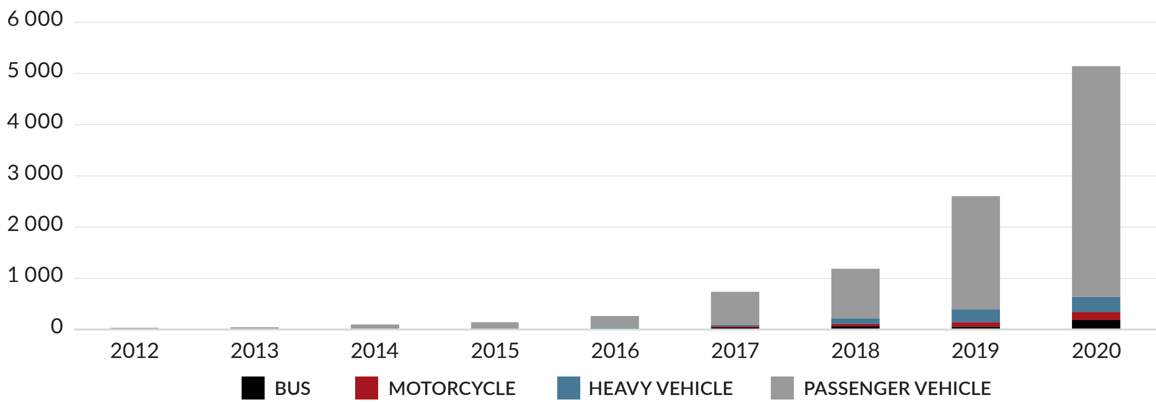
Delays in the implementation of plans and failure to release LETF funds have led to the failure related to achieving the 2020 target and the chances of achieving the 2025 target are marginal[11], even impossible, with current trends.

According to the *Electromobility meter*, at the end of May 2021 25 407 electric passenger cars (only 0.05% of the total fleet of passenger vehicles)[12], 966 trucks and delivery vehicles and 526 electric buses were registered in Poland. Among electric passenger cars, approximately 49% were battery electric vehicles (BEV), while the remainder were plug-in hybrid electric vehicles (PHEV).

During the first five months of 2021, the fleet of electric passenger cars increased by 149% compared to the corresponding period in 2020.[13] Despite the positive trend, this figure is much lower than planned by the government. For instance, in 2020, in Germany, the fleet of electric passenger cars alone amounted to more than 595 thousand (about 1.2% of the total fleet of passenger vehicles), in Norway there were almost 453 thousand (about 16% of the total fleet of passenger vehicles) and in the Netherlands almost 273 thousand (over 3% of the total fleet)[14].

Although EV include both BEV and PHEV vehicles, in order to maximise the benefits of the sector's electrification, it is particularly important to increase BEV - i.e. fully electric vehicles. Despite the insufficient pace, the steadily increasing feet is encouraging (Fig. 1). In 2012, 22 fully electric passenger cars were registered in Poland. In 2015, it was 111 cars, and in 2020 it was already over 4.5 thousand. Compared to 2019, the number of registrations of electric passenger vehicles increased more than twice in 2020. A similar trend is observed for heavy goods vehicles and buses. In 2015, 10 and 16 vehicles of this type were registered, and in 2020 there were already 295 and 196.

Fig. 1. Number of battery electric vehicle registrations (BEV) in Poland 2012-2020



Source: Own study on the basis of: CEPIK, 2020.

At present, electric vehicles are registered primarily in large cities, i.e. Warsaw or Cracow (Fig. 2). Therefore, the Mazowieckie Voivodeship or Małopolskie Voivodeship are the leaders in this ranking.

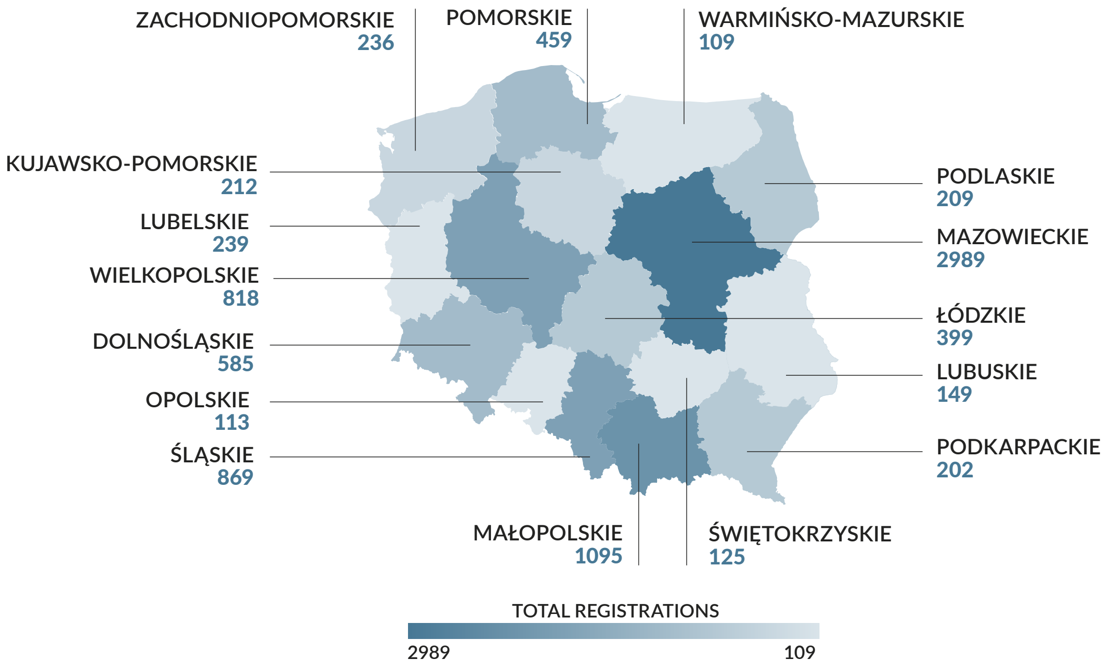
11 Supreme Audit Office, *Information on audit results: Electromobility development support*, 2020, https://www.nik.gov.pl/plik/id,23045,vp,25751.pdf

12 European Alternative Fuels Observatory, 2021, https://www.eafo.eu/vehicles-and-fleet/m1#

13 Polish Automotive Industry Association (PZPM), *Electromobility Meter*, 2021, https://www.pzpm.org.pl/pl/Rynek-motoryzacyny/Metnik-elektromobilnosci/Marzec-2021

14 European Alternative Fuels Observatory, 2021, https://www.eafo.eu/vehicles-and-fleet/m1#

Fig. 2. Number of registered passenger cars of the BEV type in each Polish voivodeship, figures as at 2020

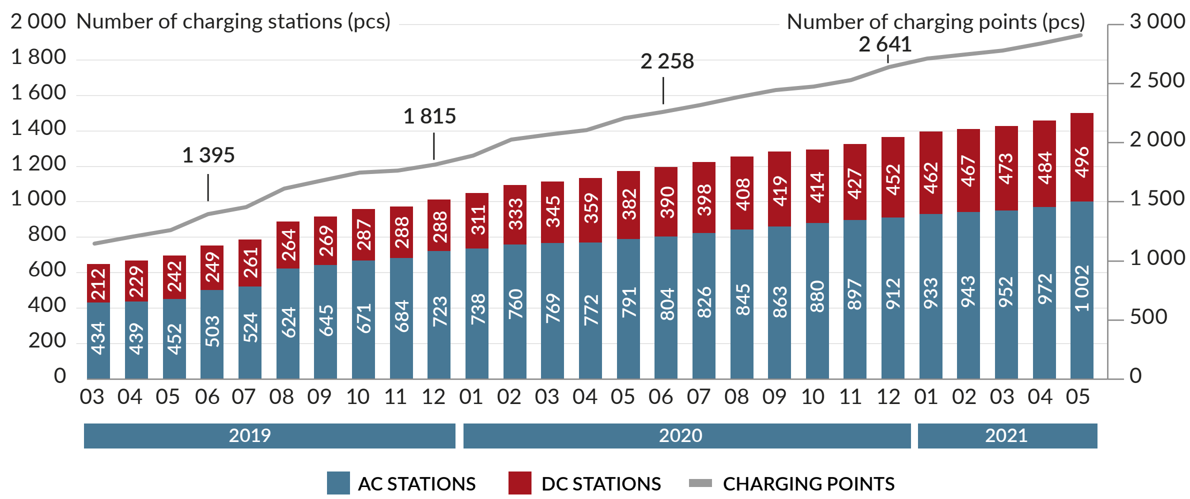


Source: Own study on the basis of: CEPIK, 2020.

The availability of charging infrastructure is an integral part of the development of electromobility, and this also requires improvement in Poland. From 6400 public charging points planned for 2020, only 2642 points were created by the end of December 2020, and by the end of May 2021 their number increased to 2931 only (Fig. 3).

These points are currently concentrated in 1498 stations – 67% of them constitute slow charging *alternating current* (AC) points with a standard capacity less than or equal to 22 kW and the remaining 33% are high power *direct current* (DC) charging stations.

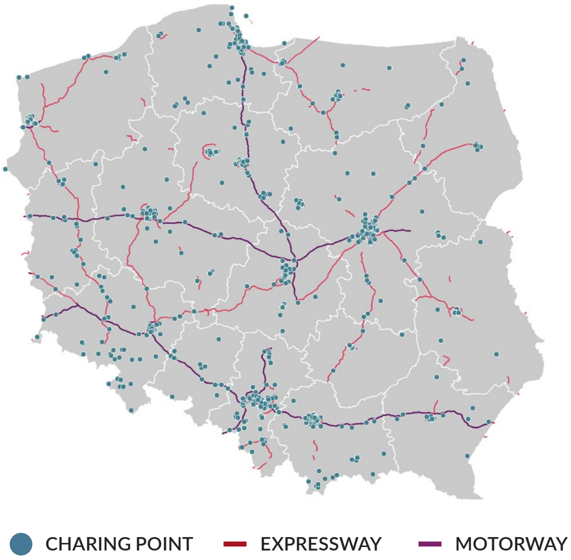
Fig. 3. Number of stations and charging points in Poland in 2019-2021



Source: Own study on the basis of: ORPA, 2021.

In addition, the locations of stations indicate high irregularity in different areas of the country (Fig. 4). The vast majority of charging points are located in large urban agglomerations as well as along motorways and expressways. However, there are areas where the infrastructure for electromobility nearly does not exist– for example, in Podlaskie or Lubelskie voivodeships we will find only a few publicly available charging stations.

Fig. 4. Locations of publicly available charging points in Poland



Source: Own study on the basis of: Office of Technical Inspection UDT (2021)[15].

This means that owners of electric vehicles still face significant restrictions on free movement across Poland. This translates into a poorer incentive to purchase electric cars among the society and thus slowed down pace of electromobility development. However, the Electromobility Act of 2018 obliged municipalities to monitor the number of charging points, and when the implementation of the plan was threatened, they were to develop a plan for the location of missing points. Once the locations were agreed, the obligation to build charging points fell on distribution system operators (DSOs). However, it was only an intervention mechanism, not a system mechanism, which is to be removed as part of the planned amendment of that act, and DSOs will no longer be able (except for certain exceptions) to be charging stations' operators.

This role will be taken over by third parties - operators of publicly available charging networks (PACN). This change will not improve the expansion of the charging infrastructure in Poland, and in this context, it is important introduce support programmes for its expansion as quickly as possible[16]. On the other hand, the amendment of the Act will require the installation of duct infrastructure for at least 1 out of 5 parking spaces and at least one charging point on parking areas belonging to the existing non-residential buildings by the owners or administrators of those buildings by 1 January 2025, which may lead to positive market developments.

It is clear that such a large discrepancy between the current state of electromobility and the plans for 2020, coupled with current little support for its development, will not lead to the achievement of the target of one million vehicles by 2025. Despite the growing interest in EV, we are only in the initial stages of electromobility development. In order to speed up its development, it will be necessary to introduce programmes to increase the interest of electric vehicles among private users, businesses and public institutions. In chapter 2.2, we are focusing on showing possible support to increase interest in EV. The impact of the changing electric vehicle fleet on the National Power System (NPS), together with the necessary upgrades, has been analysed in chapters 4-6.

15 Office of Technical Inspection, *Register of Alternative Fuels Infrastructure* [Ewidencja Infrastruktury Paliw Alternatywnych], https://eipa.udt.gov.pl/ [access date: 30.06.2021].

16 Ministry of Climate and Environment, *Draft Act amending the Act on Electromobility and Alternative Fuels and Certain Other Acts* [Projekt ustawy o zmianie ustawy o elektromobilności i paliwach alternatywnych oraz niektórych innych ustaw], 2020, https://legislacja.rcl.gov.pl/projekt/12340506.

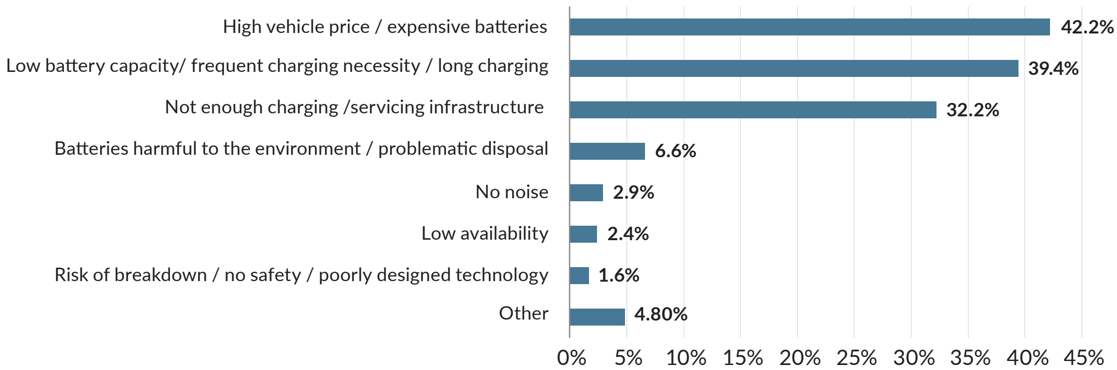
2.2. Tariffs and incentives

The rapid development of electromobility in Poland will depend on the introduction of programmes and mechanisms to encourage vehicle users to purchase EV. Studies carried out by industry organisations show that the biggest barriers for the adaptation of electric vehicles are:

1. High price of vehicles (42.2% of respondents).
2. Poor range of cars (39.4% of respondents).
3. Insufficient access to the charging infrastructure (32.2% of respondents) (Fig. 5).

The demand for EV vehicles will not increase until the barriers mentioned above are addressed. The small penetration of the market by EV vehicles so far means that the expansion of the charging points network is often unprofitable for private investors, and the absence of these points discourages potential buyers from buying EV. Unblocking this process will therefore require government stimulation for each of the areas mentioned above. It will also be important to phase out high-emission vehicles from roads, for example through increased emission controls, higher charges for registration of high-emission vehicles (implementation of the "polluter pays principle"), transport emissions charges or the introduction of clean transport zones.

Fig. 5. The biggest barriers for purchasing and using electric cars according to respondents



Source: PSPA, *New Electromobility Barometer 2020/2021* [Barometr Nowej Elektromobilności 2020/2021], 2020, https://pspa.com.pl/media/2020/11/barometr_nowej_Mobilosci_2020_raport_S_1.pdf.

Incentives to purchase electric vehicles

Incentive schemes for the purchase of electric vehicles - subsidies, tax reductions and sometimes both - have been introduced in many European countries. Examples of these mechanisms are listed in Table Z.1.1 of the appendix.

Considering countries offering direct subsidies for the purchase of vehicles, for example in Belgium, the government offers up to EUR 4 000, and in Germany the subsidies amount even to EUR 9 000 in the case of BEV vehicles (PHEV EUR 6 750).

In Poland, schemes aiming at co-financing EV were practically non-existent, although in July 2021 the "My electric vehicle" scheme was launched. Previous support attempts were limited to pilot schemes - "Green Car", "eVAN" and "Humming bird" - to subsidise the purchase of electric vehicles for individuals, entrepreneurs and passenger transport undertakings. However, they failed to encourage a significant number of recipients - in total, only 344 applications for subsidies were submitted for a total of PLN 11.2 million from a pool of nearly PLN 150 million[17]. "My electric vehicle" extends the catalogue of beneficiaries - it is aimed at individuals, public finance sector entities, research institutes, entrepreneurs, associations, foundations, cooperatives, individual farmers and others - its budget will be up to 500 million. In addition, it allows subsidies for leased vehicles, which in Poland is the main way of financing new cars[18].

17 Clean Energy, *Subsidies as part of the "green public transport" programme are to be launched before summer holidays* [Przed wakacjami mają ruszyć dopłaty w programie "zielony transport publiczny"], *2021, https://cleanerenergy.pl/2021/03/24/przed-wakacjami-maja-ruszyc-doplaty-w-programie-zielony-transport-publiczny/ are to start*.

18 T. Sevastianowicz, *New subsidies for electric veicileles, "My Electric Vehicle" programme to bring major changes* [Nowe dopłaty do samochodów elektrycznych, *program „Mój elektryk" to duże zmiany*], Dziennik.pl, 2021, https://auto.dziennik.pl/aktualnosci/artykuly/8193619,doplata-samochod-elektryczny-leasing-kwota-moj-elektryk.html.

Apart from direct subsidies, another important factor supporting the development of electromobility is the creation of a friendly tax ecosystem for zero-emission vehicles, especially for entrepreneurs, which includes, inter alia, the possibility to deduct 100% of VAT on the purchase and operation of electric vehicles, also in the case of business/private use or the possibility of deducting 100% of the operating costs of electric vehicles. Similar tax advantages are applied in many EU countries, where they often operate in parallel to vehicle purchase subsidies. For example, in Germany, BEVs registered in 2011-2030 are exempt from vehicle tax (German *Kfz-Steuer*), while PHEV vehicles are subject to a lower tax than internal combustion vehicles (ICE), in proportion to the lower emission of the vehicle. In Italy, BEVs are exempt from property tax for five years after registration of the vehicle. In Norway, on the other hand, boasting the biggest share of electric vehicles in the national fleet from all EU countries, it was the VAT exemption (together with three other taxes on vehicle purchases) that was the main instrument to support the development of this market. The development of electromobility has gained such a pace that some fuel stations have started replacing fuel pumps with charging points for electric vehicles. In Poland, it will also be significant for the development of electromobility to effectively block the influx of old and high-emission vehicles. As they are cheaper and there is no policy in the country to encourage the purchase of new vehicles meeting emission standards, the average age of passenger cars in Poland is 15 years, which also translates into high emission levels. The introduction of appropriate regulations encouraging the acquisition of electric cars and limiting the use of the highest-emission old vehicles will be crucial in this context.

Support for the expansion of charging infrastructure

Similarly to vehicle purchase incentives, support programmes for charging infrastructure used to be and still are being implemented in many European countries (Tab. Z.1.2). In Germany, subsidies are offered for the construction of publicly available charging points - up to EUR 3 000 for charging stations up to 22 kW; up to EUR 13 000 per DC point up to 100 kW; up to EUR 30 000 per DC point above 100 kW. In addition, the German Government has announced an ambitious financing programme for hydrogen charging and refuelling infrastructure amounting to a total of EUR 4.1 billion by 2023 for both light and heavy vehicles. According to the plan, the Federal Government should put in place a specific financing instrument to support operators in the installation of charging infrastructure at depots and destinations of municipal and regional commercial vehicles[19].

In the Netherlands, EV users have the possibility to submit applications for the installation of a publicly available charging point. If there is no such charging point in the vicinity of the home or place of work, it is built free of charge. Countries such as, inter alia, Germany, France or Spain also offer subsidies for the construction of private charging points. The Polish Government has not financed the development of the charging infrastructure so far, but this is to change.

The published in December 2020 *draft regulation on detailed conditions for granting state aid for the establishment of infrastructure for charging electric vehicles and for refuelling hydrogen*[20] announces that by the end of 2023 PLN 800 million will be earmarked for investments in charging infrastructure. This funding will be aimed at energy companies, enterprises, local governments, housing communities and other organisations, and will come from the National Fund for Environmental Protection and Water Management. Non-repayable subsidies covering up to 75% of eligible investment costs are intended to support the construction of new charging points, the expansion of existing infrastructure and hydrogen refuelling stations (there are no such installations in Poland yet)[21]. Apart from subsidy or tax relief schemes, the governments of some European countries have taken on top-down responsibility for investing in the development of charging infrastructure. The activities undertaken in Norway include, for instance, public financing of high power charging points every 50 km along main roads or the availability of funds for housing cooperatives to install charging points.

19 F. Unterlohner, How to decarbonise long-haul trucking in Germany: an analysis of available technologies and their associated costs, Transport & Environment, 2021, https://www.transportenvironment.org/sites/te/files/publications/2021_04_TE_how_to_decarbonise_long_haul_trucking_in_Germany_final.pdf.

20 Ministry of Climate and Environment, *Draft regulation of the Ministry of Climate and Environment on detailed conditions for granting state aid for electric vehicle charging infrastructure and hydrogen refuelling infrastructure* [Projekt rozporządzenia Ministra Klimatu i Środowiska w sprawie szczegółowych warunków udzielania pomocy publicznej na infrastrukturę do ładowania pojazdów elektrycznych i infrastrukturę do tankowania wodoru], 2020, https://legislacja.rcl.gov.pl/projekt/12341508.

21 Ł. Kifer, *The government is preparing PLN 800 million to support electromobility. Hydrogen refuelling stations and current charging stations will be built* [Rząd szykuje 800 milionów zł na wsparcie elektromobilności. Powstaną stacje tankowania wodorem i ładowania prądem], 2020, https://moto.pl/MotoPL/7,170318,26631740,rzad-szykuje-800-milionow-zl-na-wsparcie-elektroMobilosci.html.

In Portugal an Electrical Mobility Network was established. It is a project managed by the entity named MOBI.E, thanks to which nearly 1.5 thousand charging stations have been installed within 10 years of the launch of the initiative. In Switzerland, the Federal Road Office (FRDRO) was established under the Electromobility Programme to set up a dense, nationwide network of high-power charging stations over the next few years. As a result, national motorways will receive approximately 160 high-speed charging stations, making the Swiss network one of the most developed and dense in Europe. To make it possible, FEDRO will finance the necessary power infrastructure[22].

Public transport incentives

The provisions adopted by the European Union in June 2019 require that a quarter of new buses purchased by the public authorities be running on alternative fuels until 2025.[23] Since 2030, this index is expected to increase to a third. At the same time, 40 cities (including Warsaw) signed the C40 Declaration, which shows, among other things, that by 2025 the fleet of urban buses will be emission-free[24]. The electrification of public transport is one of the priorities of the EU and the governments of many countries in Europe. The Netherlands is currently the leader of this transformation, and in 2025 it plans to have a completely decarbonised bus fleet, while Germany intends to use an additional 3000 electric buses by 2025.[25] Only until the end of 2021 Germany plans to spend EUR 650 million on the development of the electric bus fleet[26]. In March 2021, the UK Government launched a programme under which GBP 120 million will be earmarked for the electrification of approximately 500 zero-emission buses in British cities[27]. The Act on Electromobility and Alternative Fuels introduced in Poland in 2018 also obliges municipalities with over 50,000 inhabitants to operate at least 5% of zero-emission buses in the municipal fleet in 2021, 10% in 2023, 20% in 2025 and 30% in 2028. As in other European countries, the development of the bus market in Poland is supported by public administration efforts. Thanks to the support from the 2021 Green Public Transport Programme, Polish governments intend to buy 302 electric buses, 122 hydrogen buses and 7 trolleybuses using a pool available under the financing programme amounting to PLN 1.1 billion[28]. In addition, in the National Reconstruction Plan the government declared the purchase of another 1,200 zero-emission buses (electric and hydrogen). The funds for both stages of the programme are to come from the Reconstruction Fund.

Other schemes and regulations encouraging the purchase of zero or low emission vehicles

In addition to financial incentives for the purchase of green cars, appropriate regulations, emission standards, additional taxation for high-emission cars or different soft incentives for the use of EV shall also apply. The European Commission itself is imposing ever more stringent emission standards for new cars registered in the EU. In the meantime, EU countries impose significant fees for the registration of high-emission vehicles.

France, for instance, increased the maximum fee rate – for cars emitting more than 225 g CO_2/km in 2020 the fee increased to EUR 20 000, it increased to EUR 40 000 in 2021 and it was raised to EUR 50 000 for 2022. However, these values are maximum values.

In 2020, the emission threshold in France for which the additional fee was charged equalled to 138 g CO_2 per km. A vehicle emitting between 138 and 160 g CO_2 per kilometre was subject to an emission fee of EUR 1 000 on registration. In 2021, this limit was reduced to 131 g CO_2 per km and is to be reduced again to 123 g CO_2 per km

22 IEA, 2019, http://www.ieahev.org/assets/1/7/Report2019_Switzerland.pdf.
23 Directive (EU) 2019/1161 of the European Parliament and of the Council of 20 June 2019 amending Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles, https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX:32019L1161&from=pl.
24 C40 Cities, *Fossil Fuel Free Streets Declaration*, 2019, https://www.c40.org/other/green-and-healthy-streets.
25 Ch. Nijhuis, *Number of e-buses in German public transport doubled in 2020, fuel cell falling behind - report*, Clean Energy Wire, 2021, https://www.cleanenergywire.org/news/number-e-buses-german-public-transport-doubled-2020-fuel-cell-falling-behind-report.
26 Sustainable BUS, *German fundings for e-buses grow up to 650 million euros*, 2021, https://www.sustainable-bus.com/news/german-fundings-for-e-buses-grow-up-to-650-million-euros/#:~:text=Subsidies%20for%20electric%20buses.&text=of%20300%20million.-,The%20German%20aid%20scheme%20is%20valid%20until%20the%20end%20of,setting%20up%20the%20charging%20infrastructure.
27 T. Stone, *UK government announces 120 funding for electric vehicles*, TTI, 2021, https://www.traffictechnologytoday.com/news/electric-vehicles-ev-infrastructure/uk-government-announced-120m-funding-for-electric-buses.html#:~:text=The%20UK's%20Transport%20Secretary%20Grant,continues%20to%20build%20back%20greener.
28 Czubiński R., *Green Public Transport: local governments aim high* [Zielony Transport Publiczny: samorządy mierzą wysoko], 2021, https://www.transport-publiczny.pl/mobile/zielony-transport-publiczny-samorzady-mierza-wysoko-67564.html

in 2022[29]. On the other hand, an eco-tax has been introduced in the Netherlands, under which, since 2019, high-emission vehicles over 12 years old have been subject to an additional fee of 15% above the applicable property tax. The prices of petrol and diesel fuels are also being raised in the country[30]. As a consequence of these activities, the cost of purchasing a combustion vehicle is constantly increasing, making the electric car more economically attractive.

There are also countries that announce specific dates for banning the sale of internal combustion engine passenger cars.

In Norway, the deadline is 2025 and in Sweden, Denmark, the Netherlands, Slovenia or Ireland the year 2030. Great Britain also plans to ban the sale of internal combustion engine cars in 2030, but to allow the sale of certain hybrid cars until 2035.[31,32]

France and Spain set themselves the goal of 2040.[33] In March 2021, nine countries called on the European Commission to set a specific date after which the sale of internal combustion engine cars will be prohibited within the European Union. This call has proved effective – the proposal for a regulation on CO_2 emission limits published under the Fit for 55 proposed that the ban on registration of new internal combustion engine vehicles should enter into force on 1 January 2035. Although this near deadline may be opposed by the automotive industry, the sector is already aware of the inevitability of the transition to electromobility. This is evidenced by the declarations made by the automotive companies themselves. For instance, Ford is to stop manufacturing internal combustion engine cars in Europe in 2030, as is Jaguar and Land Rover. In addition, recent studies show that 63% of the population in 15 European cities surveyed supports the introduction of the ban on the sale of fossil-fuelled cars after 2030, and only 29% of respondents are against it. The pool of cities surveyed included Warsaw and Cracow - 60% of respondents from both cities support the introduction of the ban after 2030. EU[34] countries are also introducing a number of soft incentives to make the use of electric cars more attractive. They include: free parking of electric cars on public parking spaces, dedicated parking spaces or temporary possibility of using bus lanes. Such solutions were, inter alia, adapted in Germany under the German Electromobility Law (Elektromobilitatsgesetz) of 2015.[35]

The effectiveness of these incentive schemes for the acquisition of electric vehicles is analysed in many studies. Experience with Norway, the leader in the development of electromobility in Europe, shows that exempting the purchase of electric vehicles from VAT is an effective way of increasing the interest in these vehicles. The results of studies carried out in Greece show that the introduction of direct subsidies for the purchase of vehicles is more advantageous than the taxation of CO_2 emissions.[36] In turn, studies carried out on the German market show that the low penetration of the market by electric cars is directly linked to the high price of these vehicles, a barrier that can be reduced through remedies such as tax and energy cost reductions or the provision of a dense charging station network.[37]

29 C. Hampel, France decreases electric vehicle subsidies as sales rise, Electrive.com, 2020, https://www.electrive.com/2020/09/29/france-decreases-ev-subsidies-as-sales-rise140521/.

30 The Wallbox, *The ultimate guide to EV initiatives in the Netherlands*, 2020, https://wallbox.com/en_us/netherlands-ev-incentives.

31 J. Jolly, *Car industry lobbied UK government to delay ban on petrol and diesel cars*, The Guardian, 2021,https://www.theguardian.com/business/2021/mar/15/car-industry-lobbied-uk-government-delay-ban-petrol-diesel-cars

32 In years 2030-2035, new passenger and commercial vehicles will be sold provided they are zero-emission highly capable, including some plug-in hybrids and full hybrids. The definition of zero-emission high capability will be consulted as early as this year.

33 S. Wappelhorst, H. Cui, *Growing momentum: Global overview of government targets for phasing out sales of new internal combustion engine vehicles*, The International Council on Clean Transportation, 2020,https://theicct.org/blog/staff/global-ice-phaseout-nov2020#:~:text=In%20addition%2C%20the%20country%20is,Ireland%2C%20Slovenia%2C%20and%20Sweden.

34 E. Bannon, *In cities 63% support EU ban on petrol and diesel car sales after 2030*, Transport & Environment, 2021, https://www.transportenvironment.org/press/cities-63-support-eu-ban-petrol-and-diesel-car-sales-after-2030.

35 The Wallbox, *The ultimate guide to EV initiatives in Germany*, 2020, https://wallbox.com/en_catalog/ev-incentives-in-germany.

36 E. A. Nanaki, S. Kiartzis, G. A. Xydis, *Are only demand-based policy incentives enough to deploy electromobility?*, Policy Studies, 2020, https://www.heliev.gr/wp-content/uploads/2020/02/Are-only-demand-based-policy-incentives-enough-to-deploy-electromobility-1.pdf.

37 J. A. Bühne, D. Gruschwitz, J. Hölscher, *How to promote electromobility for European car drivers? Obstacles to overcome for a broad market penetration*, European Transport Research Review, 2015, https://etrr.springeropen.com/articles/10.1007/s12544-015-0178-0.

Tariffs

Another mechanism supporting efficient transport electrification are adapted electricity sales tariffs. From the Polish charging points network expansion point of view, the introduction of the so-called E-tariff constitutes a breakthrough. The new tariff group, which entered into force on 1 April 2021, is dedicated exclusively to publicly available charging stations. Its task is to reduce the fixed operating costs of charging stations by reducing the cost of charging stations' energy supply. With the introduction of this tariff, the financial burden associated with the maintenance of the station was transferred from the fixed component to the variable component, reflecting actual electricity consumption. Where the use of a station does not exceed 10% of its capacity, the fixed distribution charge shall be abolished in exchange for introducing a three-fold increase in distribution variable fee. The elimination of fixed costs in the current situation of low charging station utilisation is an opportunity for dynamic market development, since with the number of charging sessions in Poland as low as it is now, covering high fixed costs and achieving station profitability is practically impossible. The introduced e-tariff can therefore make a significant contribution to eliminating this barrier.

Considering the ability to meet the increased demand for electricity and capacity from the grid, it may be necessary to introduce time-differentiated tariffs. They will allow to shift the electricity consumption and capacity demand over time, relieving NPS from peak load hours. However, in order to achieve the best possible quality change compared to the current model dominated by fixed prices, the flexible tariff system must be adequately designed. The table below presents the main categories of time-variable tariffs.

Tab. 3. Time variable tariff categories

Tariff categories	Characteristics
Time-of-Use Rates (TOU)	The price varies over specified hours of the day (depending on demand, i.e. peak or off-peak). These may be different hours depending on the time of the year, but both the prices and the hours of the price range are fixed on a permanent basis
Peak Time Rebate (PTR)	Consumers receive payment for demand reduction during peak hours
Critical Peak Pricing (CPP)	Tariff reflecting higher costs of the system on specific days or hours
Real Time Pricing (RTP)	The price changes in real time (usually from hour to hour) depending on the balance between demand and supply. The reference price is normally the day-ahead market price

Source: Forum Energii, *Dynamic and just. Network tariff design for the future in Poland*, 2021, https://forum-energii.eu/en/analizy/taryfy.

Although dynamic tariffs are not yet widespread, there is a gradual change in the approach to charging. Although dynamic tariffs have not yet been introduced in Poland, countries such as Norway, Spain, Estonia and Sweden already benefit from them. A dynamic tariff model is a cheaper - than grid expansion - way to meet the increased demand for capacity and electricity. It allows to change the demand profile - reducing it at the peak and increasing the load curve at the bottom, which supports balancing the energy system. This is due to the introduction of lower electricity prices at a time when demand for electricity is low and higher at high demand times. Consequently, price-driven energy users charge their cars at a time of lower demand, thereby relieving the grid. Studies carried out by the Norwegian Water Resources and Energy Directorate (NVE) have shown that smart charging of electric cars with the support of price signals allows handling the EV electricity demand in the future. In the uncontrolled charging scenario, the development of electromobility will require grid investments in the amount of PLN 400-800 million[38]. However, the application of dynamic tariffs depends on several factors, including large-scale deployment of smart meters. The key is to send the price signal to the recipient and correlate the model of using the car with the price. The user must be able to connect to a charging point at the right time.

38 Regulatory Assistance Project, *Start with smart: Promising practices for integrating electric vehicles into the grid*, 2019, https://www.raponline.org/wp-content/uploads/2019/03/rap-start-with-smart-ev-integration-policies-2019-april-final.pdf.

2.3. Existing market growth forecasts in Poland and worldwide

The introduction of appropriate and effective incentive mechanisms will be a key factor in supporting faster electrification of road transport. Their lack has hitherto caused that the achievement of 1 million electric vehicles in the Polish fleet by 2025. is unrealistic. This has already been reflected *in the Sustainable Transport Development Strategy up to 2030* of 2019, which forecasts that in 2030 600 thousand batteries and hybrid plug-in-type vehicles will be registered in Poland.[39] The latest report of the Polish Alternative Fuels Association (PSPA) "Polish EV Outlook 2020" proposes further updated scenarios for the development of the EV market in Poland. In the realistic scenario involving the introduction of subsidies for the development of electromobility in the form of subsidies or tax incentives, it is expected that in 2025 over 280 thousand fully electric vehicles (BEVs) might be driven on Polish roads and that their number may reach 900 thousand in 2030. In the absence of appropriate aid, the fleet of electric cars running on Polish roads in 2025 will be approximately twice as low as in the scenario assuming support mechanisms. In addition, there is also an increase in interest in hybrid plug-in vehicles.

According to PSPA forecasts, there will be 160 thousand pieces in Poland in 2025 and even around 570 thousand pieces in 2030. In total, according to forecasts, approx. 1.5 million zero-emission and low-emission vehicles will be driven around Poland by 2030. The analysis of other forecasts taking into account current trends in the sector indicates a different pace of development of electromobility in Poland.

Published in August 2020 scientific publication of Piotrowski et al. (2020), which also tests various development scenarios based on historical data, predicts that 101 324 BEV type vehicles, 60 477 PHEV type vehicles, i.e. total of 161 801 electric cars will be registered in the optimistic scenario in 2025. The balanced scenario assumes that the fleet is expected to increase to 81 894 electric vehicles (total of BEV and PHEV)[40]. In the case of buses and heavy vehicles, the optimistic scenario assumes that their fleet will increase to 5005 electric buses and 9410 electric commercial vehicles (in total 14 415), and the balanced scenario estimates their total of only 5769 pieces.

In Italy, on the other hand, 6 million electric vehicles, including 4 million BEV type vehicles, are to be driven by 2030. The Netherlands plans to achieve a 100% share of zero-emission vehicles (ZEVs) in the sale of new passenger cars by 2030, and in 2025 50% of the taxi fleet is to be ZEV vehicles.[41] In the case of charging points, approximately 165 000 public charging points for electric vehicles were available within the European Union in 2020, but the European Commission proposes that their number should increase to 1 million by 2025 in order to meet the requirements of the European Green Deal[42]. According to PSPA forecasts, the number of charging points available in Poland is expected to increase to 40 thousand in 2025 and 91 thousand in 2030.[43]

This report also proposes scenarios for the development of electromobility in Poland. These scenarios are based on the previous work of Forum Energii[44,45,46]. Based on the above sources, it is estimated that in the baseline scenario in 2030 the EV fleet will amount to approx. 700 thousand vehicles and will be supported by approx. 785 thousand private charging points (including typical household sockets) and public ones, and then it will increase to 4.1 million vehicles and approx. 8.6 million charging points by 2050. The alternative scenario proposes a more dynamic growth rate to achieve 17.5 million electric vehicles and 19.7 million private and public charging points by 2050. Details of these scenarios are presented in section 4.1.

---

39 Ministry of Infrastructure, *Sustainable Transport Development Strategy up to 2030*, 2019, https://www.gov.pl/web/infrastruktura/projekt-strategii-zrownowazonego-rozwoju-transportu-do-2030-annuy2.

40 P. Piotrowski, D. Baczyński, S. Robak, M. Kopyt, M. Piekarz & M. Polewaczyk, *Comprehensive forecast of electromobility mid-term development in Poland and its impacts on power demand system*, 2020, http://journals.pan.pl/Content/117262/PDF/06_697-709_01508_Bpast.No.68-4_27.08.20.pdf.

41 International Energy Agency, *Global EV Outlook 2020*, 2020, https://webstore.iea.org/download/direct/3007.

42 International Energy Agency, *Global EV Outlook 2020*, 2020, https://webstore.iea.org/download/direct/3007.

43 Polish Alternative Fuels Association, Polish EV Outlook 2020, https://orpa.pl/najnowsza-prognoza-rozwoju-elektromobilnosci-w-polsce/.

44 Forum Energii, *How to fill the coal gap? 43% RES by 2030*, 2020, https://forum-energii.eu/en/analizy/jak-wypelnic-luke-weglowa.

45 Forum Energii, Poland: climate neutrality by 2050. Electrification and sector coupling, 2020, https://www.forum-energii.eu/en/analizy/integracja-sektorow.

46 E. Płuska, I. Rackiewicz, M. Rosicki, I. Sobecki, I. Szczepanik-Retka, M. Załupka, A. Skarbek-Żabkin & P. Matuszewski, *Analysis of the state of development and current development trends in the area of electromobility in Poland* [Analiza stanu rozwoju oraz aktualnych trendów rozwojowych w obszarze elektromobilności w Polsce], ATMOTERM S.A. & Forum Elektromobilności, 2019, https://www.gov.pl/web/rozwoj-praca-technologia/rozwoj-elektromobilnosci-w-polsce.

2.4. Logistical conditions for the development of electromobility and review of charging modes and methods depending on the vehicle type

When planning the electric vehicle charging infrastructure, both the technical parameters of the vehicles and their users' charging preferences should be taken into account. In the first case, the key element is the distance a vehicle is able to travel on a single charge. The shorter the distance, the greater the demand for a denser charging points' network. The increase in the fleet of vehicles at a specific location will also increase the demand for charging points.

In addition, it is crucial to understand the demand for charging station type. The types of charging stations for electric cars are divided according to the type of current and their capacity. From a current type perspective, charging points may use alternating current (AC) or direct current (DC). AC points are slower than DC devices and can charge the car with a capacity of up to 22 kW[47]. Such capacity allows a standard vehicle to be charged within 2-5 hours. High and very high power charging points can be distinguished among DC devices. They offer up to 350 kW (very high power charging point), but in Poland the vast majority of points offer 50 kW. There are only a few stations offering a maximum capacity of 150 kW and the first two hubs with 350kW points were launched at the beginning of July 2021. They allow vehicles to be charged very quickly, depending on the capacity, between 15 minutes and 2 hours[48].

Choosing a charging point depends on the type of vehicle to be charged. Home charging will most often take place with low capacity on-board chargers of 3.6-7.4 kW powered by a single-phase or a three-phase current from household installations.[49] However, more and more models of electric passenger cars can also be charged using very high power points (150 kW or more - e.g. Porsche Taycan can use a charging point of up to 250 kW). Stationary charging points between 20 and 500 kW of capacity are designed to charge buses and heavy vehicles. The overview of the types of charging points available on the market is presented in Table 4 below.

47 Grzybowski M., Charging electric vehicles - types of chargers [Ładowanie samochodów elektrycznych – rodzaje ładowarek], Elektryczne Autocentrum, 2019, https://www.autocentrum.pl/publikacje/porady/ladowanie-samochodow-elektrycznych-rodzaje-ladowarek/

48 as above

49 Malinowski M., *Home electric car charging station: types and important parameters* [Domowa stacja ładowania samochodów elektrycznych: rodzaje i ważne parametry], 2020,https://muratordom.pl/instalacje/instalacja-elektryczna/domowa-stacja-ladowania-samochodow-elektrycznych-rodzaje-i-wazne-parametry-aa-vhiW-DQSk-Eckn.html

Tab. 4 Overview of charging points available on the market

Power rating (kW)	Properties	Potential impact of a single installation on the power grid	Potential impact of multiple installations on the power grid
3.7	low power point, capable of supplying power from a single-phase 230 V socket (16 A current)	low for a single installation	the effect of accumulating issues related to the quality parameters of electricity locally, regionally and nationally occurs for a large number of installations
7.4	low power point, capable of supplying power from a single-phase 230 V socket (32 A current)		
11	minor, free-standing charging point supplied by a three-phase 400 V circuit (16 A current)	moderate for a single installation	
22	minor, free-standing charging point supplied by a three-phase 400 V circuit (32 A current)		
40-150	free-standing high power charging point offering direct current charging	high for a single installation	
> 150	very high power charging point allowing quick charging of passenger cars		
20	stationary charging point for charging buses and heavy vehicles		
40			
60			
80			
200			
> 300	very high power pantograph point for quick charging		

Source: Own study based on Kłos, 2019 and literature review.

Another issue is the understanding of users' preferences regarding vehicle charging, which in turn also depend on the vehicle type. According to data from the United States and Western Europe, most of the users of passenger electric cars charge their vehicles at home or at work, only 5% of them use charging points at shopping centres or hubs[50]. Similar preferences are also observed in Poland.

According to the New Mobility Barometer 2020/21 prepared by PSPA, as many as 96.7% of Poles surveyed would most likely take advantage of the option of charging their vehicle at the place of residence[51]. CleanTechnica data shows that more than 80% of electric car owners charge their vehicles at the place of residence, and even if they have access to a charging point at their workplace, they prefer to do it at home.[52] Household charging preferences can be explained by several factors. Firstly, charging at home is cheaper, as the home tariff prices are usually lower than those at public charging stations. Secondly, the relatively long charging time of vehicles discourages users from using public stations instead of charging in the privacy of their homes, especially if there are no leisure activities of interest to the consumer around charging stations[53].

50 Transport & Environment, *Roll-out of public EV charging infrastructure in the EU*, 2018, https://www.transportenvironment.org/press/only-5-percent-ev-charging-happens-public-charging-points.

51 PSPA, *New Electromobility Barometer 2020/21* [Barometr Nowej Elektromobilności 2020/2021], 2020, https://pspa.com.pl/media/2020/11/barometr_nowej_mobilnosci_2020_raport_S_1.pdf

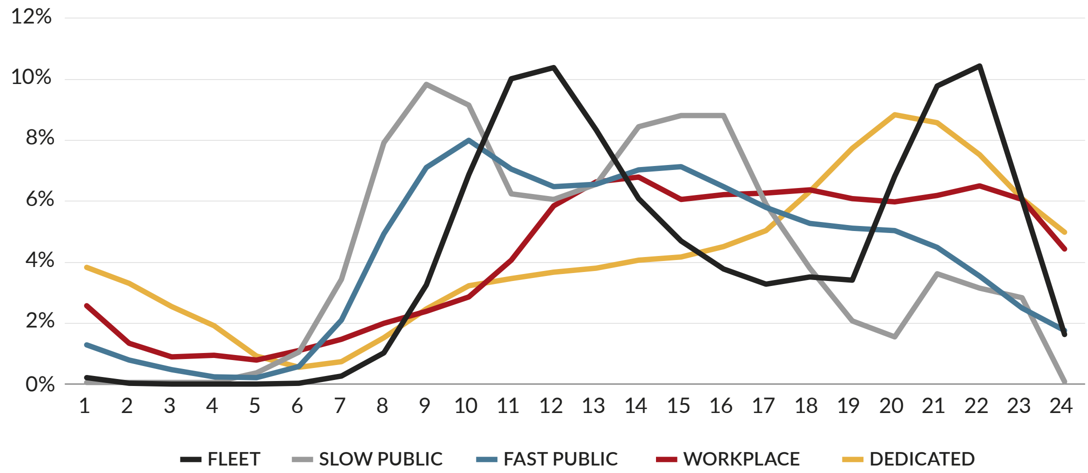
52 Z. Shahan, *CleanTechnica Busts Into Electric Car Wilderness*, Clean Technica, 2015, https://cleantechnica.com/2015/10/31/cleantechnica-busts-into-electric-car-wilderness/.

53 Kwiatkiewicz P., Szczerbowski R., Śledzik W., *Electromobility - infrastructural environment and technical challenges faced by intra-regional policy* [Elektromobilność - środowisko infrastrukturalne i techniczne wyzwania polityki intraregionalnej], Poznań 2020.

However, some electric car users do not have a household charging point, which is even a normal socket of a house or garage installation, and are therefore forced to use the public charging network. In the case of charging a car using a publicly available charging station, as much as 44.2% of Poles declare that the charging time should not exceed 30 minutes, and one hour for 33.9% of respondents[54]. At the same time, nearly 60% of the Poles surveyed believe that the availability of high-power charging points enabling cars to be charged within 30-60 minutes is a priority on long distances connecting main city centres, and over 20% would like to see them in the areas of shopping centres[55].

Preferences related to charging vehicles, also depending on the charging location, determine the profile of power demand from the grid. The highest charging sessions' rate is recorded in afternoon and evening hours and falls significantly at night. Charging sessions at workplaces start at the arrival of workers, i.e. after 9 a.m., reaching a peak in early afternoon hours. Similarly, the highest demand at dedicated charging points (at homes) is observed during evening hours - after 5 p.m., i.e. after returning from work, and the peak is reached during early evening hours (approximately at 8 p.m.). In the case of available public points, the demand varies very intensively throughout the day. The peak is reached during early afternoon hours (approximately at 12 p.m.) and late evening hours (approximately 10 p.m.). Public high power charging points do not record such large differences in the charging session start schedule, but similarly to other points, demand increases here in the morning and decreases at night (Fig. 6). Such large differences in demand for the charging service require the grid to provide sufficient electricity and power at a given time, and where the demand is excessive, it may lead to overload and failure. Therefore, in order to maintain the stability of the system, it is necessary to upgrade the grid to provide the necessary electricity and capacity, as well as to make electric car users active parties in balancing the grid, for example by introducing dynamic tariffs encouraging vehicle charging at a time when the demand for energy and power in the system is falling.

Fig. 6. Charging sessions' start time by hour and location



Source: Forum Energii, Poland: climate neutrality by 2050. Electrification and sector coupling. 2020.

Taking up investments aimed at adapting the grid to the increased demand for electricity and capacity requires an understanding of the current technical condition of the NPS. This is dealt with in chapter there of this report. In turn, chapters 4 to 6 examine the impact of the development scenarios for electromobility on the distribution grid in different areas and estimate the scale of the necessary upgrades.

54 PSPA, *New Electromobility Barometer 2020/21* [Barometr Nowej Elektromobilności 2020/2021], 2020, https://pspa.com.pl/media/2020/11/barometr_nowej_mobilnosci_2020_raport_S_1.pdf

55 PSPA, *New Electromobility Barometer 2020/21* [Barometr Nowej Elektromobilności 2020/2021], 2020, https://pspa.com.pl/media/2020/11/barometr_nowej_mobilnosci_2020_raport_S_1.pdf

3. Diagnosis of the state of distribution grids in the context of electromobility implementation in Poland

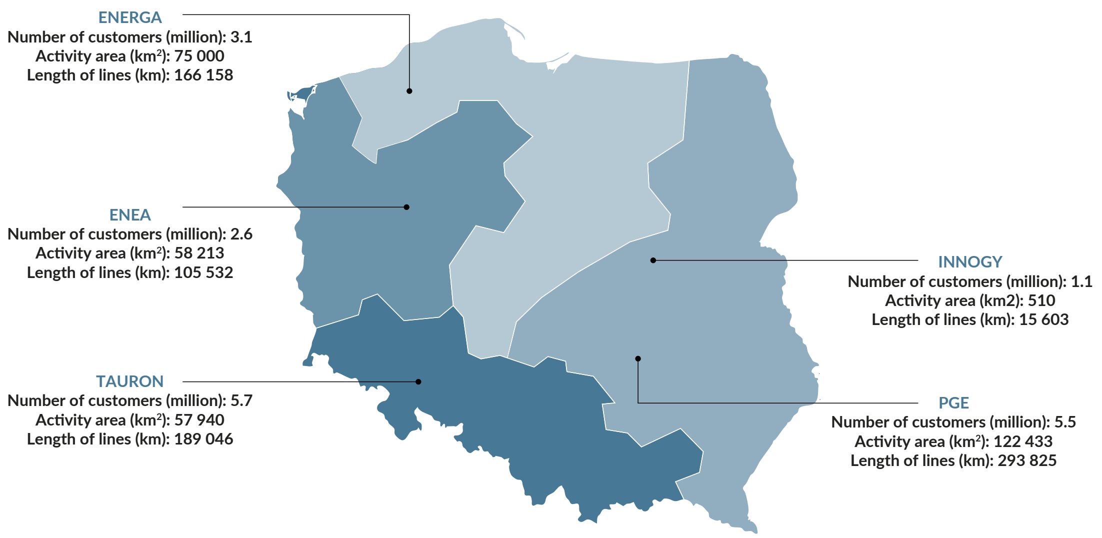
The development of electromobility affects each segment of the national grid and its impact on the medium and low voltage distribution grids is crucial. The electrification of the transport sector entails an increase in electricity demand and capacity demand at individual nodes, which may contribute to local peak overloads of distribution grids and, as a consequence, the deterioration in the reliability of power supply, the quality of power supplied or even grid failures[56].

Investments in the distribution grid must be correlated with the development of electromobility. Efforts to accelerate the rate of electrification of the vehicle fleet must therefore be accompanied by investments aimed at ensuring energy security, which will require investing in the modernisation and expansion of the grid[57].

3.1. Determination of the state of distribution grids in Poland

Distribution System Operators (DSOs) are responsible for energy distribution and delivery to final customers using primarily medium and low voltage lines (MV and LV). Most consumers in Poland receive electricity from five distributors. These include: Tauron Dystrybucja, PGE Dystrybucja, Enea Operator, Energa Operator and Innogy Stoen Operator.

Fig. 3.1.1. Distribution System Operators in Poland



Source: Own study based on PTPiREE 2020 and CIRE 2020 data.

Distribution System Operators are also responsible for making investments in the grid and, in fact, in recent years companies have invested in various types of modernisations and expansion. These investments have slightly "restored" the distribution grid and have contributed positively to increased security and reliability of power supply.

In 2019 Enea Operator allocated over PLN 900 million to upgrade and expand the grid infrastructure, while Energa Operator spent over PLN 1.3 billion for similar purposes. Innogy Stoen Operator allocated over PLN 230 million for

56 U. Maier, F. Peter, A. Jahn & J. Hildermeier, *Distribution grid planning for a successful energy transition - focus on electromobility*, Agora Verkehrswende, Agora Energiewende, Regulatory Assistance Project, 2019, https://www.agora-verkehrswende.de/fileadmin/Projekte/2019/EV-Grid/AgoraRAP2019_VerteilnetzausbauElektromobilitaet_EN.pdf.pdf.

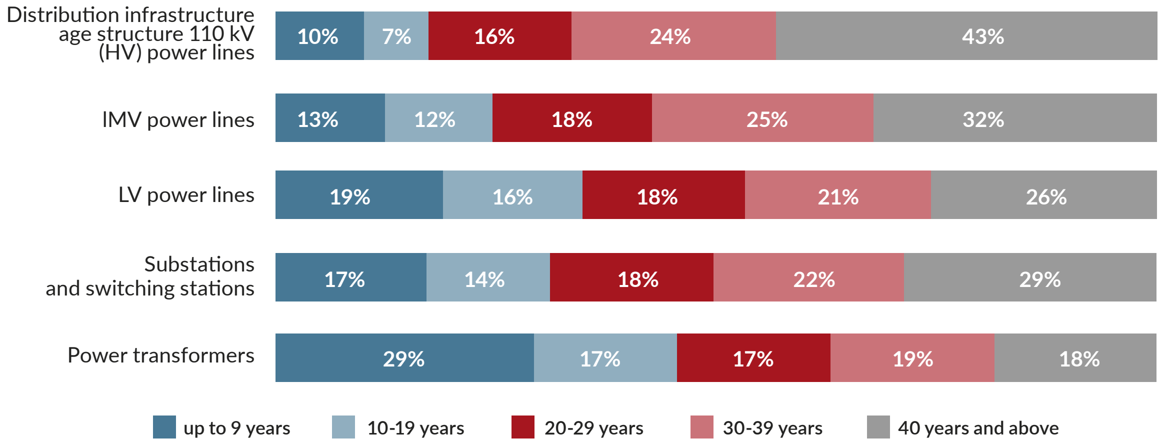
57 Kwiatkiewicz P., Szczerbowski R., Śledzik W., *Electromobility - infrastructural environment and technical challenges faced by intra-regional policy* [Elektromobilność - środowisko infrastrukturalne i techniczne wyzwania polityki intraregionalnej], Poznań 2020.

investments, including PLN 67.5 million for works concerning connections to the low and medium voltage grid, PLN 57 million for the development of the high voltage grid and PLN 18 million for projects with medium voltage grids.

In 2016-2019, PGE Distribution earmarked over PLN 7 billion for investments in grid infrastructure, and in 2019 alone they amounted to PLN 2.2 billion. In the case of Tauron Dystrybucja, investments in the distribution grid, mainly including projects aimed at improving the reliability of electricity supply, amounted to over PLN 1.8 billion in 2019[58]. The investment details of individual companies in 2019 are summarised in Appendix Z.2.

These investments were definitely needed because, according to the latest available data, at the end of 2017, the state of Polish distribution grids was characterised by high age, low density and low level of cabling. According to the study of the Supreme Audit Office (NIK), as many as 90% of high-voltage power lines were over 10 years old in 2017, including 43% of 40 years and over. The condition of medium voltage lines was slightly better, but still as many as 32% of them were over 40 years old and 87% were over 10 years old. Relative youngest were low voltage lines. In 2017, 26% of them were over 40 years old and only 19% less than 10 years old. The condition of power infrastructure was not much better for substations, switching stations or power transformers. More than half of the substations and switching stations were built more than 30 years ago. Despite the fact that power transformers were slightly younger, only 29% of them are under 10 years old and still as many as 54% are over 20 years old[59].

Fig. 8. Age structure of distribution infrastructure in Poland



Source: NIK based on data obtained from audited Distribution System Operators.

In addition, the Polish transmission and distribution grid was characterised by low density and significantly lower number of transformer stations compared to other Western European countries.

Poland has only 41 km of power lines per one thousand km^2. In Germany, this value reaches 100 km and even 161 km in Switzerland[60].

In other Western European countries, the lack of infrastructure quality resulting from, for instance, its age is often compensated by grid density[61]. Another, and still present, problem of the Polish power grid is the low level of cabling, i.e. replacing overhead lines with underground lines. Despite investments made in recent years, in 2019, only 27.6%

58 PTPiREE, *Power industry, distribution and transmission* [Energetyka dystrybucja i przesył], 2020, http://www.ptpiree.pl/raporty/2020/raport_ptpiree_druk.pdf.

59 Supreme Audit Office, *Protection of electricity consumer rights* [Ochrona praw konsumenta energii elektrycznej], 2018, https://www.nik.gov.pl/aktualnosci/ochrona-praw-konsumenta-energii.html

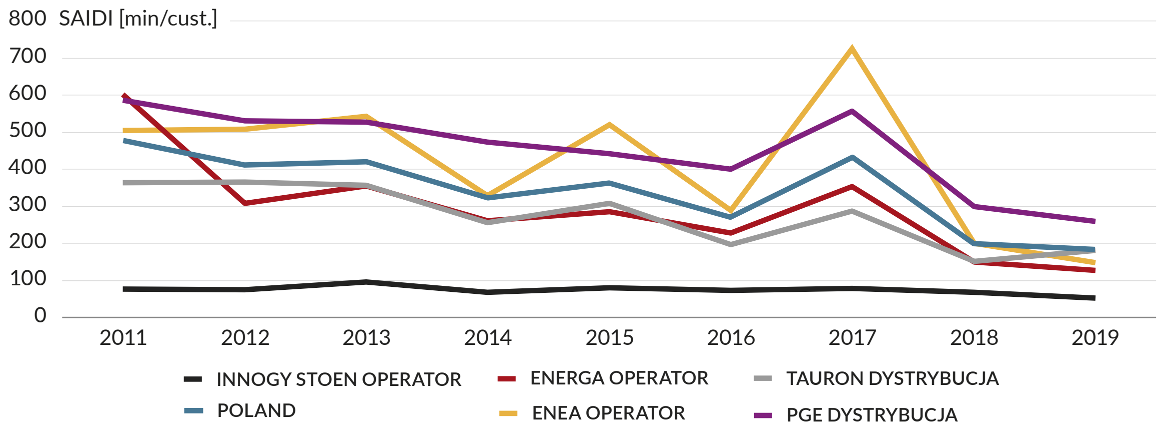
60 S.Zakrzewska, A. Gil-Świderska & P. Szmitkowski, *Age structure of the Polish electrical power infrastructure* [Struktura wiekowa polskiej infrastruktury energetycznej], 2020, https://www.cire.pl/pliki/2/2020/str_wiek.pdf

61 Portal na rzecz czystej energii i klimatu, *Polish power sector needs innovations. Not only due to excessive heat* [Polska energetyka potrzebuje innowacji. Nie tylko ze względu na upały], 2018, https://leonardo-energy.pl/artykuly/polska-energetyka-potrzebuje-innowacji-nie-tylko-ze-wzgledu-na-upaly/.

of the medium voltage grid and 35% of low voltage was cabled. This is one of[62] the lowest coefficients in Europe[63] and has a real impact on the continuity of power supply to customers and the ability to connect other entities to the grid.

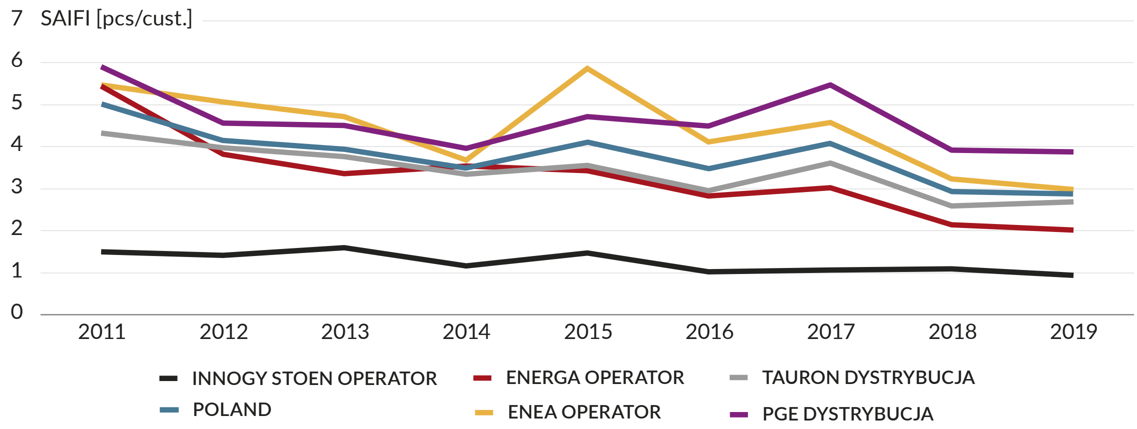
The age structure and the degree of cabling of Polish distribution grids make it faulty and sensitive to atmospheric phenomena. As a result, this leads to long interruptions in electricity supply compared to other Western European countries. The duration of interruptions in electricity supply is determined by the System Average Interruption Duration Index (SAIDI) and (System Average Interruption Frequency Index) SAIFI. SAIDI is to be understood as the total duration of power interruptions (in minutes) that the consumer can expect on average annually, without unplanned disaster interruptions. SAIFI, in turn, informs about the frequency (units) of interruptions that the recipient is experiencing on average annually. As shown in Fig. 9 and Fig. 10, Innogy Stoen Operator notes significantly lower SAIDI and SAIFI indexes than other distributors. In 2019 SAIDI for this operator was 52.51 min/cust., when in the case of PGE Dystrybucja it was 260.51 min/cust. Analogically, in 2019 Innogy Stoen Operator had the lowest value of SAIFI compared to other distributors - 0.94 units/cust., while PGE Dystrybucja the highest and equal to 3.88 units/cust.

Fig. 9. SAIDI indexes on HV, MV and LV among five largest DSOs in Poland



Source: Own study on the basis of PTPiREE, 2020.

Fig. 10. SAIFI indexes on HV, MV and LV among five largest DSOs in Poland



Source: Own study on the basis of PTPiREE, 2020.

62 PTPiREE, *Power industry, distribution and transmission* [Energetyka dystrybucja i przesył], 2020, http://www.ptpiree.pl/raporty/2020/raport_ptpiree_druk.pdf

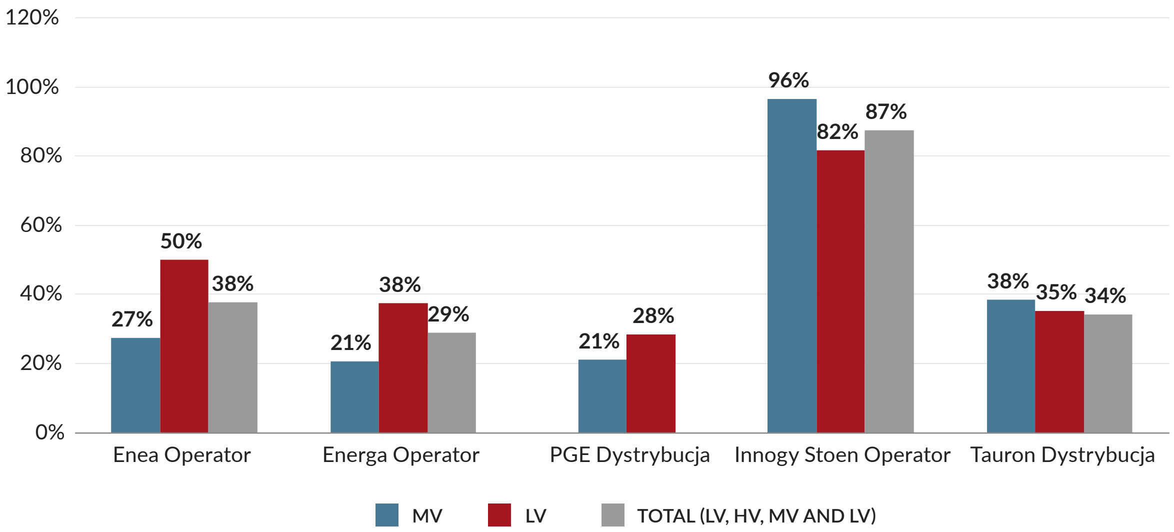
63 R. Tomaszewski, *Power grid needs a revolution: how to transform the Polish power distribution sector* [Sieć do zmainy: jak zreformować polski sektor dystrybucji energii elektrycznej], Polityka Insight, 2019, https://www.politykainsight.pl/prawo/_resource/multimedium/20182100

SAIDI and SAIFI indexes for individual electricity distributors have slightly improved over recent years, which may be reflected by investments made. However, the correlation between SAIDI and SAIFI levels and the degree of cabling offered by operators is important.

Innogy Stoen Operator is a DSO with the largest share of underground cables in Poland. Of all the grids owned by the company, more than 87% of them are underground, and in the case of MV, this even exceeds 96%. The distributors with the poorest grid cabling are PGE Dystrybucja and Energa Operator, which have respectively about 21% and 20.5% of MV cable grids in their portfolio.

It is clear from the analysis of the data in Figures 9, 10 and 11 that operators with the most extensive grid cabling experience the lowest and least frequent interruptions in electricity supply. The increase of indexes in 2017 was caused by storms which were passing through the country at the time. This event further illustrates that overhead grids are more susceptible to a failure. This dependency also exists in other European countries. Countries such as Denmark, the Netherlands and Germany, where already in 2016 the cabling was properly laid in 86%, 100% and 78% respectively, show significantly lower SAIDI and SAIFI indexes than those with low grid cabling degree. For example, in 2016 SAIDI equalled to 14 min/customer in Germany and SAIFI only 0.4 of interruptions per customer. In Poland, however, it was 205 min/customer and 3.5 interruptions/customer, respectively.[64,65]

Fig. 11. Degree of cabling of distribution grids among five largest DSOs in Poland in 2019



Source: Own study on the basis of: PTPiREE, 2020.

Increasing the share of underground lines is one of the priorities for Polish DSOs. For instance, in 2019 Enea Operator completed the modification of 674.4 km of overhead lines, replacing them, among others, with underground cables, and PGE Dystrybucja moved 950 km of MV grid underground[66]. It is recommended that the Polish distribution grids achieve a much higher cabling level- at 75% for medium voltage grids and 65% for low voltage grids[67]. However, such values are similar to those of Western European countries, and the costs of necessary investments to achieve this goal will exceed PLN 46 billion[68]. With the current level of investment expenditure of distribution grid operators, this

64 W. Chojnacki, *Cabling of low and medium voltage distribution grids* [Kablowanie sieci dystrybucyjnych średniego i niskiego napięcia], 2019, https://www.elektro.info.pl/artykul/kable-i-przewody/150706,kablowanie-sieci-dystrybucyjnych-sredniego-i-niskiego-napiecia.

65 Council of European Energy Regulators, *CEER Benchmarking Report 6.1 on the Continuity of Electricity and Gas Supply*, 2018, https://www.ceer.eu/documents/104400/-/-/963153e6-2f42-78eb-22a4-06f1552dd34c.

66 PTPiREE, Energetyka dystrybucja i przesył [Power industry, distribution and transmission], 2020, http://www.ptpiree.pl/raporty/2020/raport_ptpiree_druk.pdf.

67 PTPiREE, *Power industry: Distribution and transmission* [Energetyka dystrybucja i przesył], 2018, http://www.ptpiree.pl/_examples/raport_2018/raport_ptpiree.pdf.

68 PTPiREE, *Power industry: Distribution and transmission* [Energetyka dystrybucja i przesył], 2018, http://www.ptpiree.pl/_examples/raport_2018/raport_ptpiree.pdf.

degree of cabling will only be possible in 2070[69]. Grid upgrades are very costly, but they have to be undertaken now in order to allow a rapid and secure transition towards a new model of energy based on dispersed generation, as well as an electrified transport sector. At present, with rapid development of electromobility, the technical condition of the Polish distribution grid is still insufficient to enable reliability and security of electricity supply[70]. One of the biggest technical threats related to the impact of the development of electromobility in Poland on the functioning of the power grid is the overload of currently existing elements of the distribution grid, mainly transformers and power lines. Increasing active and reactive power demand and changing the daily load profile may contribute to even more frequent and longer grid failures.

3.2. Challenges for existing infrastructure related to the development of the EV market

Mass charging of electric vehicles will result in an increase in peak capacity demand, leading to an increase in peak loads[71] and, as a result, an increased likelihood of grid failure. The increase in the fleet of electric vehicles to around 700 thousand in 2030, as calculated by Forum Energii, will lead to an increase in electricity demand of almost 3 TWh.[72] According to the estimates of the Ministry of Energy, one million electric cars in Poland will cause a 4.3 TWh increase in electricity demand annually[73], and according to the study of the Institute of Heat Engineering of the Warsaw University of Technology it will be 4.41TWh[74]. This is equivalent to a maximum of about 5-6% increase in one-off power consumption[75].

Although such an increase is not very significant considering the systemic level, it will be important at the local level, for example in urban agglomerations. Grid overloads may be caused by the charging of a small number of vehicles requiring high power or a large number of vehicles requiring low power but located within a short distance from each other, and especially during peak hours of power demand in the area concerned. Furthermore, the emergence of a large number of such receivers in the grid has a negative impact on the quality of electricity. The increase in the number of charging points operating within the same circuit will increase the risk of uneven energy consumption, i.e. increasing the differences between peak and off-peak demand[76], and may also contribute to more frequent decreases and voltage fluctuations. This problem will grow with the increase in the number, density and capacity of charging stations[77] and may be particularly noticeable in large agglomerations. All of the above effects of electric vehicles on the grid pose major challenges for DSOs and it is therefore so important to plan the infrastructure accordingly, taking into account local grid conditions.

69 R. Tomaszewski, Power grid needs a revolution: how to transform the Polish power distribution sector [Sieć do zmainy: jak zreformować polski sektor dystrybucji energii elektrycznej], Polityka Insight, 2019, https://www.politykainsight.pl/prawo/_resource/multimedium/20182100

70 M. Kłos, *Elektromobilność. Development of electromobility in Poland and related challenges for the power system* [Rozwój elektromobilności w Polsce i związane z tym wyzwania dla systemu elektroenergetycznego], 2020, https://www.muratorplus.pl/technika/elektroenergetyka/elektromobilnosc-w-polsce-rozwoj-elektrom.

71 U. Maier, F. Peter, A. Jahn & J. Hildermeier, *Distribution grid planning for a successful energy transition - focus on electromobility*, Agora Verkehrswende, Agora Energiewende, Regulatory Assistance Project, 2019, https://www.agora-verkehrswende.de/fileadmin/Projekte/2019/EV-Grid/AgoraRAP2019_VerteilnetzausbauElektromobilitaet_EN.pdf.pdf.

72 M. Borkowski, *Electromobility - issue or remedy for the power system* [Elektromobilność - problem czy lekarstwo dla systemu elektroenergetycznego], Forum Energii, 2020, https://www.forum-energii.eu/pl/blog/elektromobilnosc-kse?utm_source=twitter&utm_medium=post_13112020&utm_campaign=EV.

73 Ministry of Energy, *Electromobility Development Plan in Poland "Energy for the future"*, 2017, https://www.gov.pl/documents/33372/436746/DIT_PRE_PL.pdf/ebdf4105-ef77-91df-0ace-8fbb2dd18140.

74 Bralewski P., Szabłowski ł., Badyda K., Bujalski W., *Perspectives for the development of electromobility in Poland from the point of view of the National Power System* [Perspektywy rozwoju elektromobilności w Polsce z punktu widzenia Krajowego Systemu Elektroenergetycznego], "Nowa Energia" No. 4/2018.

75 Bralewski P., Szabłowski ł., Badyda K., Bujalski W., *Perspectives for the development of electromobility in Poland from the point of view of the National Power System* [Perspektywy rozwoju elektromobilności w Polsce z punktu widzenia Krajowego Systemu Elektroenergetycznego], "Nowa Energia" No. 4/2018.

76 Bralewski P., Szabłowski ł., Badyda K., Bujalski W., *Perspectives for the development of electromobility in Poland from the point of view of the National Power System* [Perspektywy rozwoju elektromobilności w Polsce z punktu widzenia Krajowego Systemu Elektroenergetycznego], "Nowa Energia" No. 4/2018.

77 E. Płuska, I. Rackiewicz, M. Rosicki, I. Sobecki, I. Szczepanik-Retka, M. Załupka, A. Skarbek-Żabkin & P. Matuszewski, *Analysis of the state of development and current development trends in the area of electromobility in Poland* [Analiza stanu rozwoju oraz aktualnych trendów rozwojowych w obszarze elektromobilności w Polsce], ATMOTERM S.A. & Forum Elektromobilności, 2019, https://www.gov.pl/web/rozwoj-praca-technologia/rozwoj-elektromobilnosci-w-polsce.

3.3. Scope of necessary modifications to the existing infrastructure related to the development of the EV market

In view of the challenges described above, the possibility of safe development of electromobility in Poland for the grid and the entire power system require modification of the existing grid infrastructure. The main tasks are to adapt the grid to the growing demand for electricity and capacity as well as to the volatility of the demand profile. The upgrades in this direction will take the form of both infrastructure expansion and grid upgrades which take into account increasing their flexibility, i.e. the ability to balance electricity supply and demand in different timeframes.

Modernisation and expansion of the grid

Local grid overloads due to connection of charging points and increase of instantaneous power demand may be limited by upgrading and expanding the grid. As necessary upgrades distribution grid operators indicate:

- Replacement of existing cables with those with higher transmission capacity,
- Replacement of transformers into units of higher capacity
- Expansion of transformer stations[78].

The expansion of the grid will be particularly important in areas where a dense charging station network is planned. Another issue is the supply of charging points from local power sources (microinstallations), e.g. in connection with energy storage means. This solution can be applied both in rural, urban and rural areas as well as in areas with large agglomerations.

Investment in smart charging and vehicle-grid technologies

One of characteristics features of the power system is its technologically limited capability of storing energy on a large scale. The demand for electricity and capacity varies over time and depends on many technical and external factors. Changes in capacity demand result in the need for continuous balancing of the grid, and with an increase in the number of electric cars, this demand will be increasingly variable. The increasing share of renewable energy sources will have an additional impact on the grid. It is therefore necessary to upgrade the grids by adapting them to uneven power consumption. The way to maintain the continuity of grid operation in conditions of increased generation and capacity fluctuations is to increase grid flexibility.[79] Greater grid flexibility can be achieved through the use of smart devices, including smart meters, information systems enabling the proper integration of vehicles into the grid and allowing controlled, optimal (a two-way as the final variant) energy flow as well as the expansion of energy storage facilities. This will also help to achieve better control over grid capacity demand and efficient grid management by DSOs. The main objective of proper integration and its core is to use batteries of electric cars as mobile energy storage means.[80] In order for this integration to take effect, it is necessary to develop an appropriate measurement and control infrastructure and to automate the operation of the grid.

Currently, there are two technologies for integrating electric vehicles into the power grid

1) smart charging, V1G
2) *vehicle-to-grid* (V2G) technology.

V1G allows controlling the energy flow from the grid to the vehicle while adjusting the time - start and end of charging - as well as the volume of energy consumption when charging the vehicle[81].

V2G goes beyond V1G as it additionally allows reversing the direction of energy flow, from the vehicle to the grid. It therefore allows for the consumption, storage and provision of electricity according to grid needs in the area concerned.

---

78 Czernicki Ł., Maj M., Miniszewski M, *How to support electromobility?* [Jak wspierać elektromobilności?], ed. B. Sobik, Economic Institute, Warsaw 2019, http://pie.net.pl/wp-content/uploads/2019/10/PIE-Raport_Elektromobilnosc.pdf

79 Komisja Europejska, *Effect of electromobility on the power system and the integration of RES*, 2018,https://ec.europa.eu/energy/sites/ener/files/documents/metis_s13_final_report_electromobility_201806.pdf.

80 D. Jóźwiak & M. Drechny, *Analysis of the possibilities of using V2G technology for power system balancing*, 2019, http://pe.org.pl/articles/2019/10/12.pdf.

81 Keay-Bright, *Accelerating electromobility in east Europe: a how-to guide (part 1)*, 2019, https://energypost.eu/accelerating-electromobility-in-east-europe-a-how-to-guide-part-1/.

By opening data transmission paths, smart charging (V1G) enables communication between the vehicle and the grid in order to optimise charging at a given location and time, taking into account its current state and conditions.

This solution contributes to reducing peak grid load, reducing or even eliminating the need to expand it[82]. In addition, it is an economically efficient solution, as it enables billions of savings which could be invested in the grid, while ensuring its flexibility[83]. However, this requires strict planning. Similarly to V1G, V2G supports the stability of the grid with periodic increased capacity and electricity demand at a given time and place. However, in this solution, an electric vehicle acts as a dispersed energy source that consumes electricity at a time when the capacity demand is not high (e.g. at night) and returns it, upon the request of DSOs, when the demand is increased and the grid is heavily used. This allows a two-way energy exchange between the electric car and the grid, reducing the risk of grid overload and possible failures. The benefits of V2G technology deployment are potentially greater than those achieved by V1G.

On the other hand, the implementation of V2G requires much greater investment compared to V1G, which has a different impact on the charging infrastructure than one-way transmission[84]. V2G charging points can be up to three times more expensive than normal one-way points, and all of them currently operate only in the ChaDeMo standard – which is a big constraint. Furthermore, V2G has the chance to significantly impact the grid only if the number of charging points available corresponds to the number of EV, which must also be significant. Since today's investments are mainly aimed at supporting the mass dissemination of electric vehicles and ensuring the wide availability of charging stations with one-way charging points, V1G is today more technologically and economically competitive solution than V2G, and investment in this technology is more frequent both in Poland and in other European Union countries.

Both V1G and V2G form part of the smart grid concept. Smart grids enable communication between electricity generators and consumers and thus optimise the operation of the entire system[85]. Failure to communicate would prevent the operation of both V1G and V2G technologies. However, in order for this communication to be possible, it is necessary to automate the grid and install smart meters. The construction of smart grids is one of the priorities of DSOs in European countries, inter alia, due to the need to electrify transport and the increasing number of prosumers connected to the grid. In Poland, this will require significant investments and large-scale adaptation of smart meters as well as development of integrated information exchange systems, such as the Central Energy Market Information System (CSIRE), which will constitute a data hub for all market participants and players, including operators of publicly available charging stations.

Investments in grid automation and smart meters

Grid automation, supported by smart decision support systems in distribution traffic management systems and grid monitoring through the use of, inter alia, smart meters, will contribute to increasing grid flexibility and thus its reliability[86]. Better monitoring of switching stations will depend on the state of deployment of smart meters, which in turn will affect the possibility of safe integration into the dispersed generation grid and electric vehicles. According to Eurelectric estimates, the adaptation of distribution grids to changing economic and climate conditions will require Europe to invest (EU and UK) EUR 400 billion by 2030. The investments in grid automation and digitisation alone should amount to approximately EUR 25 - 30 billion and an additional EUR 30 - 35 billion should be spent on the deployment of smart meters[87]. The scale of the necessary investments is therefore huge, and the projects currently undertaken in Poland may prove insufficient.

82 U. Maier, F. Peter, A. Jahn & J. Hildermeier, *Distribution grid planning for a successful energy transition - focus on electromobility*, Agora Verkehrswende, Agora Energiewende, Regulatory Assistance Project, 2019, https://www.agora-verkehrswende.de/fileadmin/Projekte/2019/EV-Grid/AgoraRAP2019_VerteilnetzausbauElektromobilitaet_EN.pdf.pdf.

83 IRENA, *Innovation Outlook: Smart charging for electric vehicles*, 2019, https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Innovation_Outlook_EV_smart_charging_2019.pdf.

84 details related to the subject in: Barone et al. 2020. How Smart Metering and Smart Charging may Help a Local Energy Community in Collective Self-Consumption in Presence of Electric Vehicles: https://www.mdpi.com/1996-1073/13/16/4163

85 PSPA, *Electric vehicles as an element of power grids* [Pojazdy elektryczne jako element sieci elektroenergetycznych], 2018, https://pspa.com.pl/media/2020/08/V2G_raport_S.pdf.

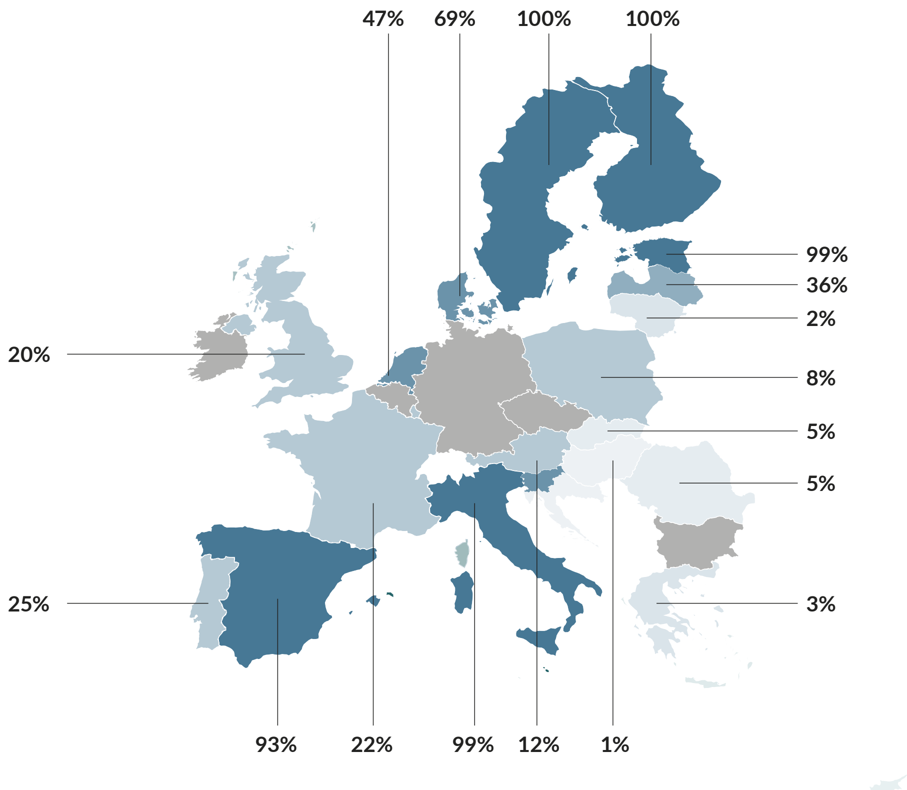
86 M. Borkowski, *Electromobility - issue or remedy for the power system* [Elektromobilność - problem czy lekarstwo dla systemu elektroenergetycznego], Forum Energii, 2020, https://www.forum-energii.eu/pl/blog/elektromobilnosc-kse?utm_source=twitter&utm_medium=post_13112020&utm_campaign=EV.

87 S. van Ranssen, Local grid investments can make or break the energy transition, Energy Monitor, 2021, https://energymonitor.ai/tech/networks-grids/local-grid-investments-can-make-or-break-the-energy-transition.

In terms of smart meters installation, Poland is at the end of the list among European countries. In 2018, smart meters installed in Poland accounted only for 8.4% of electricity consumers (Fig. 12). By comparison, the European average is 34.2% and the most advanced countries in implementing this technology are Sweden (100%), Finland (99.8%), Estonia (98.9%) or Italy (98.5%)[88]. The pace of smart meters implementation in Poland varies between electricity distributors.

The most advanced operator, considering this technology, is Energa Operator - currently more than 950 thousand customers connected to the company's grid use this type of equipment, and on 19 November 2020 the distributor announced plans to start installing another 600 thousand smart meters in 2021. This is to allow covering approximately half of the company's customers with meters enabling remote reading in 2021[89]. Innogy Stoen Operator takes the second place with 10% of customers having smart meters installed. Enea Operator falls behind in this area[90]. The slow pace of implementation of smart meters in Poland is linked to the fact that no specific regulations have existed so far. Only *the Act amending the Energy Law and other acts of June 2021* provides that remote reading meters will be installed by the end of 2023 at least at 15% of customers of a given DSO, two years later - 35%, at the end of 2027 at least at 65%, and by the end of 2028 at least at 80% of customers[91].

Fig. 12. Smart meters implementation degree in the countries of European Union, status as of 2018



Source: Own study on thebasis of data of European Commission, 2020. Grey colour - no data available.

88 European Commission, *Benchmarking smart metering deployment in the EU-28*, 2020, https://op.europa.eu/en/publication-detail/-/publication/b397ef73-698f-11ea-b735-01aa75ed71a1.

89 Energa Operator, 2020, https://media.energa.pl/pr/598609/polowa-klientow-energi-operatora-z-licznikami-zdalnego-odczytu-w-2021-r.

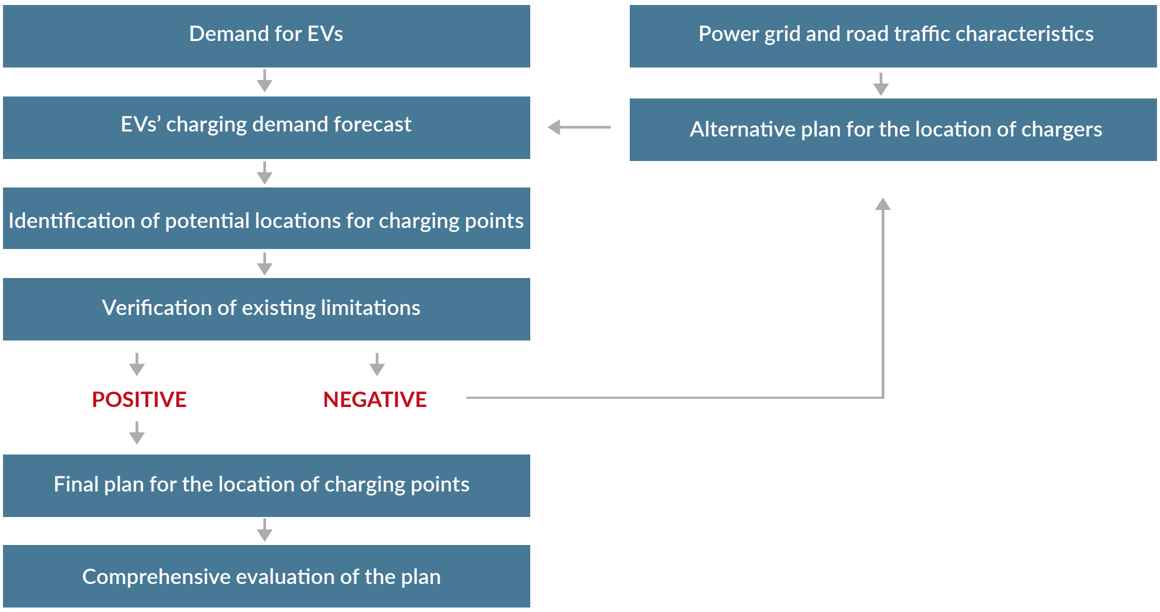
90 R. Tomaszewski, Power grid needs a revolution: how to transform the Polish power distribution sector [Sieć do zmainy: jak zreformować polski sektor dystrybucji energii elektrycznej], Polityka Insight, 2019, https://www.politykainsight.pl/prawo/_resource/multimedium/20182100.

91 Ministry of Climate and Environment, *Draft Act amending the Act on Electromobility and Alternative Fuels and Certain Other Acts*, 2021, https://legislacja.rcl.gov.pl/projekt/12340506.

3.4. Charging infrastructure planning process

The strategic plan for the expansion of the charging infrastructure should be based both on the understanding of the technical parameters of charging points, the preferences of electric car users and the technical capabilities of the distribution grid at a given location. These elements are closely linked and must therefore be analysed in parallel. First of all, individual vehicle needs should be examined in each group - passenger cars, trucks, buses - at individual locations. In parallel, the state of the distribution grid at the place of demand considered should be determined. An example of charging points location planning diagram is shown in Figure 13.

Fig. 13. An example of vehicle charging points location planning diagram



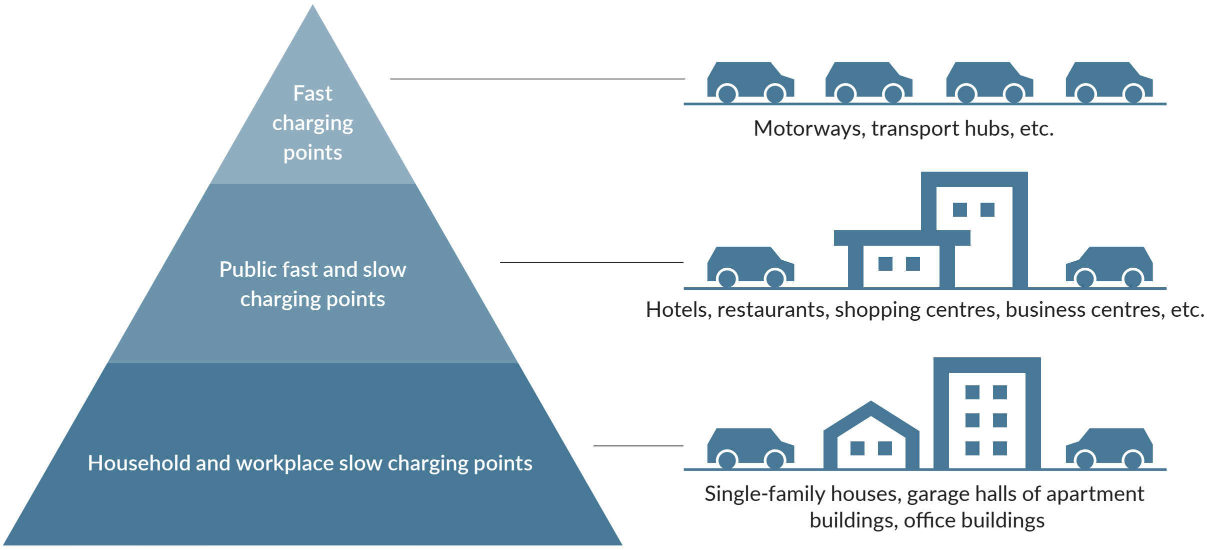
Source: Ch. Guo i in., Planning of Electric Vehicle Charging Infrastructure for Urban Areas with Tight Land Supply.

The most frequently used cars will be passenger cars, which means that in urban agglomerations there will certainly be an increase in demand for household charging points and charger posts with a capacity of less than 11kW located in the vicinity of the home or workplace. As mentioned in chapter 2.3, users of electric passenger cars usually prefer to charge their vehicles at home rather than at hubs with high power charging points.

However, the creation of hubs, i.e. 10-20 charging points located next to each other are also an effective way of building a charging infrastructure that facilitates access to the power grid and reduces waiting time for charging.[92] In addition, it should be taken into account that about half of Poles live in multi-family buildings, so they will not be able to use household chargers to the same extent as those living in single-family houses. High power charging points will be necessary along expressways and motorways, which are used both by trucks and passenger cars. Ideally, they should be installed at locations providing car users with the possibility to utilise their spare time (e.g. at restaurants along road routes located at category 1 rest areas). Unfortunately, currently published GDDKiA tenders for the lease of land intended for charging infrastructure cover primarily rest areas of third category, equipped only with basic associated infrastructure (parking spaces, toilets, roofings).

92 A. Fishbone, Z. Shahan & P. Badik, *Electric vehicle charging infrastructure. Guidelines for cities* [Infrastruktura ładowania pojazdów elektrycznych. Wytyczne dla miast], GreenTechnica & Greenway, 2017, https://greenwaypolska.pl/wp-content/uploads/sites/7/2019/09/GreenWay_Infrastruktura_ladowania_pojazdow_elektrycznych_Wytyczne_dla_miast_www_maj_2018.pdf

Fig. 14. Distribution of electrical vehicle charging infrastructure



Source: Electrical vehicle charging infrastructure. Guidelines for cities [Infrastruktura ładowania pojazdów elektrycznych. Wytyczne dla miast], GreenWay, CleanTechnica, 2017.

Once the energy demand profile of each of these sectors has been determined, it shall be examined whether the technical condition of the distribution grid allows supplying power to the required charging points. It will be important to analyse elements of the distribution grid and devices of medium and low voltage power stations. Charging points should be subject to grid impact tests at the connection point in order to determine whether their connection to the grid does not impair its operation.

In case it is necessary to build a dedicated connection, charging stations should be equipped with soft start systems and devices compensating for reactive power[93]. In the technical analysis, it is important to take into account the degree of increase in demand for capacity and electricity as well as the differences in demand over a daily period (both during business days and holidays). In addition, any "peaks" caused by weather abnormalities should be taken into account[94]. The issue of increasing demand for capacity will increase in certain locations, but potential grid loads can be reduced by appropriate integration into the grid of additional local RES.

However, a significant share of RES energy may lead to large differences in electricity supply, which may again have a negative impact on the quality aspects of electricity. It is therefore crucial to define the quality parameters of electricity consumed by a charging station. The use of V1G technology may also be a good solution. It allows the charging session to start automatically when a roof-mounted photovoltaic installation over-generates, maximising own consumption. Similarly, it allows to coordinate the charging of electric vehicles while parked, taking into account the travel preferences of vehicle users as well as the condition of batteries and grid conditions. This solution reduces the demand for power during peak hours and reduces the risk of grid overload[95.] However, it should be borne in mind that during en-route charging, the customer expects fast charging of batteries even at the expense of a higher service price. V1G solutions are limited here, unless they are associated with energy storage means. Potential grid issues related to electromobility may increase as it develops, although the expanded charging infrastructure for vehicles enabling smart and even two-way energy flows will allow electromobility to be used also in the context of system services. Two-way flows of electricity and storage capacity may be used by distributors to balance energy supply.

93 EDSO for smart grids, *Position paper on Electric Vehicles Charging Infrastructure*, on, https://www.edsoforsmartgrids.eu/wp-content/uploads/public/EDSO-on-Electric-Vehicles.pdf.

94 EDSO for smart grids, *Position paper on Electric Vehicles Charging Infrastructure*, on, https://www.edsoforsmartgrids.eu/wp-content/uploads/public/EDSO-on-Electric-Vehicles.pdf.

95 G. Barone, G. Brusco, D. Menniti, A. Pinnarelli, G. Polizzi, N. Sorrentino, P. Vizza, & A. Burgio, *How Smart Metering and Smart Charging may Help a Local Energy Community in Collective Self-Consumption in Presence of Electric Vehicles*, *Energies*, 2020, https://doi.org/10.3390/en13164163.

However, this application has significant limitations - in order to have the greatest impact on the grid, cars must be connected to the charging points basically at all times and in large numbers. In fact, it may be limited to private charging points (garages and private parking spaces), but the cars will be more frequently connected to the night valley there - although the afternoon peak of energy demand can also be addressed as the cars will be connected to charging points once their users return from work. So far, Polish DSOs have not taken sufficient measures to adapt the distribution grid specifically to the development of the charging infrastructure. This is due to the fact that investments are expensive and detailed plans for the location of charging points have not been prepared yet. The current state of affairs clearly indicates how significant parallel planning of distribution grid upgrades and the locations of charging stations grid are. To this end, cooperation at various levels is required, both from DSO representatives, local authorities and from the operator of publicly available charging stations.

4. Work methodology and scenarios

The estimation of electromobility development impact on distribution grids included a number of stages described in the following chapters. These stages can be divided as follows:

1. Preparing scenarios for changing the number of electric vehicles by vehicle category.
2. Assessment of the impact of scenarios on emissions, including CO_2.
3. Breakdown of electromobility development by individual areas of the country.
4. Analysis of the behaviour of EV users determining the course of power demand for charging vehicles.
5. Calculation of electricity demand from the electromobility sector.
6. Calculation of peak power demand for EV charging, assessment of the impact of electromobility on NPS balancing.
7. Estimation of local energy demand and capacity from electromobility.
8. Analysis of the current condition of distribution grids and plans for their modernisation in selected locations, representing the characteristics of individual areas of Poland.
9. Calculation of the impact of power consumption for EV charging on the load of individual distribution grid components at local level.
10. Assessment of which grid components will require investments in order to adapt to the growing number of electric vehicles.
11. Calculation of the total costs of investments in distribution grids related to the development of electromobility.

The scenarios adopted in the publication were based on previous studies of Forum Energii (described in detail in section 4.1). Both proposed scenarios have been analysed for two options of flexibility of charging - depending on the behaviour of users, the use of dynamic tariffs or other types of incentives, as well as the type of charging points installed (see section 4.4 for a detailed definition of options). The calculations related to points 1 to 8 and 11 were performed using mainly Excel and Python's programming language to download selected data, e.g. from the Office of Technical Inspection database. Visualisation of spatial data was performed using QGIS software. The analysis of distribution grids at medium voltage level (pt. 9-10) was carried out with the use of the PyPSA environment[96] – an open optimisation model written in Python and developed in German Karlsruher Institut für Technologie (see: Box). The PyPSA model was used to reconstruct the shape of MV distribution grid at selected locations, and then the load of its individual components was calculated– main power supply station and individual lines. Excel was used to create a proprietary model for assessing the load of low voltage grid elements based on hourly electricity demand profiles,

96 T. Brown, J. Hörsch, D. Schlachtberger, PyPSA: Python for Power System Analysis, 2018, https://arxiv.org/abs/1707.09913.

EV charging, as well as power production from micro RES installations. Details of the adopted assumptions and test methods are discussed in the following sections of the report.

PyPSA is a model widely used in European energy system analyses, including scenarios for combining electricity, heating, natural gas, hydrogen and transport sectors. Examples of such analyses include German market models carried out under the CoNDyNet project, implemented by 7 leading research institutes from Germany and funded by the German Ministry of Education and Development (Bundesministerium für Bildung und Forschung), or the open-eGo project funded by the Ministry of Economy and Energy (Bundesministerium Für Wirtschaft Und Energie). The PyPSA model was quoted in many scientific publications, including the those dedicated to relations between electricity and transport sectors.

4.1. Scenarios for the development of electromobility in Poland and their impact on the reduction of CO_2 emissions

The analysis of the impact of electromobility on the operation of the NPS and distribution grids started with the preparation of scenarios for increasing the number of electric vehicles in Poland by 2030 and 2050. These scenarios were based on the previous work of Forum Energii[97,98], and used the baseline and progressive scenarios respectively, developed by Atmoterm for the Ministry of Enterprise and Technology (currently Development, Labour and Technology)[99].

Electric vehicles have been divided into the following types, corresponding to their different modes of use and charging[100]:

light vehicles up to 3.5 tonnes, usually classified as passenger cars and vans,

heavy city vehicles over 3.5 tonnes – city buses, special purpose vehicles (e.g. bin lorries) and city delivery trucks,

heavy long-haul road vehicles over 3.5 tonnes – coaches, lorries and heavy transport vehicles.

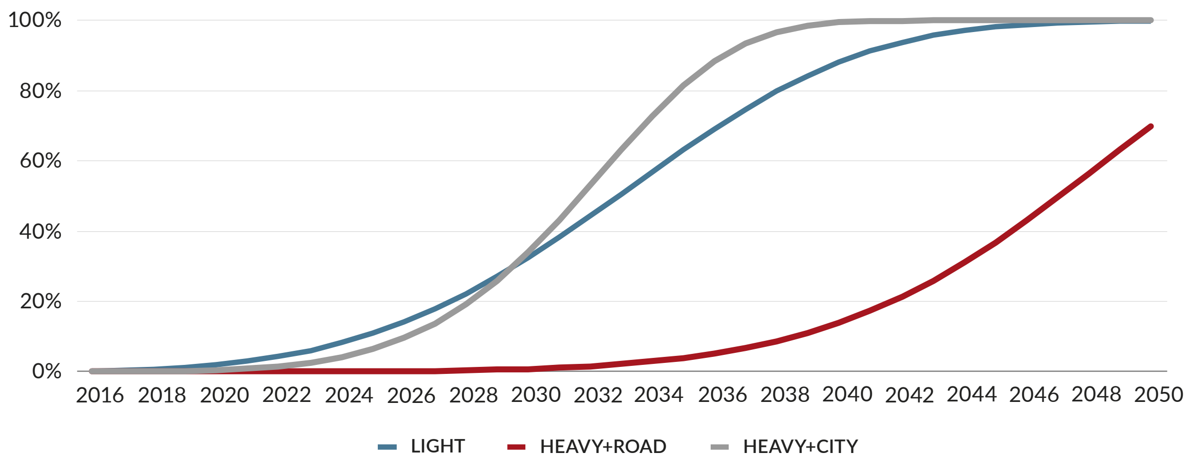
97 L. Bronk, B. Czarnecki, R. Magulski, T. Pakulski, M. Ścigan, J. Maćkowiak-Pandera, M. Jędra, *How to fill the carbon gap? 43% RES by 2030*, Forum Energii, 2020, https://forum-energii.eu/en/analizy/jak-wypelnic-luke-weglowa.

98 Kielichowska I., Staschus K., van der Leun K., Bettgenhaeuser K., Ramaekers L., Sheppard S., Staats M., Lenkowski A., Sijtsma L., *Poland's climate neutrality by 2050* [Polska neutralna klimatycznie 2050] *Electrification and sector coupling, Forum Energii*, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow.

99 E. Płuska, I. Rackiewicz, M. Rosicki, I. Sobecki, I. Szczepanik-Retka, M. Załupka, A. Skarbek-Żabkin & P. Matuszewski, *Analysis of the state of development and current development trends in the area of electromobility in Poland* [Analiza stanu rozwoju oraz aktualnych trendów rozwojowych w obszarze elektromobilności w Polsce], ATMOTERM S.A. & Forum Elektromobilności, 2019, https://www.gov.pl/web/rozwoj-praca-technologia/rozwoj-elektromobilnosci-w-polsce.

100 Kielichowska I., Staschus K., van der Leun K., Bettgenhaeuser K., Ramaekers L., Sheppard S., Staats M., Lenkowski A., Sijtsma L., *Poland's climate neutrality by 2050* [Polska neutralna klimatycznie 2050] *Electrification and sector coupling, Forum Energii*, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow.

Fig. 15. Share of EVs in the market of new vehicles by vehicle group

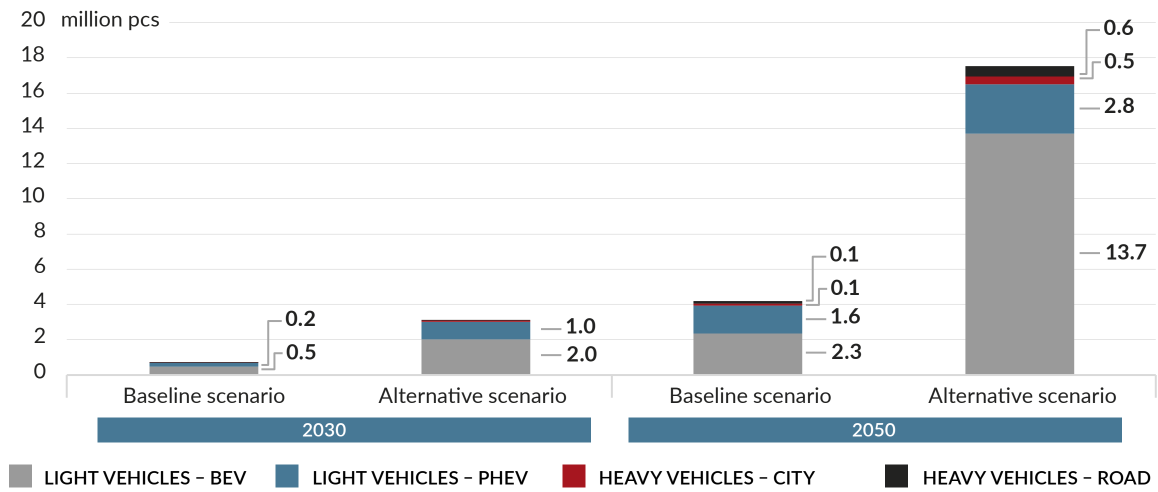


Source: Forum Energii, Poland: climate neutrality by 2050. Electrification and sector coupling, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow.

Light vehicles have been further divided into BEV and PHEV. Since Atmoterm scenarios do not contain forecasts for heavy vehicles, the EV's share of sales of new vehicles from the above-mentioned report "Poland: climate neutrality by 2050" of Forum Energii (Fig. 15) and its estimates of the number of electric vehicles per category in 2050 was used as the forecast basis. It is worth noting that the development of electromobility in the area of heavy road vehicles is projected to be significantly delayed. This means that in 2030 EVs have almost a negligible share within this class of vehicles, which is rising noticeably only in 2040s.

The baseline scenario assumes that in 2030 680 vehicles will travel on Polish roads, including 453 thousand BEV type and 227 thousand PHEV type (Fig. 16 and Tab. 5). This value will rise to 3.93 million by 2050. In addition, the number of electric heavy city vehicles is expected to increase to 18.5 thousand by 2030 and 107 thousand by 2050. For heavy road vehicles this will be 113 and 143 thousand, respectively.

Fig. 16. Change in the number of electric vehicles in individual scenarios



Source: Own study on the basis of own calculations and: E. Płuska, I. Rackiewicz, M. Rosicki, I. Sobecki, I. Szczepanik-Retka, M. Załupka, A. Skarbek-Żabkin & P. Matuszewski, *Analysis of the state of development and current development trends in the area of electromobility in Poland* [Analiza stanu rozwoju oraz aktualnych trendów rozwojowych w obszarze elektromobilności w Polsce], ATMOTERM S.A. & Forum Elektromobilności, 2019, https://www.gov.pl/web/rozwoj-praca-technologia/rozwoj-elektromobilnosci-w-polsce.

In the alternative scenario, the electromobility development pace is much more ambitious. It assumes that 3 million light electric cars (including 1 million PHEV and 2 million BEV) will travel on Polish roads by 2030. By 2050, this figure will increase to 16.5 million with a decreasing share of PHEV (17% compared to the current 46%). 82 thousand heavy electric vehicles (mainly buses) are also assumed to exist in 2030 and more than 1 million in 2050. In total, in 2050, as many as 82% of the fleet of vehicles would have been electrified, the remaining 18% would have been alternative fuel vehicles - hydrogen or biomethane, which would allow for decarbonisation of Polish transport necessary to achieve the EU climate neutrality target.

Tab. 5. Proposed scenarios for electromobility development

	2030		2050	
	Baseline scenario	Alternative scenario	Baseline scenario	Alternative scenario
Light vehicles	**680 000**	**3 000000**	**3 930 000**	**16 500 000**
BEV	453 333	2 000 000	2 330 000	13 700 000
PHEV	226 667	1 000 000	1 600 000	2 800 000
Heavy vehicles	**18 658**	**82 317**	**250 091**	**1 050 000**
Road vehicles	113	499	142 909	600 000
City vehicles	18 545	81 818	107 182	450 000
Total EV	**698 658**	**3 082 317**	**4 180 091**	**17 550 000**

Source: Own study on the basis of own calculations and: E. Płuska, I. Rackiewicz, M. Rosicki, I. Sobecki, I. Szczepanik-Retka, M. Załupka, A. Skarbek-Żabkin & P. Matuszewski, *Analysis of the state of development and current development trends in the area of electromobility in Poland* [Analiza stanu rozwoju oraz aktualnych trendów rozwojowych w obszarze elektromobilności w Polsce], ATMOTERM S.A. & Forum Elektromobilności, 2019, https://www.gov.pl/web/rozwoj-praca-technologia/rozwoj-elektromobilnosci-w-polsce

The assumed scenarios for the development of electromobility determine the necessary number of installed energy consumption points for charging purposes. As mentioned above, in Poland, as well as globally, passenger EV users definitely prefer to charge vehicles at home and it is expected that those who have a dedicated parking space (64% on average in Europe[101]) will strive to have their own charging or power supply points through a standard 230 V socket. Users who do not have such a parking space will use charging points to a greater extent at their workplaces.

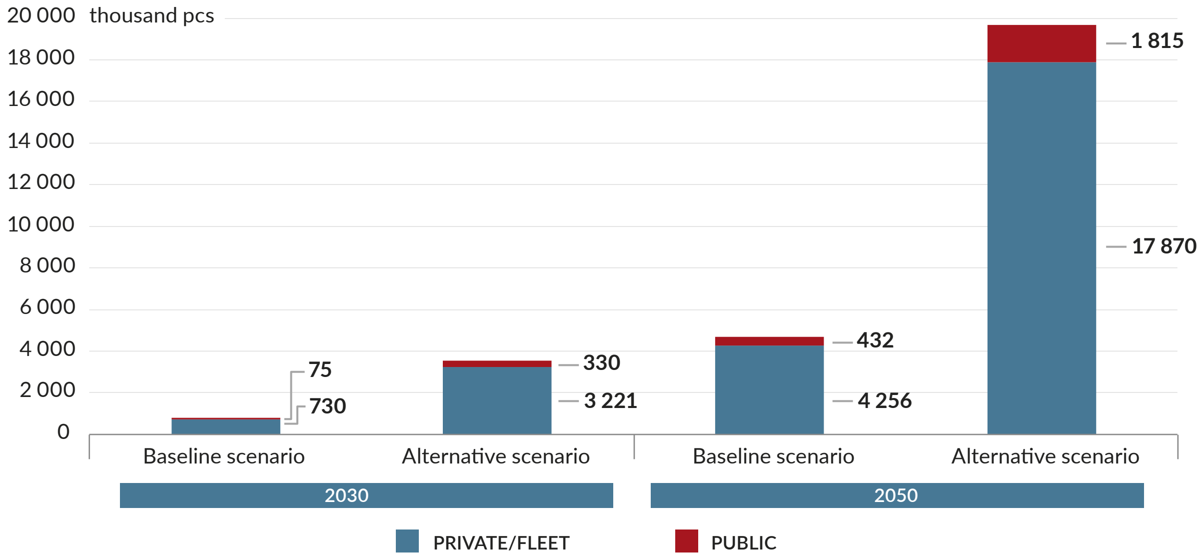
In the case of heavy city vehicles, it is assumed that they will be charged primarily at high power fleet charging points. According to the International Energy Agency's assessment[102] (Tab. 6), the proportion of the number of vehicles to the number of dedicated charging power points (including private sockets used for charging EV) is 7.69. Heavy road vehicles use both public charging points placed along motorways and expressways as well as high power fleet charging points. The proportion of heavy road vehicles to fleet charging points is 3.85 in this case. The demand for public charging points is covered by the planned expansion for light vehicles.

Based on the above assumptions and scenarios of the number of vehicles, the number of energy consumption points for charging in 2030 and 2050 was estimated (Fig. 17 and Tab. 6). In the baseline scenario, 730 thousand private and fleet charging points and 75 thousand public points are assumed in 2030, emphasising that private points are also standard private 230 V sockets. In 2050, this is respectively 4.3 million and 432 thousand. In the alternative scenario, 3.2 million private energy consumption points for charging and 330 thousand public energy consumption points are already used in 2030. By 2050, this will amount to a total of almost 20 million points, of which almost 2 million constitute public charging points, which is a huge technical and logistical challenge.

101 Kielichowska I., Staschus K., van der Leun K., Bettgenhaeuser K., Ramaekers L., Sheppard S., Staats M., Lenkowski A., Sijtsma L., *Poland's climate neutrality by 2050* [Polska neutralna klimatycznie 2050] *Electrification and sector coupling, Forum Energii*, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow.

102 IEA, Global EV Outlook 2020, https://www.iea.org/reports/global-ev-outlook-2020.

Fig. 17. Number of energy consumption points for charging in individual scenarios



Source: Own study.

Tab. 6. Forecasted number of energy consumption points for charging in individual scenarios

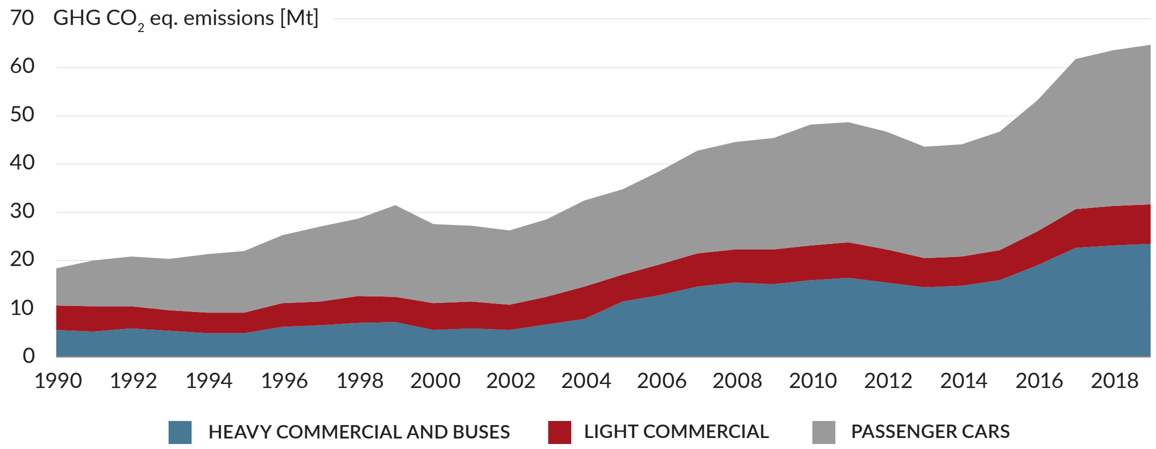
<table>
<tr><th colspan="2" rowspan="3"></th><th rowspan="3">Type</th><th rowspan="3">Number of EV per energy consumption point for charging</th><th colspan="4">Number of points</th></tr>
<tr><th colspan="2">2030</th><th colspan="2">2050</th></tr>
<tr><th>Baseline scenario</th><th>Alternative scenario</th><th>Baseline scenario</th><th>Alternative scenario</th></tr>
<tr><td colspan="2" rowspan="3">Light vehicles</td><td>Private*</td><td>0.93</td><td>727 600</td><td>3 210 000</td><td>4 205 100</td><td>17 655 000</td></tr>
<tr><td>Public - normal power</td><td>11.11</td><td>61 200</td><td>270 000</td><td>353 700</td><td>1 485 000</td></tr>
<tr><td>Public - high power</td><td>50.00</td><td>13 600</td><td>60 000</td><td>78 600</td><td>330 000</td></tr>
<tr><td rowspan="2">Heavy vehicles</td><td>Road</td><td>Fleet - high power**</td><td>3.85</td><td>29</td><td>130</td><td>37 156</td><td>156 000</td></tr>
<tr><td>City</td><td>Fleet - high power</td><td>7.69</td><td>2411</td><td>10 636</td><td>13 934</td><td>58 500</td></tr>
</table>

*Includes standard (single-phase) and three-phase 230 V sockets used for charging EV and charging points at workplaces
** Heavy road vehicles also use public high power charging points shared with light vehicles
Source: Own study on the basis of own calculations and IEA/OECD Global EV Outlook 2020.

4.2. Consequences of electromobility development for the environment and emissions of harmful substances

The implementation of the scenarios proposed in section 4.1. for the development of electromobility will contribute to the reduction of GHG emissions from road transport. This is particularly important in view of the fact that Polish transport is one of the most emissive in the EU, so reducing emissions from this sector is necessary in order to achieve the Community's climate objectives. Since 1990, the emissions of this sector in Poland have been increasing at an unprecedented pace. In 2019, they reached a level of approximately 65 million tonnes of CO_2eq - 252% more than in 1990. Even when compared to 2015, as much as 38% of growth is recorded. Proportionally with the largest share of passenger cars in the vehicle structure in Poland, these cars are responsible for the largest part of the emissions, although the impact of heavy vehicles and buses is not irrelevant (Fig. 18). The electrification of each of the transport sub-sectors is therefore necessary to reduce emissions and as a result sector decarbonisation.

Fig. 18. GHG emissions from the road transport sector in Poland



Source: Eurostat.

On the other hand, electrification does not mean decarbonisation or even a significant reduction in emissions from road transport. In order to decarbonise the sector, it is necessary to change the structure of the national power mix to low and eventually zero-emission mix.

In 2018, the average emissions of generation units in the national system amounted to 792 kg CO_2e/MWh[103].

In accordance with the assumptions contained in the Polish Energy Policy until 2040. (PEP2040) The CO_2eq emission intensity from electricity production will gradually decrease over the next decades. PEP2040 assumes that in 2025 electricity emissions will amount to 509 kg CO_2eq/MWh, in 2030 they will fall to 461 kg CO_2eq/MWh, while in 2040 they are expected to be 268 kg CO_2eq/MWh[104]. PEP2040 does not provide forecasts until 2050. The need to achieve climate neutrality by 2050 means that electricity production should be zero-emission in 2050. The "Poland: climate neutrality by 2050" report of Forum Energii predicts that energy emissions will fall from the current level of 792 kg CO_2eq/MWh to 30 kg CO_2eq/MWh by 2050.[105]

In 2019, light vehicles - passenger cars and light commercial vehicles were responsible for around 41 million tonnes of GHG emissions. While this segment will be electrified as soon as possible, the still relatively high emissions of

103 KOBIZE, *CO_2, SO_2, NO_X, CO and particulate matter emission factors for electricity* [Wskaźniki emisyjności CO2, SO2, NOX, CO i pyłu całkowitego dla energii elektrycznej], 2019, https://www.kobize.pl/uploads/materialy/materialy_do_pobrania/wskazniki_emisyjnosci/Wskazniki_emisyjnosci_grudzien_2019.pdf

104 Ministry of Climate and Environment, *Polish Energy Policy until 2040*, 2021, https://www.gov.pl/web/klimat/polityka-energetyczna-polski#:~:text=PEP2040%20represents%20Light√C4%85%20wizja√C4%99%20strategii,os√C5%82abienia%20economics%20pandemic√C4%85%20COVID%2D19.

105 Forum Energii, *Poland: climate neutrality by 2050. Electrification and sector coupling*, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow.

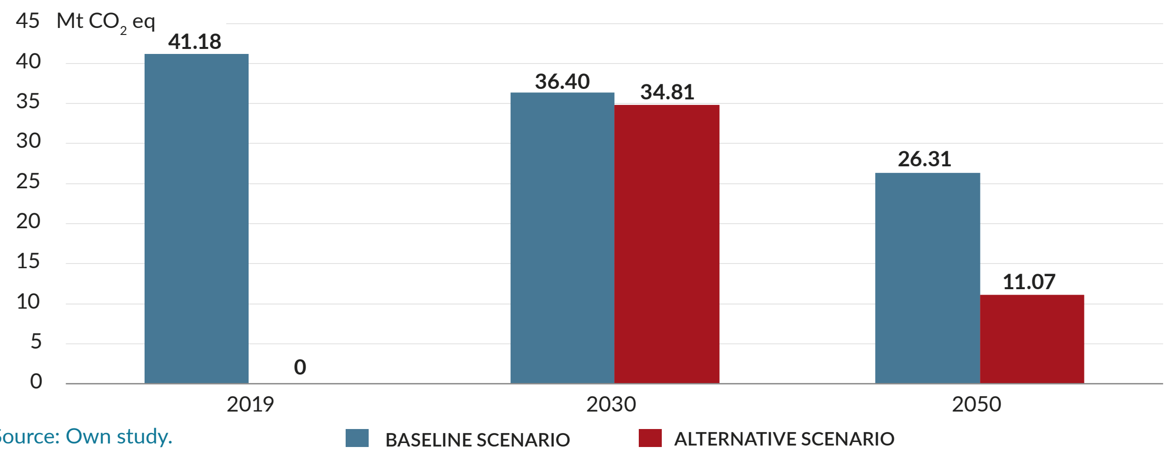
electricity production in 2030, combined with the fact that in 2030 light EV will represent a relatively small part of the entire vehicle fleet, will not translate into a significant reduction in emissions in the transport sector - both considering the baseline and alternative scenarios (Fig. 19.). On average, a light vehicle (passenger and light commercial vehicles) emitted 1.75 tonnes of CO_2eq in 2019.[106] As the majority of the fleet of light vehicles in Poland represented a combustion engine vehicle in 2019, this value is taken as the average annual emission value of a light combustion type vehicle. The emissions of BEV and PHEV depend on the emissions of the Polish NPS and the consumption of electricity resulting from the average annual mileage of cars. The carbon rich structure of the Polish energy mix means that vehicles using electricity currently emit as many as 125 g of CO2/km.[107] In accordance with chapter 4.5. it is also assumed that light vehicles BEV and PHEV use an average of 0.21 kWh/km and travel 12 000 km/year.

In the case of BEV, the annual mileage will be covered in full with electricity, whereas PHEV uses electricity for 5 thousand km per year and the rest of the mileage is covered by the combustion mode. Based on the above, emissions for electric vehicles were calculated and an average per vehicle amounted to 1.5 tonnes of CO_2eq/year for BEV and 1.6 tonnes of CO_2eq/year for PHEV.

The decrease in electricity emissions expected in 2030 will translate into a reduction in emissions from EV to around 60 g of CO_2eq/km and in 2040 it will be 20 g of CO_2eq/km.[108] Moreover, given the commitment of Poland under the Paris Agreement to achieve climate neutrality by 2050, it is assumed that the electricity produced at that time should be zero-emission and that EV vehicles should therefore no longer emit CO_2. Due to increasingly stringent emission standards, it is also assumed that emissions from combustion engine cars will fall by up to 1% per year.[109]

The modelling results indicate that the electromobility development for 2030 baseline scenario results in a reduction of emissions in the light vehicle segment by around 5 million tonnes compared to 2019. The implementation of the alternative scenario will allow to reduce emissions to 34.81 million tonnes of CO_2eq in 2030, i.e. by around 6 million tonnes compared to the current situation. Such small difference between the baseline and the alternative scenario is due to the fact that even at a more ambitious rate of growth in the number of electric vehicles, 1/3 are still PHEV type emission vehicles – even with decreasing emissions of the NPS, in 2030 they emit only a little less than combustion engine vehicles. With the growth of the electric vehicle fleet and the decarbonisation of NPS, transport emissions will decrease dynamically. The baseline scenario for 2050 shows a decrease in emissions in the light vehicles sector to approximately 26 million tonnes of CO_2eq. In the alternative scenario that assumes electrification of 16.5 million vehicles, this will only be 11 million tonnes of CO_2eq, or around 1/4 of current emissions.

Fig. 19. GHG emission reduction potential in the light vehicle segment



Source: Own study.

106 Own calculations based on Eurostat and GUS data.

107 Transport & Environment, *How clean are electric cars?*, 2020, https://www.transportenvironment.org/sites/te/files/downloads/T%26E%E2%80%99s%20EV%20life%20cycle%20analysis%20LCA.pdf.

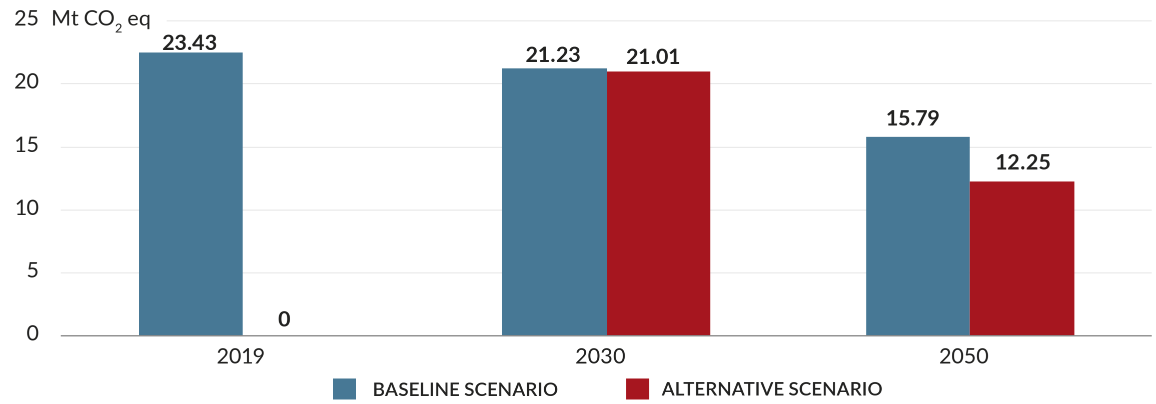
108 as above

109 W. Rabiega, P. Sikora, J. Gąska, *CO_2 emissions reduction potential in transport sector in Poland and the EU until 2050*, Centre for Climate and Energy Analysis, 2019, http://climatecake.pl/wp-content/uploads/2019/11/CAKE_Transport_emission_reduction_potential_2050_paper__final.pdf.

Electrification of heavy vehicles will be slower. Although the electric fleet of city buses is expected to grow dynamically, the remaining (and larger) portion of heavy transport is more difficult to electrify under the current technical conditions. In 2019, heavy city and road vehicles emitted a total of approximately 23.4 million tonnes of CO_2eq. Using a methodology similar to that applied to passenger vehicles, both scenarios for 2030 forecast a decrease in emissions, but only to 21 million tonnes of CO_2eq.

Nevertheless, heavy vehicles will also be subjected to electrification by 2050. The results for the alternative scenario indicate that in 2050 it will be possible to reduce GHG emissions to 12.25 million tonnes, meaning 50% below the current level.

Fig. 20. GHG emission reduction potential in the heavy vehicle segment



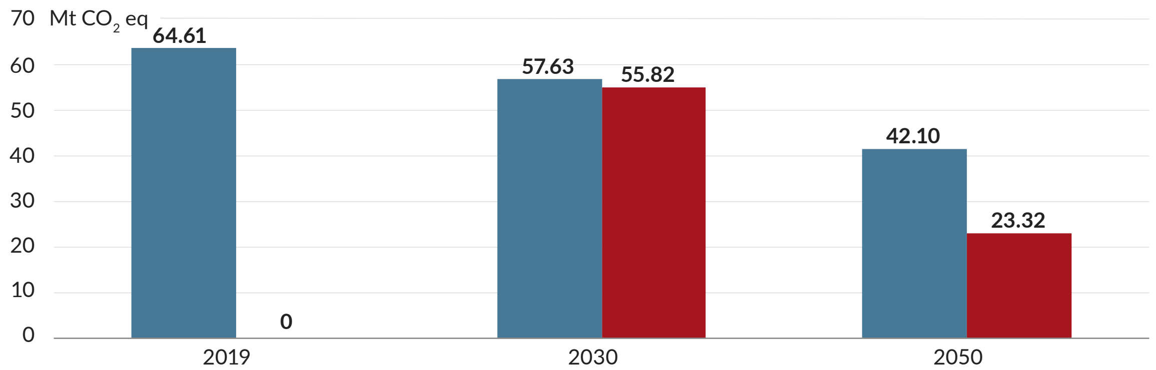
Source: Own study.

This means that the electrification of light and heavy vehicles will allow for a total reduction in transport emissions from the current level of 64.61 million tonnes of CO_2eq to 23.32 million tonnes by 2050, in the alternative scenario. This represents a decrease of almost 2/3 compared to the current level - but it is still very far from the 90% target for this sector at EU level, and it indicates the need to change the habits of road vehicle consumers towards more frequent use of public transport and bicycles instead of private cars.

Nevertheless, the possibility of achieving such GHG reductions depends on the possibility of safe integration of electric vehicles into the NPS, which has not yet been adapted to such a large scale of grid-connected charging points.

An in-depth analysis of the impact of electromobility development scenarios on the grid is therefore required, indicating the locations and grid elements that will require modernisation investments. This is the focus of further chapters of this report.

Fig. 21. GHG emission reduction potential for light and heavy vehicles

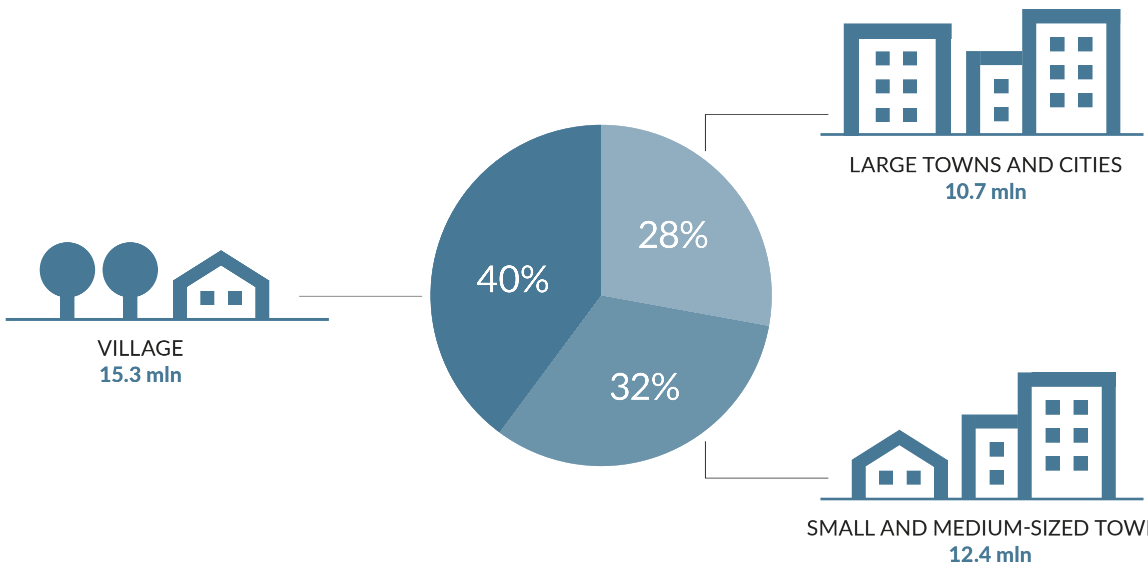


Source: Own study.

4.3. Potential for developing electromobility in individual regions of the country

As described in the second chapter of this study, the Polish electromobility is currently concentrated mainly in urban centres. This trend will continue in the initial stages of its growth, but with the development of vehicle charging infrastructure, the drop in technology prices or the social interest in electric vehicles, the differences between urban and rural regions will decrease and will ultimately vanish. Other EU countries face similar development dynamics as Poland. According to the study carried out by the International Council on Clean Transportation (ICCT), the average share of electric vehicles in the fleet of passenger vehicles in cities in EU countries was the highest (4%) compared to intermediate urban and rural regions (3.5%) and villages (2.9%)[110]. However, experience with, for example, Norway shows that electromobility is spreading, and its interest is also growing in rural areas. In addition, Poland does not follow a Europe-wide trend of population distribution between cities and rural areas. The proportion of the population living in rural areas in Poland is one of the largest in the EU - about 40% of the population live in rural areas and 60% in cities (Fig. 22). For instance, in Western countries, only about 20-30% of the population live in rural areas. As much as 83.4% of Norwegian population live in urban areas[111].

Fig. 22. Population distribution structure in Poland



Source: Own compilation based on data of GUS, 2018.

Given the large differences in the structure of population distribution in EU countries, it is difficult to clearly identify the differences in the pace of electromobility development in cities and villages. If electromobility develops at a faster pace throughout the country, the growth pace in rural areas approaches the pace of cities (Norway's case). We assume that in 2030 and 2050, the number of vehicles registered in urban and rural areas will correspond to the population distribution structure, i.e. 40% of passenger cars will be registered in rural areas and 60% in cities. In the case of electric buses fleet, all will be located in urban areas, further increasing the fleet of electric vehicles used there. Since heavy goods vehicles and commercial vehicles travel mainly over long distances, these will most often be used on expressways and motorways. The key to achieving this assumption is to provide appropriate charging infrastructure in each of the above types of areas.

110 S. Wappelhorst, Beyond major cities: *Analysis of electric passenger car uptake in European rural regions*, The International Panel on Clean Transportation, 2021, https://theicct.org/sites/default/files/publications/Ev-europe-rural-mar2021.pdf.

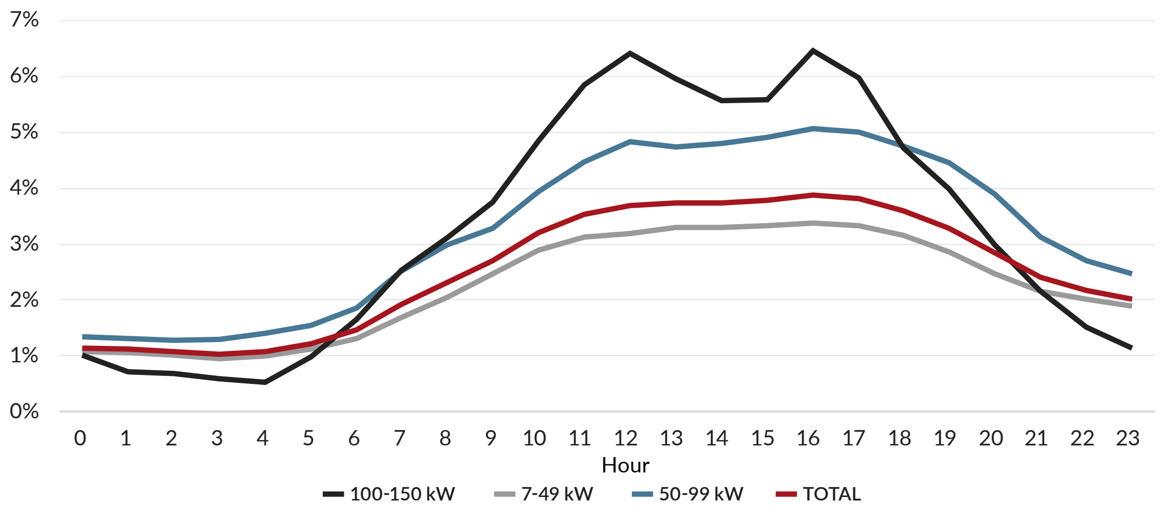
111 Worldometer, Norway Population, 2020, https://www.worldometers.info/world-population/norway-population/.

4.4. Behaviour projections of electric vehicle users

The behaviour of electric vehicle users determines peak capacity and energy demand. The models for using publicly available stations are different from those related to points at home.

Historical trends from publicly available charging points in the National Register of Alternative Fuel Infrastructure (EIPA) indicate that the demand for charging service increases from 5:00 a.m. in the morning to reach its peak at 4:00 p.m., and decreases in the evening, noting the lowest level at night. Public charging infrastructure is used on average only for about 4% of the time. Although demand for charging points is expected to increase as electromobility develops, most passenger cars will still be charged at home. The most popular points of public charging stations are those with a higher power of 100-150 kW - allowing the vehicle to be charged in a relatively short time. However, with the current state of electromobility in Poland, even these points do not charge more than for approx. 6% of the time during hours with the greatest demand for power. Charging points with a power of 7-49 kW are used the least.

Fig.23. Charging profile of electric vehicles at publicly available charging points in Poland (percentage of use at a given hour)



Source: Own compilation based on Poland's Office of Technical Inspection data.

Similar trends in vehicle charging are described in the above-mentioned study of Forum Energii "Poland's climate neutrality by 2050". This case, however, takes into account not only publicly available charging points but also those used in homes, workplaces and fleet areas. Based on user preferences described in section 2.4, the distribution of the demand for individual means of charging was proposed for the classes of vehicles under study – Tab. 7. Light vehicle owners prefer to charge them at home, but not everyone has this possibility (they have a dedicated parking space)[112]. In this case, they are therefore forced to use public charging points. Heavy city vehicles are charged using dedicated points located mainly at bus depots. Heavy road vehicles mainly use public high power charging points, but also the equipment installed at fleet centres.

Combining the projections from Tab. 7 with usage profiles of each charging point type (Fig. 6), vehicle charging profiles have been prepared by dividing them into examined classes. An example of a profile for a winter business day is presented in Fig. 24.

112 As many as 36% of vehicle owners in Europe do not have a dedicated parking place, which means that they cannot have their own charging point and must use public infrastructure or charge vehicles at their workplace. Source: Forum Energii, Poland: climate neutrality by 2050. Electrification and sector coupling, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow.

Tab. 7. Assumptions regarding vehicle charging times by parking place (annual share in %)

	House	Public - normal power	Place of work	Public - high power	Fleet (high power)
Light (dedicated space)	80%	0	15%	5%	0
Light (no dedicated space)	0	10%	25%	65%	0
Heavy — city	0%	0%	0%	0%	100%
Heavy — road	0%	0%	0%	80%	20%

Source: Forum Energii, Poland: climate neutrality by 2050. Electrification and sector coupling, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow.

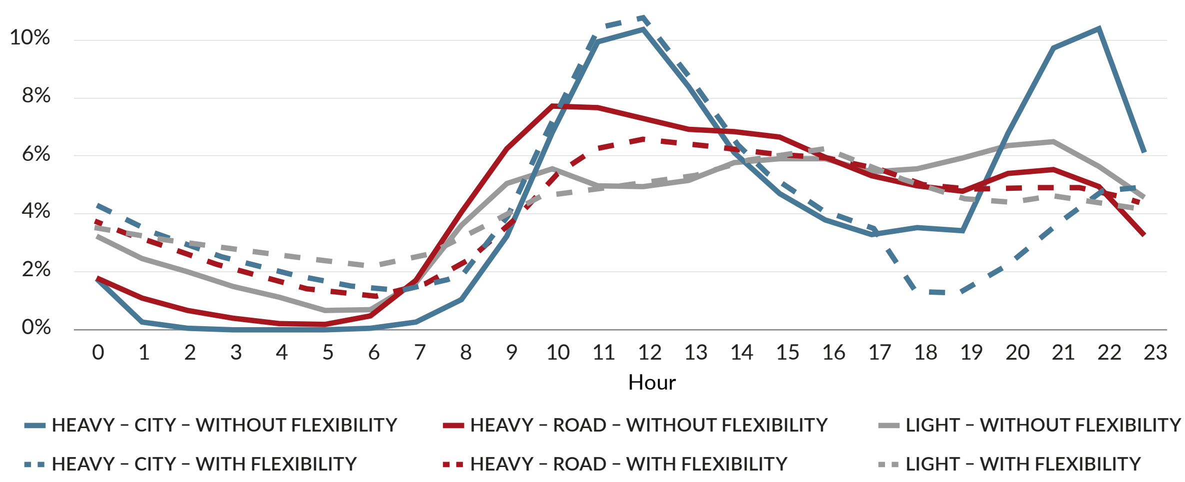
If electric vehicle users use a charging service at any time they choose with the maximum possible power, then we are talking about an inflexible profile. It is characterised by large differences in demand for electricity between peak hours and when demand for the service decreases. Inflexible charging can lead to a grid overload, especially as the peak of demand for charging vehicles coincides, for example, with the evening peak of households' electricity demand. Flexible charging of vehicles, stimulated by the use of flexible charging points combined with suitably selected tariffs encouraging users to reduce peak demand, is a solution allowing to minimise this risk. Flexible charging means that the power of the charging session is adapted to the battery charge state and the charging time, obviously taking into account the actual grid load and the EV vehicle user's mobility preferences. In this case, for instance, owners of cars charged at home extend the charging session while reducing power consumption. Cars are mostly charged at night and for a longer time when the grid load is the lowest. Therefore, the flexible profile shows significantly lower differences in electricity demand than in the profile without flexible charging and reduced peak electricity demand in the evening. Differences are visible for each type of vehicle. Flexibility change is more difficult for publicly available high power charging points, which are mainly used by heavy commercial vehicles. In their case, the charging is based on the demand for energy of a vehicle moving continuously during the day, but in their case the profile may also be significantly smoothed by charging at night, for a longer period of time and with less power at fleet headquarters or goods delivery points.

Based on the preferences discussed concerning the charging of electric vehicles, two scenarios for the development of electromobility were prepared:

- **Inflexible variant** in which users use the charging service at any time with maximum possible power;
- **Flexible variant** where the power of the charging session is adjusted to the battery charge state and the planned charging time. In this case, for instance, owners of cars charged at home extend the charging session while reducing power consumption. Cars are mostly charged at night when the total grid power demand is the lowest. This scenario allows to reduce the load of NPS and distribution grids. However, its introduction requires a number of factors to be met - the introduction of dynamic tariffs, the use of smart charging points enabling the vehicle to communicate with the grid and the wide automation of the entire grid operation.

Charging profiles in individual variants for individual vehicle types are discussed in the remaining part of the subchapter.

Fig. 24. Daily electric vehicle charging profile, winter business day



Source: Own study on the basis of own calculations and Forum Energii, Poland's climate neutrality by 2050. Electrification and sector coupling, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow.

The relaxation of the charging profile is an important factor for ensuring security of electricity supply and facilitating the integration of renewable energy sources into the grid. However, achieving this will require the introduction of an appropriate economic, legal and technical environment that encourages electric car users to charge them at times when the demand for electricity is lower, e.g. overnight instead of quick charging during the day.[113] Dynamic tariffs are one of the mechanisms that has a real impact on smoothing the charging profiles (details in section 2.2). By differentiating electricity prices according to the level of demand, part of vehicle charging may be shifted from peak hours to hours when the demand for power and energy is lower. In this model, energy prices during peak hours are higher and lower at the time of lower demand, thereby encouraging vehicle users to charge them at a time when it does not impact the power system. This represents a significant qualitative change for the power system since stimulating the mitigation of peak power demand causes the amount (and hence the cost) of necessary grid investments aimed at supporting electromobility to decrease.

113 M. Kłos, P. Marchel, J. Paska, R. Bielas, M. Błędzińska, Ł. Michalski, K. Wróblewski, K. Zagrajek, *Forecast and impact of electromobility development on the Polish Electric Power System*, E3S Web of Conferences, 2018, https://www.e3s-conferences.org/articles/e3sconf/pdf/2019/10/e3sconf_pe2019_01005.pdf.

4.5. Electricity demand generated by electric vehicles

Based on the scenarios presented in section 4.1., the total increase in national electricity demand resulting from the development of electromobility has been estimated. Assumptions described in Tab. 8 have been adopted, which are also in line with the assumptions of Atmoterm scenarios[114]:

Tab. 8. Electricity consumption assumptions for a single electric vehicle*

	Electricity consumption per km [kWh/km]	Annual mileage [km]	Annual electricity consumption [MWh]
Light vehicles			
BEV	0.21	12 000	3
PHEV**	0.21	5 000	1
Heavy vehicles			
Heavy vehicles	0.63	34 000	21
City vehicles	0.42	17 000	7

*As mentioned, the assumptions of the aforementioned studies of Forum Energii and Navigant have been used, but it is estimated that the annual mileage of heavy vehicles may be significantly higher and may reach 100 thousand kilometres with the appropriate development of the charging infrastructure and the pursuit of mileage typical of combustion engine vehicles.
** PHEV mileage takes also the use of petrol/oil into account; only a part of vehicle use takes place with the engagement of the electric motor.

Source: Forum Energii, Poland: climate neutrality by 2050. Electrification and sector coupling, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow.

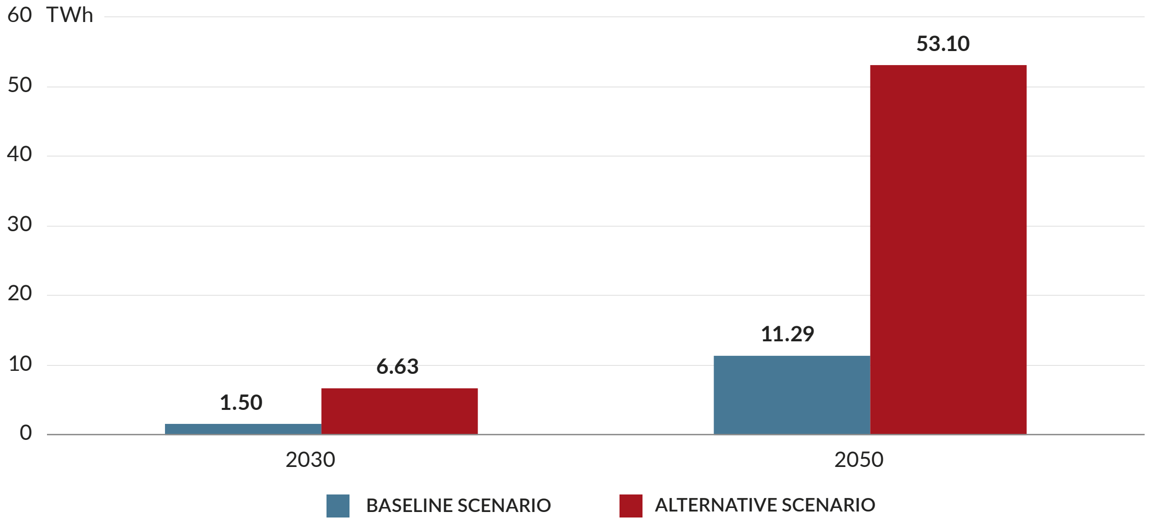
Light vehicles are characterised by lower electricity consumption per kilometre (mainly due to their lower mass) and their annual mileage is typically significantly lower. In particular, for road vehicles, the intended mileage is almost three times higher, resulting in seven times higher annual energy consumption.

The above assumptions were used to estimate the total electricity demand of the entire electric vehicle fleet of the baseline and alternative scenarios (Fig. 25). In 2030, the demand is estimated at 1.5 TWh in the baseline scenario and 6.6 TWh in the alternative scenario. In 2050, this is 11.3 and 53.1 TWh respectively - in the latter case, electromobility accounts for around 20% of national energy consumption[115] and must be taken into account in the appropriate planning of capacity development.

114 Own study on the basis of own calculations and: E. Płuska, I. Rackiewicz, M. Rosicki, I. Sobecki, I. Szczepanik-Retka, M. Załupka, A. Skarbek-Żabkin & P. Matuszewski, *Analysis of the state of development and current development trends in the area of electromobility in Poland* [Analiza stanu rozwoju oraz aktualnych trendów rozwojowych w obszarze elektromobilności w Polsce], ATMOTERM S.A. & Forum Elektromobilności, 2019, https://www.gov.pl/web/rozwoj-praca-technologia/rozwoj-elektromobilnosci-w-polsce.

115 Own study on the basis of own calculations and: E. Płuska, I. Rackiewicz, M. Rosicki, I. Sobecki, I. Szczepanik-Retka, M. Załupka, A. Skarbek-Żabkin & P. Matuszewski, *Analysis of the state of development and current development trends in the area of electromobility in Poland* [Analiza stanu rozwoju oraz aktualnych trendów rozwojowych w obszarze elektromobilności w Polsce], ATMOTERM S.A. & Forum Elektromobilności, 2019, https://www.gov.pl/web/rozwoj-praca-technologia/rozwoj-elektromobilnosci-w-polsce.

Fig. 25. Annual electricity consumption for charging electric vehicles [TWh]



Source: Own study on the basis of own calculations and: E. Płuska, I. Rackiewicz, M. Rosicki, I. Sobecki, I. Szczepanik-Retka, M. Załupka, A. Skarbek-Żabkin & P. Matuszewski, *Analysis of the state of development and current development trends in the area of electromobility in Poland* [Analiza stanu rozwoju oraz aktualnych trendów rozwojowych w obszarze elektromobilności w Polsce], ATMOTERM S.A. & Forum Elektromobilności, 2019, https://www.gov.pl/web/rozwoj-praca-technologia/rozwoj-elektromobilnosci-w-polsce Forum Energii, Poland: climate neutrality by 2050. Electrification and sector coupling, 2020, https://forum-energii.eu/pl/analizy/integracja-sektorow.

Tab. 9. Annual electricity consumption for charging electric vehicles by scenarios and categories of vehicles [TWh]

	2030		2050	
	Baseline scenario	Alternative scenario	Baseline scenario	Alternative scenario
Light vehicles	**1.37**	**6.04**	**7.49**	**37.17**
BEV	1.13	5.00	5.83	34.25
PHEV	0.24	1.04	1.67	2.92
Heavy vehicles	**0.13**	**0.59**	**3.80**	**15.94**
Road vehicles	0.00	0.01	3.04	12.75
City vehicles	0.13	0.58	0.76	3.19
Total EV	**1.50**	**6.63**	**11.29**	**53.10**

Source: Own study on the basis of own calculations and: E. Płuska, I. Rackiewicz, M. Rosicki, I. Sobecki, I. Szczepanik-Retka, M. Załupka, A. Skarbek-Żabkin & P. Matuszewski, *Analysis of the state of development and current development trends in the area of electromobility in Poland* [Analiza stanu rozwoju oraz aktualnych trendów rozwojowych w obszarze elektromobilności w Polsce], ATMOTERM S.A. & Forum Elektromobilności, 2019, https://www.gov.pl/web/rozwoj-praca-technologia/rozwoj-elektromobilnosci-w-polsce Forum Energii, Poland: climate neutrality by 2050. Electrification and sector coupling, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow.

In both scenarios, due to their numbers, light vehicles dominate the demand structure (Tab. 9). However, the great individual electricity demand of heavy road vehicles means that they account for as much as 24% of the total sector demand. It is worth bearing in mind that the demand for charging these vehicles is cumulated at a relatively small number of charging points located along expressways and motorways, which may give rise to specific challenges in terms of ensuring the stability of capacity and electricity supply at these locations.

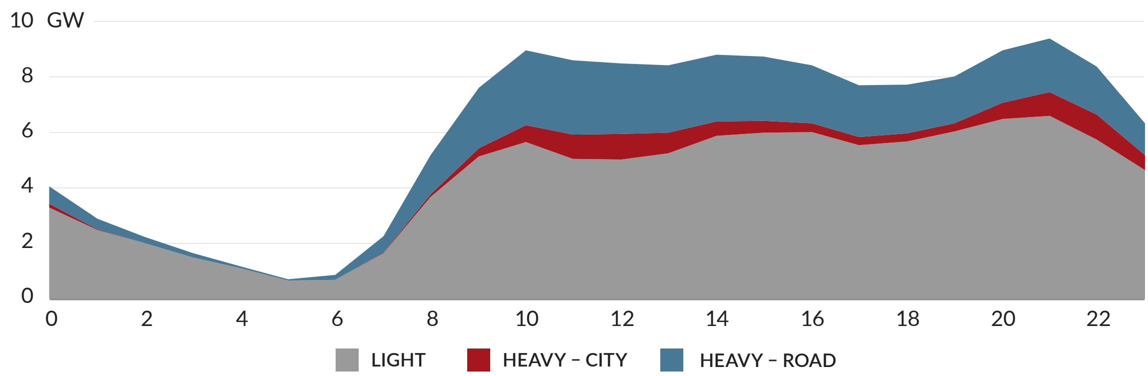
5. Impact of electromobility on NPS balancing

In the context of balancing the National Power System and planning the development of transmission and distribution grids, peak power consumption by electric vehicle users is extremely important. The analysis of this phenomenon at national level has been set out below, while the impact of peak load on individual components of distribution grids is discussed further in chapter 6.

Based on the charging profiles discussed in section 4.4. and the scenarios for electromobility development considering individual vehicle types (section 4.1.), the total power demand generated by the electromobility sector has been estimated (as shown in Fig. 26. and 27). Fig. 26. shows the variant without charging flexibility[116] - a very clear increase in load at the evening peak is visible. Light vehicles play a dominant role in peak power demand due to their quantities. However, the peak load of light vehicles coincides with the peak load of heavy city vehicles, with a high demand in the heavy road vehicle class at the same time, which multiplies the negative effects influencing the operation of the grid.

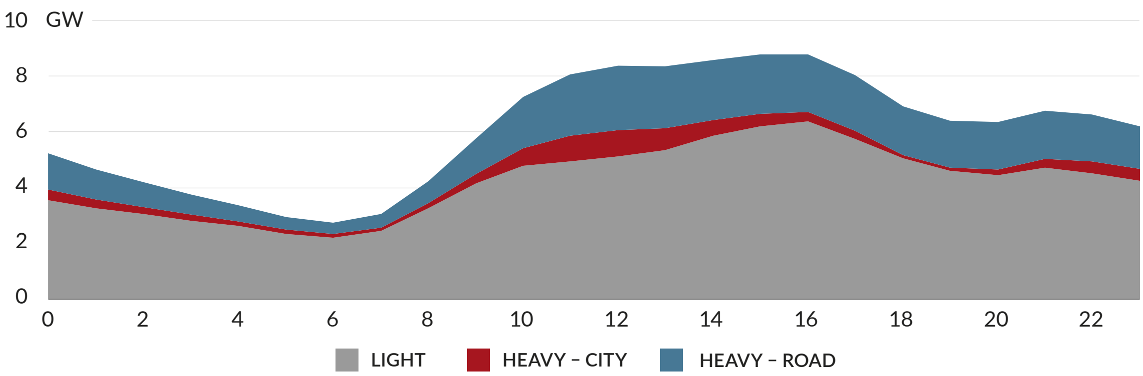
In the charging flexibility variant (Fig. 28), the total daily demand profile flattens and peak power is significantly reduced. The evening peak is completely eliminated and vehicles are charged with less power, but throughout the night. The maximum demand is spread over the remaining business hours, which correlates with the profile including production of energy from sun and thus significantly reducing the negative effects on NPS balancing.

Fig. 26. Daily power demand profile in the electromobility sector - winter business day, alternative scenario, 2050, variant without flexibility



Source: Own study..

Fig. 27. Daily power demand profile in the electromobility sector - winter working day, counterfactual scenario, 2050, variant with flexibility

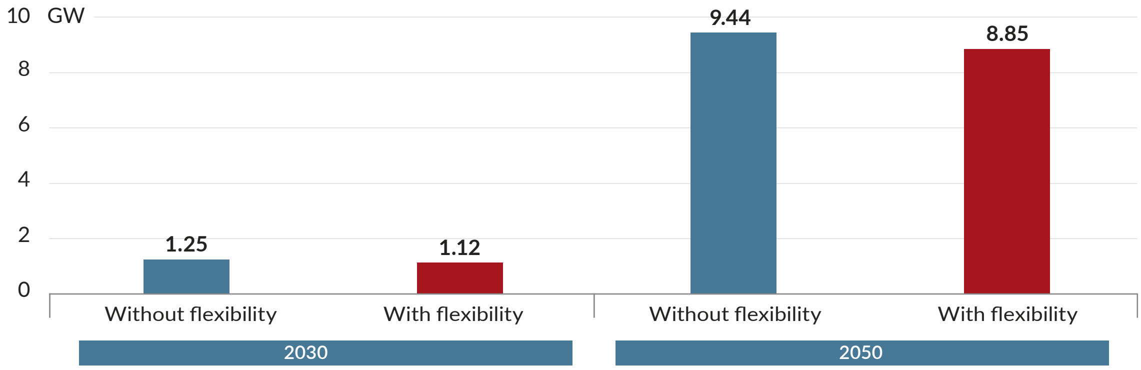


Source: Own study.

116 The definitions of each charging variant have been contained in section 4.4.

The impact of charging flexibility on the annual peak power demand in the alternative scenario is presented in Fig. 28. The use of charging flexibility reduces the peak load by 0.1 GW in 2030 and 0.6 GW in 2050.

Fig. 28. Peak power demand in the electromobility sector - alternative scenario



Source: Own study.

Charging profiles vary slightly depending on the time of the year[117], but the differences in peak power demand between the time of the year do not exceed 10% (Tab. 10). In the baseline scenario, due to the significantly lower number of electric vehicles, the power demand is also much lower.

Tab.10. Peak power demand in the electromobility sector depending on the time of the year - variant with flexibility [GW]

	2030		2050	
	Baseline scenario	Alternative scenario	Baseline scenario	Alternative scenario
Winter	0.25	1.10	1.86	8.79
Spring	0.23	1.02	1.73	8.17
Summer	0.24	1.07	1.79	8.45
Autumn	0.25	1.12	1.87	8.85

Source: Own study.

Tables 11 and 12 contain detailed results of peak power modelling for individual vehicle classes. The total peak load in 2030 is slightly above 1 GW, which should not endanger the power system and the grid infrastructure. The use of the flexible variant in the light vehicle class allows for a significant peak power reduction - for an alternative scenario of 0.23 GW in 2050. In the heavy vehicle class, the peak daily power demand in the flexible variant decreases by 0.4 GW. In addition, as shown in Fig. 27, the shift of the charging profile towards working and night hours has a positive impact on flattening of the overall charging profile of all electric vehicles.

It is worth noting the small impact of heavy city vehicles on peak load, partly due to their small number, but also due to lower average mileage than for the road vehicle fleet. The development of urban transport can contribute to a significant reduction of greenhouse gases and harmful substances emissions while not posing an excessive burden for the grid infrastructure. This means that the electrification and development of public transport in Polish cities should be a priority.

117 Kielichowska I., Staschus K., van der Leun K., Bettgenhaeuser K., Ramaekers L., Sheppard S., Staats M., Lenkowski A., Sijtsma L., *Poland's climate neutrality by 2050* [Polska neutralna klimatycznie 2050] *Electrification and sector coupling, Forum Energii*, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow.

Tab. 11. Peak power demand resulting from charging electric vehicles - variant without flexibility [GW]

	2030		2050	
	Baseline scenario	Alternative scenario	Baseline scenario	Alternative scenario
Light vehicles	**0.25**	**1.09**	**1.36**	**6.73**
Heavy vehicles				
Road vehicles	0.00	0.00	0.64	2.70
City vehicles	0.04	0.17	0.22	0.91
Total EV	**0.28**	**1.25**	**2.00**	**9.44**

Source: Own study.

Tab. 12. Peak power demand resulting from charging electric vehicles - variant with flexibility [GW]

	2030		2050	
	Baseline scenario	Alternative scenario	Baseline scenario	Alternative scenario
Light vehicles	**0.24**	**1.06**	**1.31**	**6.50**
Heavy vehicles				
Road vehicles	0.00	0.00	0.55	2.30
City vehicles	0.04	0.17	0.22	0.94
Total EV	**0.25**	**1.12**	**1.87**	**8.85**

Source: Own study.

Assessment of the actual impact of electromobility on the NPS balancing requires an analysis of the power demand with the wind and sun energy production profile as well as with the base (historical) NPS load profile.

The calculations include RES development forecasts from the above-mentioned studies of Forum Energii[118], with S2-100+C+EV selected as the most ambitious scenario for 2050[119]. The capacity of wind and solar energy sector is shown in Table 13. In 2050, the capacity of photovoltaic installations is expected to increase to 71.8 GW and onshore as well as offshore wind power plants to a total of 63.5 GW. The S2-100+C+EV scenario also assumes an increase in peak power demand from 26.1 GW in 2019 to as much as 55.3 GW (of which about 46 GW is the base demand - without electromobility).

118 Forum Energii, Poland: climate neutrality by 2050. Electrification and sector coupling, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow and Forum Energii, *How to fill the coal gap? 43% RES by 2030*, 2020, https://forum-energii.eu/en/analizy/jak-wypelnic-luke-weglowa.

119 This scenario assumes 100% of RES electricity production and integration of electricity, heating and electromobility sectors.

Tab. 13. Capacity of solar and wind power plants [GW]

	2030	2050
PV	17	71.8
Wind - onshore	18	40.2
Wind - offshore	7.7	23.3

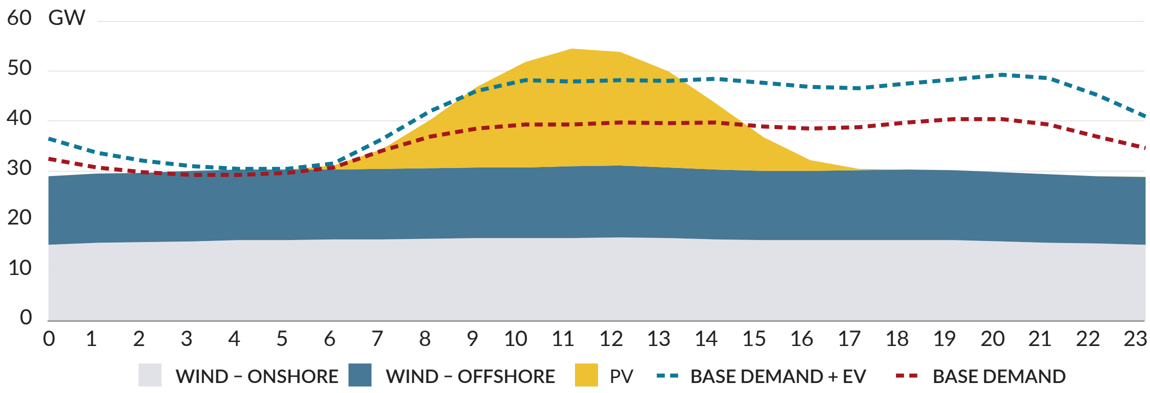
Source: Forum Energii, *Poland: climate neutrality by 2050.* Electrification and sector coupling, 2020, https://forum-energii.eu/en/analizy/integracja-sektorow and Forum Energii, *How to fill the coal gap? 43% RES by 2030*, 2020, https://forum-energii.eu/en/analizy/jak-wypelnic-luke-weglowa.

The production of wind and sun energy and the assumed installed capacity were matched with hourly solar and wind profiles in Poland[120]. The data for the whole year 2019 were averaged up to four model days corresponding to individual seasons of the year. Similarly, the power demand profile was prepared using hourly data from 2019[121]. The historical profile has been scaled up to 2050 values taking into account the projected annual peak power.

Average daily profiles for a winter business day are presented in Fig. 29. (inflexible variant) and 30. (flexible variant). As wind and sun energy production constitutes an hourly average over the whole year, the wind profile is almost constant. Of course, in practice there are significant fluctuations in wind force between days, but on a scale of several months, the profile, considering the statistics, does not show significant variability during the day. Wind-generated capacity reaches approx. a maximum of 30 GW. In addition, solar power plants are included in the production structure between 8 a.m. and 5 p.m. - accounting for up to 23 GW of capacity between 11 a.m. and 12 p.m. Such production properly completes the demand profile of the flexible variant, where the peak is between 10 a.m. and 2 p.m. Additionally, thanks to flexible EV charging the evening peak in the base demand is mitigated - in total, the power demand at 8 p.m. is almost 2.6 GW lower than in the inflexible scenario, which is extremely important in the context of lacking PV generation.

However, it is worth bearing in mind that even in the alternative scenario, electromobility accounts for 18% of the total power demand in Poland. This means that the shape of the total NPS load profile is determined primarily by the basic demand of households and industry - in these sectors, demand management should also be ensured - e.g. through mechanisms such as DSR and dynamic tariffs.

Fig. 29. Average daily electricity demand and production profile - winter business day, alternative scenario, 2050, variant without flexibility

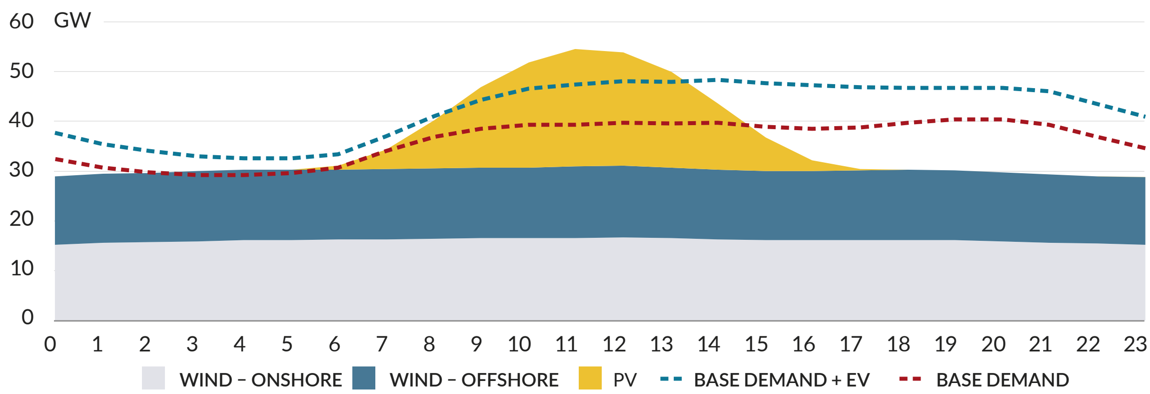


Source: Instrat own study based on own calculations, energy.instrat.pl and renewables.ninja data.

120 Power utilisation factors from the renewables.ninja model have been used for the future fleet.

121 http://energy.instrat.pl/total_load. It was decided to use 2019 as the base year, as 2020, due to the COVID-19 pandemic, was characterised by abnormally low energy consumption.

Fig. 30. Average daily electricity demand and production profile - winter business day, alternative scenario, 2050, variant with flexibility



Source: Instrat own study based on own calculations, energy.instrat.pl and renewables.ninja data.

6. Impact of electromobility on distribution grids

6.1. Scope of necessary modernisation of distribution grids related to electromobility development

The main research task of this publication was to assess the impact of electromobility development on distribution grids, in particular to determine the extent of the necessary infrastructure modernisation.

The analysis was carried out using *the bottom-up* method, taking into account the distribution grid nodes up to and including 15 kV as well as considering the low voltage grid load. Due to the number of distribution grid nodes at the average voltage level exceeding 200 thousand, it is not possible to analyse loads throughout the grid at the same time. In accordance with the methodology used in the latest literature (including *Agora Verkehrswende*[122] think-tank), the calculations were divided into categories corresponding to the structure of population distribution in Poland (p. 4.3), and in each of these categories an exemplary area was selected to illustrate the specific characteristics of a given group:

rural areas - Topólka rural municipality in Kujawsko-Pomorskie Voivodeship,

medium and small towns - Ząbki, Marki, Zielonka in Mazowieckie Voivodeship,

big and major cities - Wrocław in Lower Silesian Voivodeship.

In addition, a location which includes a motorway charging station for high-power electric vehicles was selected - in Kołbaskowo municipality, Western Pomeranian Voivodeship, at the A6 motorway. Given category results were generalised up to the national level, which allowed for the necessary scale of distribution grid modernisation to be assessed.

For selected areas, the layout, power and load of main power supply stations (the so-called GPZ), 15/0.4 kV substations, medium and low voltage lines, plans for modernisation of distribution infrastructure were analysed, existing EV charging stations as well as base demand at medium and low voltage level were taken into account. Local electricity and power demand in a given area (both basic and electromobility sector individually) resulted:

122 U. Maier, F. Peter, A. Jahn & J. Hildermeier, *Distribution grid planning for a successful energy transition - focus on electromobility*, Agora Verkehrswende, Agora Energiewende, Regulatory Assistance Project, 2019, https://www.agora-verkehrswende.de/fileadmin/Projekte/2019/EV-Grid/AgoraRAP2019_VerteilnetzausbauElektromobilitaet_EN.pdf.pdf.

- from the structure of population distribution,
- structure of buildings and residential premises distribution (mainly single-family buildings in rural areas, multi-family buildings in large cities, both in medium-sized and small towns)
- types of vehicles used (mainly light in rural areas, also heavy city vehicles in cities, and mainly heavy road vehicles along expressways).

The distribution of the load between the individual grid components resulted from the implemented model of the medium and low voltage grid[123].

The analysis result was the assessment of the impact of electromobility on the distribution infrastructure load and determination of the necessary scope of modernisation with an increasing number of electric vehicles. Since the increase in EVs number by 2030 is not important enough to have a very significant impact on the power grid, only the results for 2050 were presented.

A detailed description of the assumptions and results for each of the examined areas has been presented below.

Rural areas – example of Topólka municipality.

Rural areas in Poland are currently characterised by a very low degree of electromobility penetration. As single-family buildings are predominant in rural municipalities, the dominant role of private low power charging points is assumed. At the same time, it has been assumed that heavy city and road vehicles will not be charged in rural areas, which also means that high power charging points (apart from communities with expressways and motorways) will not be available.

The municipality of Topólka in Kujawsko-Pomorskie Voivodeship has been selected to illustrate issues related to the development of electromobility in rural areas. The municipality had 4793 inhabitants in 2019. The number has been systematically decreasing since 2010, when the population was 5026[124]. The number of residential buildings in the municipality is 1348, almost all of which are single-family buildings.

The municipality is powered by overhead medium voltage lines connected to two main power supply stations located in neighbouring municipalities[125]:

- Lubraniec main power supply station 1 x 16 MVA (14 MW),
- Piotrków Kujawski main power supply station with capacity of 2 x 16 MVA (28 MW).

In the coming years, Piotrków Kujawski main power supply station was planned to be renovated, including the replacement of transformers with units of higher capacity - 25 MVA (20 MW)[126].

The 15 kV line length from the main power supply station to the foremost 15/0,4 kV substations at the outskirts of the municipality is 5-8 km. The 15 kV grid consists of overhead AFL 35,25 mm^2 connection with a current capacity of 181 A in summer and 203 A in winter[127]. It was assumed that 0.4 kV lines were executed using typical AL 35 mm^2 connections with a current capacity of 180 A in summer and 201 A in winter. 101 transformer stations 15/0.4 kV were located in the municipality, all of them were overhead stations with a capacity of 20-250 kVA. The distribution grid map (110, 15 and 0.4 kV) is presented in Fig. 31.

123 See point 4 - medium voltage grid model implemented in the PyPSA environment, the low voltage grid model was prepared using Excel. Details of the calculations are discussed under sub-paragraphs of specific areas.

124 GUS BDL, POPULATION/ POPULATION / Population in municipalities without cities with poviat status and cities with poviat status by sex.

125 Resolution no. XIII/107/16 of the Topólka Municipal Council of 22 June 2016 on the adoption and acceptance for implementation of the Low Emission Economy Plan for Topólka Municipality: http://bip.topolka.pl/upload/Plan%20Economy%20Niskoemisj%20uchwa√C5%82a%20nr√20107%20.pdf.

126 Ted.tenders electronic daily, Poland-Gdańsk: *Voltage transformers 2020/S 141-347855. Proceeding results. Supplies*, 2020, https://ted.europa.eu/udl?uri=TED:NOTICE:347855-2020:TEXT:EN:HTML&WT.mc_id=RSS-Feed&WT.rss_f=Materials+and+Products&WT.rss_a=347855-2020&WT.rss_ev=a.

127 Eltrim Kable, Przewody do linii napowietrznych [Conductors of overhead lines], 2020, https://www.eltrim.com.pl/assets/katalogi/Katalog-przewody-napowietrzne-2020.pdf.

Fig. 31. Topólka municipality power grid map

Source: Open Infrastructure Map.

The vast majority of municipal electricity demand, as much as 86%, is generated by the household sector (Tab. 14). All customers in the municipality are connected to the low voltage grid.

According to the country-wide scenarios, the base demand (without electromobility) for electricity in Topólka municipality is projected to increase significantly from the current 5.1 GWh per year to 6.2 GWh in 2030 and 7.2 GWh in 2050. Therefore, the average municipal demand per household will increase from the current 3.3 MWh to 5.6 MWh in 2050.[128] At the same time, based on the forecasts in section 4.1, intensive development of electromobility in the municipality is assumed, resulting in an additional burden on the local distribution grid (Tab. 15.).

Tab. 14. Annual electricity demand in Topólka municipality [MWh]

[MWh]	Topólka
Public lighting	200.46
Public administration	82.56
Housing	4405.75
Services, trade, industry	413.42
TOTAL	**5102.19**

Source: Resolution no. XIII/107/16 of the Topólka Municipal Council of 22 June 2016 on the adoption and acceptance for implementation of the Low Emission Economy Plan for Topólka Municipality.

In 2030, 85-374 light electric vehicles will be travelling in the municipality depending on the scenario[129]. In 2050, it will be 490 for the baseline scenario and 2057 for the alternative scenario, which means almost complete electrification of the current fleet of vehicles registered in the municipality - 3.3 thousand[130]. Since it is assumed, in rural areas, that

128 This value also takes into account the demand arising from the installation of heat pumps in single-family buildings.
129 In the future, agricultural machinery should also be electrified in rural municipalities, however, the study does not take it into account.
130 Resolution no. XIII/107/16 of the Topólka Municipal Council of 22 June 2016 on the adoption and acceptance for implementation of the Low Emission Economy Plan for Topólka Municipality: http://bip.topolka.pl/upload/Plan%20Economy%20Niskoemisj%20uchwa√C5%82a%20 nr√20107%20.pdf.

light vehicles are mainly used and charged in homes, the planned number of energy consumption points for charging is comparable to the number of vehicles. Additional charging points will be installed at workplaces, public buildings as well as in light commercial vehicle fleet headquarters in the area of municipality.

EV charging will generate additional electricity demand - although it remains under 1 GWh until 2030, it will increase to 4.4 GWh in 2050 - almost twice the current value and as much as 38% of the total demand in the municipality in 2050.

Tab. 15. Topólka municipality electromobility development forecast

	2030		2050	
	Baseline scenario	Alternative scenario	Baseline scenario	Alternative scenario
Number of electric vehicles	85	374	490	2057
Number of energy consumption points for charging	91	400	524	2201
Energy demand for EVs [GWh]	0.16	0.72	0.89	4.40

Źródło: Opracowanie własne.

Considering the electricity generation side, there are several wind turbines in the municipality with a total capacity of 11.4 MW which allow to produce approx. 25 GWh annually. No reports have been made so far on the functioning of photovoltaic installations, but a significant increase in the capacity of installed PV microinstallations is expected in the future - up to 2.1 MW by 2030 and 7.5 MW by 2050 in accordance with the scenarios in section 4.5. This means that with an average installation capacity of 5.77 kW in the "My electricity" programme, in 2050 as much as 96% of the residential buildings in the municipality would produce their own solar energy and contribute part of it to the grid. Only PV microinstallations have been taken into account in further calculations of EVs' impact on distribution grids as these pose the greatest challenge to low voltage grids with limited load capacity. As mentioned previously, the development of household energy storage means has not been taken into account when examining the pessimistic grid load scenario. Wind power plants and larger solar power plants are typically connected to higher voltage grids or directly to main power supply stations. The challenge for DSOs is now to connect smaller photovoltaic farms to the medium voltage grid, which already requires large-scale upgrading of the grid infrastructure[131]. However, this issue goes beyond this publication. The issues of balancing electricity demand by EV and RES production at high voltage level (NPS) are discussed in section 5.

The above assumptions were used to create a distribution grid model in Topólka municipality (Fig. 31) and then to estimate the need to adapt the grid to meet the increased demand related to the development of electromobility. The analysis was carried out for all key components of the distribution grid:

- 0.4 kV ow voltage grid,
- 15/0.4 kV transformer station,
- Medium voltage branch lines (connecting 15/0.4 kV stations with the main line),
- 15 kV main lines connected to the main power supply station,
- GPZ.

The increase in power demand resulting from charging electric vehicles will contribute to a higher load of 15/0.4 kV transformer stations and 0.4 kV lines, which was examined on the part of the municipality shown in Fig. 6.1.2, covering 27 residential buildings and one 15/0.4 kV transformer station. It is worth noting that, on average, 19 residential

131 P. Czyżak, M. Sikorski, A. Wrona, *What's next after coal? RES potential in Poland*, Instrat Policy Paper 06/2021, 2021, http://instrat.pl/potencjal-oze/.

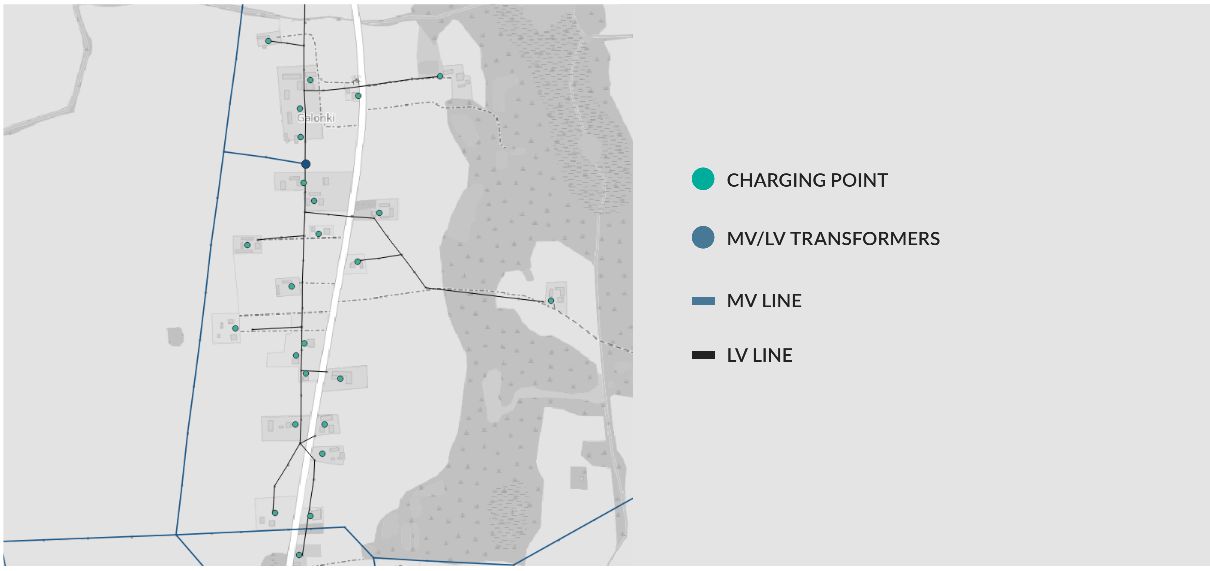
buildings are connected to one transformer station in Poland[132]. Therefore, the pessimistic area in terms of 0.4 kV lines and medium voltage transformer stations load was selected for the purposes of the analysis.

Fig. 32. indicates the planned distribution of power consumption points for charging purposes - as described above, in the alternative scenario of 2050 they are located in all residential buildings. In this case, this means 27 of such power consumption points connected to the low voltage grid. The exact capacity of MV/LV transformer is not known, according to the Low Emission Economy Plan, the capacities of 15/0.4 kV transformers in the municipality are between 20 and 250 kVA, the Energa grid average is 161 kVA[133], the weighted average for the whole of Poland (excluding Innogy grid) is 183 kVA.

The analysis carried out for the most demanding scenario - alternative in 2050, using demand profiles and charging profiles from points 4.4. and 4.5. (business winter day), showed that even almost complete electrification of transport does not pose a threat to low voltage grid elements. The 15/0.4 kV transformer load ranges from 24.1% to 30.5% depending on the time of the year and the flexibility variant. The load increase in relation to the baseline scenario equals a maximum of 12%. The load on the 400 V line, which connects the lower section of the presented part of the grid (19 buildings) with the 15/0.4 kV transformer, is higher and varies between 27.3% to 38%. The line would withstand the load (a safe limit of 70% has been assumed) even using a conductor with a minimum cross-sectional area of 16 mm^2. The increase in the load compared to the baseline scenario in 2050 is up to 15%.

Applying the above example to the low-voltage grid for the entire municipality of Topólka, the results are similar. Although, in the municipality, the average number of charging points exceeds the number of households (it has been assumed that additional charging points are also installed at workplaces), the 15/0.4 kV transformers' and 400 V grid load remains below 30% even for the inflexible scenario. Similar conclusions result from the generalisation of results to the level of rural areas in Poland - with the use of transformers with a capacity corresponding to the average capacity of MV/LV transformers in Poland (excluding the typical city Innogy grid) and a comparable density of their distribution, the increase in their load associated with the EV charging infrastructure does not pose a threat to grid security, and the implementation of standard planned upgrades will be fully sufficient. The higher load is recorded by low voltage main lines - in the summer - up to 44% (an increase of 19% in relation to the base load), but it is still a safe value despite a much higher density of private charging points.

Fig. 32. Location of chargers on a selected part of Topólka municipality



Source: Instrat own study. OpenStreetMap base map.

132 By dividing the number of residential buildings (approx. 5 million) by the number of MV/LV stations (261 thousand) - PTPiREE, *Power industry, distribution and transmission* [Energetyka dystrybucja i przesył], 2020, http://raport.ptpiree.pl/raporty/2020/raport_ptpiree_druk.pdf.

133 PTPiREE, *Power industry, distribution and transmission* [Energetyka dystrybucja i przesył], 2018, http://www.ptpiree.pl/documents/raport_ptpiree.pdf.

It is worth noting that the development of photovoltaic microinstallations seems to be a greater challenge in designing low-voltage grids than the development of electromobility. As mentioned previously, ambitious national scenarios for 2050 mean that the vast majority of single-family houses will be equipped with PV installations. In the absence of household energy storage, the load on the 400 V line, at noon in summer, from houses to the 15/0.4 kV transformer reaches 69%, i.e. a value close to the permissible one. Therefore, this means that modernisation investments to connect RES will be fully sufficient to secure a possible load increase caused by the development of electromobility. The development of electromobility should be regarded as beneficial - increasing local energy consumption in households reduces the amount of energy returned to the grid by prosumers. In the base scenario with fewer electric vehicles, the load of the low-voltage grid at summer noon increases by 10% to a dangerous 79%.

The development of electromobility also does not jeopardise the internal 15 kV municipality grid. On average, 4 transformer stations were connected to one 15 kV branch line, and the maximum load of this section of the medium voltage line is 5.7%. The line can easily cover villages with up to 10 times the grid density (number of lines per transformer), which means that this component in rural areas does not require modernisation in relation to the development of electromobility.

The last research area was 15 kV main lines supplying power to the municipality and the main power supply stations (GPZ). In order to assess the impact of electromobility on the load of the examined components, a distribution grid model was prepared in the Topólka and neighbouring municipalities using the aforementioned PyPSA environment[134]. The prepared model includes 15 kV main grids and main power supply stations.

The current load of GPZ to which the municipality is connected is estimated to be:

- Lubraniec GPZ: 60%
- Piotrków Kujawski GPZ: 49%

In the future, this load will increase slightly due to the increase in the base demand, but the impact of the electromobility development, in Topólka municipality alone, on the load of the main power supply stations is marginal - for the alternative scenario in 2050 the increase is 3.6% for Lubraniec GPZ and 2.3% for Piotrków Kujawski GPZ in the inflexible scenario as well as 2% and 1.3% respectively in the flexible scenario. Such load should therefore be regarded as negligible in the context of GPZ development planning in rural areas.

The impact of electromobility on the main (meaning lines running from GPZ) medium voltage lines is slightly higher. These lines were assumed to have been constructed using typical for main line connections AFL-6 70 mm^2 conductors[135] with a permissible peak capacity of up to 4.6 MW in winter[136]. The application of the alternative scenario increases the line load by 10% in the inflexible scenario and by 5.5% in the flexible scenario. The maximum load on connections to GPZ does not exceed 23%, which means that such values do not constitute an issue. However, it is worth noting the benefits of applying the flexibility variant- it allows to flatten the evening peak load on medium voltage lines reducing the load at 8 p.m. by 4.4% in relation to the inflexible scenario.

A summary of the above conclusions for rural areas in Poland in 2050 is presented in Tab. 16. The development of electromobility does not negatively affect low and medium voltage grids, and the increase in load resulting from the application of the ambitious alternative scenario is insignificant. In particular, using the flexibility variant, the load increase at the most sensitive point - low voltage line upstream the 15/04. kV transformer - is only 11%. Importantly, the development of electromobility can contribute to reducing the investments needed to adapt distribution grids to the rapid RES development. Increased penetration of electric vehicles and local energy consumption within a household or company limits energy flow from the prosumer to the grid, reducing the LV grid load even by 11%. In turn, this allows to keep the load below the safe value of 70% and avoid the need to upgrade thousands of kilometres of the low-voltage grid.

134 T. Brown, J. Hörsch, D. Schlachtberger, *PyPSA: Python for Power System Analysis*, 2018, https://arxiv.org/abs/1707.09913.
135 BEZEL, *Overhead power lines* [Linie napowietrzne], 2018, https://bezel.com.pl/2018/08/01/linie-napowietrzne/#odstepy
136 Eltrim Kable, Conductors of overhead lines [Przewody do linii napowietrznych], 2020, https://www.eltrim.com.pl/assets/katalogi/Katalog-przewody-napowietrzne-2020.pdf

Tab. 16. Impact of electromobility development on rural distribution grid components in 2050

	Alternative scenario values		Change in relation to baseline scenario		Is modernisation necessary
	Inflexible variant	Flexible variant	Inflexible variant	Flexible variant	
Low-voltage grid load - EV	44.49%	34.47%	19.29%	11.29%	No
15/0.4 kV transformer load - EV	22.02%	16.98%	9.32%	5.32%	No
Local medium voltage grid load - EV	4.66%	3.59%	1.97%	1.13%	No
Average load of medium voltage main lines	22.45%	18.02%	9.97%	5.54%	No
Maximum GPZ load	63.61%	62.01%	3.61%	2.01%	No

Source: Own study.

Medium and small towns – Marki, Ząbki, Zielonka

Another area selected for the study was medium-sized and small towns. These areas are inhabited by 1/3 of the Polish population. Unlike rural municipalities, in towns only a part of the population (about 40%) has access to dedicated parking spaces, others use workplace charging points as well as low and high power public charging points. Heavy city vehicles (in particular buses) and road vehicles are also charged in urban areas.

The challenges related to the development of electromobility in small and medium-sized towns are illustrated by a group of towns in the suburbs of Warsaw: Marki, Ząbki and Zielonka, sharing a part of the power infrastructure.

In total, they had 91 thousand inhabitants in 2019[137]. The number of residential buildings was 17 thousand, the number of apartments was 37.5 thousand - single-family and multi-family buildings are present in the area.

All three cities are powered by two GPZ:

- Pustelnik GPZ with a capacity of 2 x 25 MVA and current load of approx. 55% (after recent modernisation),
- Ząbki GPZ with a capacity of 2 x 25 MVA and a load of over 65%

Unlike rural areas, in cities, the medium and low voltage grid is largely wired - in Ząbki, the share of cable connections for the 15 kV grid amounts to as much as 84$, for the 0.4 kV grid it is 48%.[138] This means that these grids have recently undergone upgrading and should be characterised by a significant overload capacity - in Ząbki, the average load on the 15 kV line is only 26.3%, on average 9 MV/LV transformer stations were connected to one main line - twice as much as in rural areas.

A total of 484 transformer stations 15/0.4 kV with a capacity of 63-630 kVA are located in the three towns, on average approx. 300 kVA[139]. The load on 15/0.4 kV transformer stations is relatively high - in Ząbki as much as 36% of the station has a load exceeding 75%, which means that they are already eligible for modernisation.

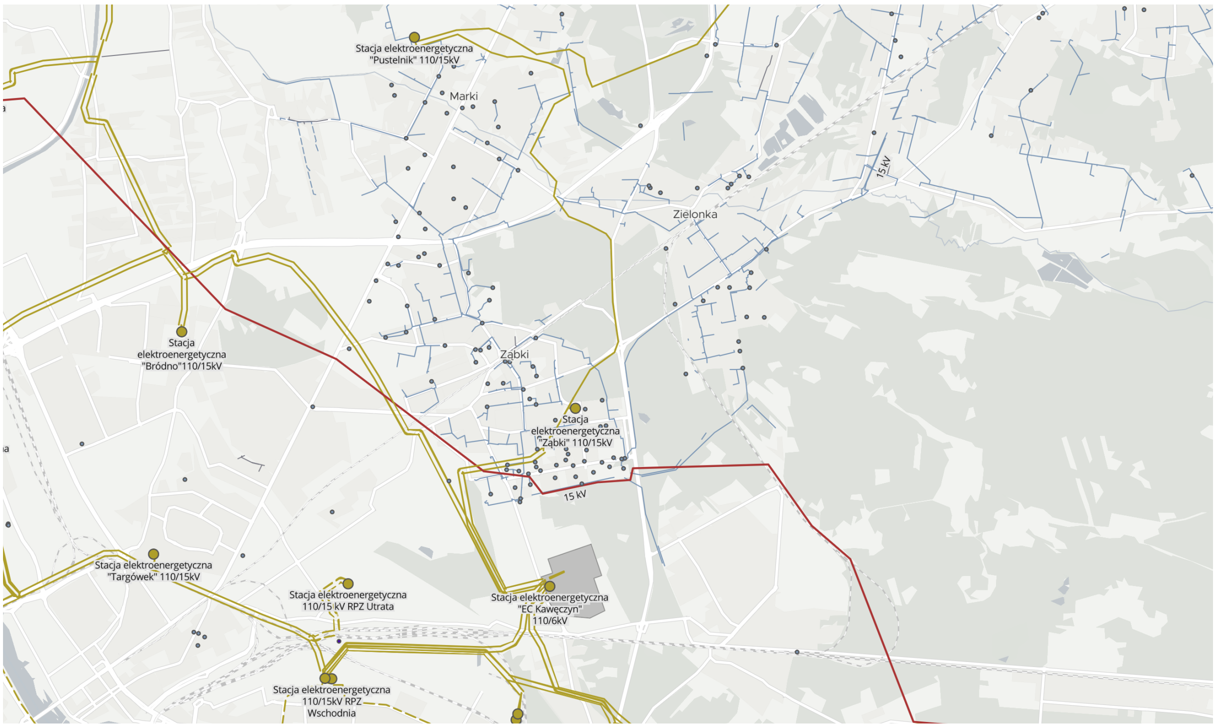
137 GUS, Local Data Bank, section: POPULATION/ POPULATION / Population in municipalities without cities with poviat status and cities with poviat status by sex.

138 Low emission economy for the town of Ząbki: https://bip.zabki.pl/zalacznik/97667.

139 Average value for grids in Marki and Wołomin: Public Information Bulletin, *Draft assumptions for the plan of heating, electricity and gas fuels supply for Wołomin municipality for the years 2012-2027* [Projekt założeń do planu zaopatrzenia w ciepło, energię elektryczną i paliwa gazowe dla gminy Wołomin na lata 2012-2027], 2012, https://wolomin.bip.net.pl/index.php?c=525.

The map of the distribution grid is presented in Fig. 33.

Fig. 33. Marki, Ząbki and Zielonka municipalities power grid map



Source: Open Infrastructure Map.

Unlike rural areas, small and medium-sized towns are characterised by much greater energy consumption in the services, trade and industry sectors. This is particularly visible in Marki, where energy consumers from these sectors, who are connected to the medium voltage grid, consume even above 50% of electricity (Tab. 17). The base demand (without electromobility) for electricity is projected to increase from 180 GWh per year to 217 GWh in 2030 and 255 GWh in 2050.

Tab. 17. Annual electricity demand in Marki, Ząbki, Zielonka municipalities [MWh]

	Medium voltage	Low voltage
Marki	46015	43342
Ząbki	3697	49717
Zielonka	2588	34802

Source: Own study based on Low emission economy plan for the town of Ząbki.

The additional increase in electricity consumption is due to the planned development of electromobility (Tab. 18). In 2030, approximately 1609-7099 light electric vehicles will be travelling in the municipality depending on the scenario. In 2050, according to our estimates, this will be approx. 9.3 thousand for the baseline scenario and approx. 39 thousand in the alternative scenario. In 2050, there will be 421-1770 heavy city vehicles and 562-2359 road vehicles, depending on the scenario. There are 144 thousand passenger vehicles, 688 buses, 26 thousand heavy vehicles registered in the whole Wołomin poviat (in which the cities examined account for 36% of the population)[140]. Assuming an even number of vehicles per person, the alternative scenario means almost complete electrification of light vehicles and a total electrification of public transport (and even an increase in the number of buses according to the mobility transition effect). As indicated in section 4.1, the electrification of heavy road vehicles will take at the very end.

140 GUS, Local Data Bank, section: TRANSPORT AND COMMUNICATION/ VEHICLES /Vehicles total.

The planned number of energy consumption points for charging is much higher than the number of vehicles - not only charging points and sockets of private homes and workplaces are used in cities, but also numerous public and fleet equipment, which also supply vehicles from rural areas.

Electric vehicles will generate additional energy demand - between 3.6 and 15.9 GWh by 2030, from 22.2 GWh in the baseline scenario to 106.1 GWh in the alternative scenario in 2050. In the latter case, the demand for energy from the electromobility sector will account for 29.4% of the total demand in the three cities described, in the baseline scenario it is only 8%.

Tab. 18. Marki, Ząbki and Zielonka electromobility development forecast [GWh]

	2030		2050	
	Baseline scenario	Alternative scenario	Baseline scenario	Alternative scenario
Number of electric vehicles	1 682	7 422	10 283	43 172
Number of energy consumption points for charging	2 025	8 933	11 836	49 695
Energy demand for EVs [GWh]	3.60	15.87	22.21	106.11

Source: Own study.

A significant development of PV microinstallations is assumed in the three cities- up to 13.2 MW in 2030 and 47.3 MW in 2050 in accordance with the scenarios described in section 4.5. Depending on the city, this would mean that the share of residential buildings with photovoltaic installation will be between 40% and 59% - significantly less than in rural areas. By converting these values into one residential unit, on average 22% of them will be equipped with PV microinstallations.

Using the methodology described in the rural section, the impact of electromobility development on the grid infrastructure load in medium-sized and small cities has been assessed. It has been assumed that by 2050 the low and medium voltage grids would be fully cabled. For the 400 V line, the use of cables with a load capacity of 135 A was assumed[141]. As mentioned, the average capacity of 15/0.4 kV transformers in medium-sized cities is about 300 kVA and such value has been assumed as some stations already need to be upgraded. This value may increase in the future. On average, there are 77 residential units per transformer station in the area under examination (in single and multi-family houses). The average base electricity consumption per residential unit is 2134 kWh annually[142] and is assumed to increase to 3015 kWh in 2050 according to national scenarios. The calculations take into account the development of micro-installations of PV in cities, but their penetration is definitely lower than in rural areas and they do not have such a significant impact on low and medium voltage infrastructure.

Unlike rural areas, city areas take into account not only the deployment of charging points in homes and workplaces, but also normal and high power public charging points as well as fleet charging points for city and road vehicles. An example of energy consumption points for charging purposes is presented using a part of Ząbki city in Fig. 34. The area is powered by eight 15/0.4 kV transformer stations, covering approximately 187 single-family houses and over 400 residential units in multi-family buildings, with an average of approximately 78 units per transformer station - which almost perfectly corresponds to the city average. Residents of all single-family houses use charging points or standard sockets for charging EVs. The location of numerous private charging points for residents of multi-family buildings was also assumed - on average, in cities only 40% of residents have a private parking space[143]. There are numerous service and commercial buildings in the vicinity with private charging points for staff as well as public normal power charging

141 YAKXS 4 x 35 mm^2: HELUKABEL, *YAKXS - product data sheet*, https://www.helukabel.pl/files/YAKXS-karta-katalogowa.pdf.

142 GUS, Energy consumption of households in 2018 [Zużycie energii w gospodarstwach domowych w 2018 r.], https://stat.gov.pl/download/gfx/portalinformacyny/pl/defaultaktualnosci/5485/2/4/1/zuzycie_energii_w_gospodarstwach_domowych_w_2018.pdf.

143 The average for the whole country is 64%, assuming 100% in rural areas and 40% in cities: Kielichowska I., Staschus K., van der Leun K., Bettgenhaeuser K., Ramaekers L., Sheppard S., Staats M., Lenkowski A., Sijtsma L., Polska neutralna klimatycznie 2050 [Poland's climate neutrality by 2050] Electrification and sector coupling, Forum Energii, 2020, https://forum-energii.eu/pl/analizy/integracja-sektorow.

points. At the south-western end of the quarter, a storage hall with high-power fleet charging points can also be found. High and normal power public charging points are located at the parking lot of the Municipal Sport Centre. The area presented is characterised by a wide variety of buildings and, therefore, charging infrastructure - hence it constitutes a proper visualisation of the method of planning charging infrastructure in cities.

The load analysis in the low-voltage municipal grid has shown that, even in a demanding alternative scenario, the development of electromobility does not necessarily entail additional costs for the grid infrastructure.

The average load of 15/0.4 kV transformers in Ząbki, Marki and Zielonka in 2050 ranges between 26.1% and 32.1% depending on the flexibility variant (Tab. 19.). The flexible variant allows to reduce the peak load by 6%. The increase in the alternative scenario load compared to the baseline scenario is only 9-13% (depending on the flexibility variant). Similarly to line load, the transformers' load varies - considering the example of Ząbki, 64% of them is characterised by a safe load up to 74%, the remaining ones would have to be modernised regardless of electromobility development scenario. The average load increase of 9-13% should not pose any threat to transformers upgraded regularly in response to the growing base demand.

A bigger challenge may be the load on the 400 V line. With the assumed relatively low load capacity of typically used 4x35 mm^2 cable lines, in the inflexible variant of the alternative scenario, the load in summer reaches 71%. The flexibility variant allows to reduce this value to a safe 59%. The difference in relation to the baseline scenario is significant here: 19-28%, depending on the variant. The use of flexible charging is therefore crucial to avoid costly upgrades of the low voltage grid.

Fig. 34. Location of energy consumption points for EV charging in the selected Ząbki section

Source: Instrat own study based on Open Infrastructure Map, Open Street Map, Geoportal, Google Maps.

Similarly to the Topólka municipality, a medium voltage grid model has been developed for Marki, Ząbki and Zielonka, including main lines and main power supply stations. It is worth noting that a much higher increase in the base electricity demand is forecasted in relation to cities. In order to maintain the current level of GPZ load, regardless of the electromobility development scenario, it will be necessary to increase both the capacity of the "Pustelnik" and "Ząbki" stations to 2x40 MVA. Otherwise, the base demand (without electromobility) in 2050 will overload the GPZ.

Even with GPZ capacity increased to 2 x 40 MVA, the development of electromobility poses a challenge to maintain the power reserve in GPZ. In Pustelnik GPZ, the load increases from 55% to 58% in the base scenario, and in the alternative scenario to 74%. The results for the flexible scenario are almost identical. Pustelnik GPZ may therefore require further modernisation - potentially up to 63 MVA, i.e. the maximum value typically possible for 110/15 kV substations without significant interference in their design. The situation of Ząbki GPZ is even more demanding - the initial load of 65% increases to 72% for the baseline scenario and 97% for the alternative scenario. Smart charging variant application allows to reduce the load to 70% in the baseline scenario and 88% in the alternative scenario.

This means that in all scenarios for 2050 (the baseline scenario with flexibility is at the safety limit), Ząbki GPZ requires an increase in capacity up to a maximum of 2 x 63 MVA.

The load on the main 15 kV lines varies and already ranges from 5% to 70% in Ząbki. Detailed information on the type of medium voltage cables used are not available, which is why the model permissible capacity of the line was selected in such a way as to obtain the average load of 26% reported for Ząbki only with the basic demand (without electromobility). The application of the alternative scenario increases the average line load by 6.6-13% in the inflexible scenario and by 4-13% in the flexible scenario. In the baseline scenario, those are negligible values around 3%. Despite similar maximum load values, the flexible variant allows to reduce the total load at the evening peak by as much as 1.8 MW. The average line load does not exceed 40% in the alternative scenario. As mentioned, there is a large variation in the current line load, but the lines that already reach 60-70% of load are the remaining overhead lines, which will be replaced in the coming years with cable lines regardless of electromobility development, which means that an increase in the load of 13% resulting from charging electric vehicles does not pose a threat.

Tab. 19. Electromobility development impact in small and medium-sized cities on distribution grid components

	Alternative scenario values		Difference in relation to the baseline		Is modernisation necessary
	Inflexible variant	Flexible variant	Inflexible variant	Flexible variant	
Low-voltage grid load	71.37%	58.76%	28.45%	19.36%	Depending on the variant
15/0.4 transformer load	32.12%	26.44%	12.80%	8.71%	No
Average load of medium voltage main lines	38.12%	35.93%	9.13%	7.65%	No
Maximum GPZ load	97.33%	87.89%	25.39%	18.26%	Yes

Source: Own study.

The analysis of the impact of electromobility on low and medium voltage grids and main power supply points in medium-sized and small cities has shown that even the nearly complete electrification of the vehicle fleet resulting from the alternative scenario does not necessarily entail an overload of grid infrastructure and costly investments. The only component of the grid requiring absolute upgrade is GPZ, which even in the base scenario shows a load of approximately 70&. The use of flexible charging makes it possible to avoid investments in the low voltage grid even in the alternative scenario.

Large towns and cities – Wrocław.

The group of large town and cities constitutes a particular analytical challenge. The high population density and dynamically growing energy demand mean that the upgrading of the grid infrastructure must be planned many years in advance. The challenges related to the development of electromobility in large cities are presented on the example of Wrocław.

It is worth noting that most large cities already consider the development of electromobility in their strategies, including the electrification of public transport. In Wrocław, it is *Electromobility development strategy of Wrocław*[144]. The increase in energy demand due to the growing number of electric vehicles was also included in the *Heat, Electricity and Gas Fuel Supply Plan for the Municipality of Wrocław for the years 2020-2035*[145]. The data and assumptions of the above documents were used in the analysis, but it should be noted that their time horizon does not reach 2050, and the forecasts for the development of electromobility are conservative - the increase in EV by 2030 is set only at 4000, much less than in the considered baseline scenario.

In 2019 Wrocław had 639 thousand inhabitants[146]. The number of residential buildings was 43 thousand, the number of apartments was 340 thousand[147] - there are mainly multi-family buildings in the area. It is worth noting that over the last five years 7.8 thousand new apartments were handed over in Wrocław annually[148].

Wrocław is supplied via numerous GPZ (Tab. 20). 110 kV grid infrastructure is growing dynamically, for instance, by 2030 the following are planned:

- construction of Mennicza GPZ,
- modernisation of Pułaskiego GPZ,
- modification of Swojec GPZ,
- modification of Krzywoustego GPZ,
- modernisation of Walecznych GPZ,
- construction of Jagodno GPZ,
- construction of Złotniki GPZ,
- construction of Psie Pole Przemysłowe GPZ (optionally),
- construction of Muchobór Wielki GPZ,
- construction of Stysia/Owsiana GPZ,
- construction of Nowa WuWA GPZ,
- construction of Ligota GPZ.

This means that it is extremely difficult to estimate the impact of electromobility on GPZ load as it must take into account the continuous changes in the grid layout, transformers' capacity and so on in the 2050 perspective.

144 *Electromobility development strategy of Wrocław* [Wrocławska strategia rozwoju elektromobilności]: http://wrosystem.um.wroc.pl/beta_4/webdisk/211025/0675ru08z.pdf

145 Draft assumptions for the plan of heating, electricity and gas fuels supply for Wrocław municapality for the years 2020-2035 [Projekt założeń do planu zaopatrzenia w ciepło, energię elektryczną i paliwa gazowe dla obszaru gminy Wrocław na lata 2020-2035]: https://bip.um.wroc.pl/artykul/859/41655/projekt-zalozen-do-planu-zaopatrzenia-w-cieplo-energie-elektryczna-i-paliwa-gazowe-dla-obszaru-gminy-wroclaw-na-lata-2020-2035

146 GUS, Local Data Bank, section: POPULATION/ POPULATION / Population in municipalities without cities with poviat status and cities with poviat status by sex

147 GUS, Local Data Bank, section: Housing economy and municipal infrastructure / Dwelling stocks

148 Public Information Bulletin, *Heat, Electricity and Gas Fuels Supply Plan for the Municipality of Wrocław for the years 2020-2035* [Plan zaopatrzenia w ciepło, energię elektryczną i paliwa gazowe dla obszaru Gminy Wrocław na lata 2020-2035], 2019, https://bip.um.wroc.pl/artykul/859/41655/projekt-zalozen-do-planu-zaopatrzenia-w-cieplo-energie-elektryczna-i-paliwa-gazowe-dla-obszaru-gminy-wroclaw-na-lata-2020-2035

Tab. 20. Main power supply stations in Wrocław

	Capacity [MVA]	Voltage levels
Pułaski GPZ	2 x 40	110/20/10 kV
Wrocław West GPZ	2 x 63	110/20/10 kV
Walecznych GPZ	2 x 63	110/20/10 kV
Zacharzyce GPZ	2 x 25	110/20 kV
Swojec GPZ (container station)	1 x 25	110/20/10 kV
Żelazna GPZ	1 x 40, 2 x 25	110/20/10 kV
Wilcza GPZ	2 x 40	110/20/10 kV
Pilczyce GPZ	2 x 40	110/20/10 kV
Leśnica GPZ	2 x 25	110/20 kV
Bielany Wrocławskie GPZ	2 x 63	110/20 kV
Krzywoustego GPZ	2 x 16	110/20/10 kV
Skarbowców GPZ	2 x 25	110/10 kV
Żmigrodzka GPZ	2 x 40	110/20/10 kV
Wieczysta GPZ	2 x 40	110/20/10 kV
Pafawag GPZ	1 x 40, 1 x 16	110/10 kV
Psie Pole GPZ	3 x 40	110/20/10 kV
Kurkowa GPZ	2 x 63	110/20/10 kV
Długa GPZ	2 x 40	110/20/10 kV
Klecina GPZ	1 x 25	110/20 kV
Hutmen GPZ (industrial)	2 x 16	110/10 kV

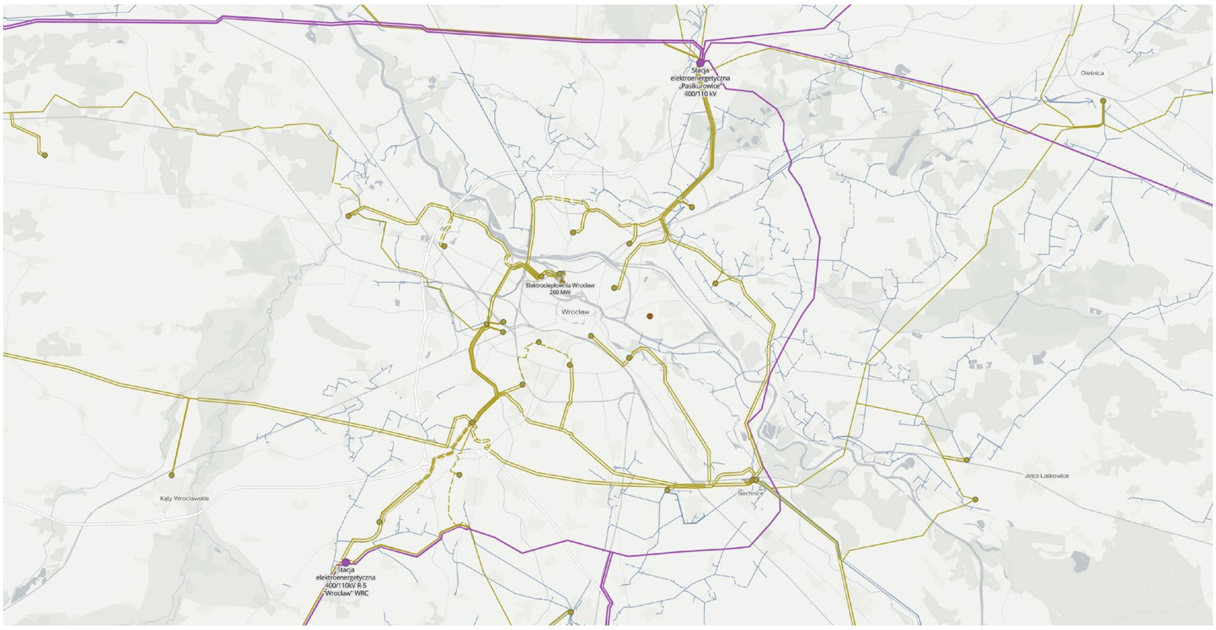
Source: Assumptions for the heating, electricity and gas fuels supply plan for the Municipality of Wrocław for the years 2020-2035.

The medium voltage grid operates in Wrocław at two voltages - 20 kV (1241 km) and 10 kV (1059 km), while gradually aiming at switching entirely to 20 kV. The state of the grid should be described as good - over 90% are cable connections (for the 10 kV line it is as much as 96%). There are 2433 MV/LV transformer stations in the city, mainly indoor stations (94%), and only about 20% of them currently require modernisation. The MV grid operates in a loop partition system with the possibility of secondary emergency power supply. The low voltage grid owned by Tauron Dystrybucja is also almost completely cabled (83%).

Apart from the main grid managed by Tauron Dystrybucja, there is also, inter alia, PKP Energetyka's infrastructure in the city - medium voltage 55.8 km long grid and low voltage 21.7 km long grid, both almost entirely cabled (87%). PKP Energetyka also has 75 transformer stations with an average capacity of 348 kVA and an average load of 82%.

The map of the distribution grid (HV and MV) is presented in Fig. 35.

Fig. 35. Map of the power grid in Wrocław



Source: Open Infrastructure Map.

As one of the largest cities in Poland, Wrocław has a very high consumption of electricity - in 2018 it was 2388 GWh. Similarly to medium-sized cities, large industrial and service customers connected to the medium voltage grid play an important role in the consumption structure (53%) (Table 6.1.8.). Households account only for 25% of energy consumption. This means that the spatial distribution of demand is much less even than in rural areas - grid components in the vicinity of, for instance, industrial plants will cause an incomparably higher load than areas focusing only residential buildings. In the future, the base demand (without electromobility) is expected to increase from the current 2388 GWh annually to 2860 GWh in 2030 and 3350 GWh in 2050.

Tab. 21. Annual electricity demand in Wrocław [GWh]

A tariffs - high voltage	19.6
B tariffs - medium voltage	1255.1
C+G+R tariffs - low voltage	1113.2
including G tariff (households)	593.5
in total	**2387.8**

Source: Assumptions for the heating, electricity and gas fuels supply plan for the Municipality of Wrocław for the years 2020-2035.

Further increase in electricity consumption results from the expected development of electromobility (Tab. 22).

We assume that in 2030 11-50 thousand light electric vehicles will be travelling in Wrocław, depending on the scenario. In 2050, this will be 65 thousand for the baseline scenario and 275 thousand for the alternative scenario. In 2050, there will be 3-12 thousand of heavy city vehicles and 4-17 thousand of road vehicles, depending on the scenario. Unlike the other areas concerned, in large cities the number of light electric vehicles does not correspond to the total of current fleet (442 thousand) as the change within the mobility model from individual transport to public transport is being pursued. 68 thousand heavy vehicles have now been registered in Wrocław, which means that in the alternative scenario, the electrification will cover 43% of them, while a total electrification of public transport (currently 429 buses) is assumed by 2035[149].

149 This is not an unrealistic assumption - under the Electromobility Strategy, the city is already planning to purchase 136 electric buses by

As in the case of medium-sized cities, the planned number of charging points slightly exceeds the number of electric vehicles due to the use of numerous points and sockets at workplaces and residential buildings as well as public normal and high power charging points.

Electric vehicles will generate additional energy demand - by 2030 from 25.3 to 111.7 GWh, depending on the scenario, in 2050 from 156.3 GWh in the baseline scenario to 746.6 GWh in the alternative scenario. It is worth emphasising that in large cities the share of the transport sector in total electricity consumption is smaller than in medium-sized towns and rural areas - in 2050, the alternative scenario it will be only 18.2%.

Tab. 22. Wrocław electromobility development forecast [GWh]

	2030		2050	
	Baseline scenario	Alternative scenario	Baseline scenario	Alternative scenario
Number of electric vehicles	11840	52235	72360	303803
Number of energy consumption points for charging	14252	62877	83392	350117
Energy demand for EVs [GWh]	25.31	111.66	156.30	746.61

Source: Instrat own study.

PV microinstallations will probably also play a proportionally smaller role in large cities. By 2030, in Wrocław, their capacity may increase to 93 MW by 2030 and 332 MW by 2050, but by converting these values into residential units, the target penetration of PV will be only 17%.

Based on the methodology used for the examples described above, the electromobility development influence on distribution grids in large towns and cities was assessed. Low and medium voltage grids are already almost completely cabled (often above 90%), they are frequently upgraded and adapted to emergency situations. In the case of the main low-voltage lines, the use of YAKXS 4 x 70 mm^2 cables with a load capacity of 196 A was assumed[150] based on a review of the guidelines for public procurement and construction projects related to the modification of low-voltage cable lines. A conservative approach was adopted which assumed that the average capacity of MV/LV transformers is approx. 400 kVA - in Warsaw it is even above 500 kVA. In Wrocław, there are 140 residential units per SN/LV station - almost twice as many compared to medium-sized cities, which also means a higher load on a single station. The average base electricity consumption in cities (without electromobility) is 2134 kWh annually, with an increase of 3015 kWh in 2050. The calculations take into account the development of PV microinstallations, but penetration of photovoltaics in large cities is so small that this does not significantly impact the distribution grids.

The analysis of electromobility power demand impact on the low voltage grid has shown that in the alternative scenario it may be necessary to upgrade the most heavily loaded sections, even taking into account their current cabling using 4 x 70 mm^2 conductors. In the inflexible variant of the alternative scenario, the summer load reaches 77%. (Tab. 23.) The flexibility variant allows to reduce this value to a safe 64-65%. The difference from the baseline scenario is significant: 17-27%, depending on the variant. The use of the flexible variant is extremely important in order to avoid the necessity of increasing the diameter of LV lines' cables.

The load of MV/LV transformers in Wrocław in 2050 ranges between 31.7% and 37.8% depending on the flexibility option (Tab. 23). The flexible variant allows to reduce the peak load by 6%. The increase in the load in relation to the baseline scenario is 8-13%, which means that the development of electromobility in large cities should not require modernising MV/LV stations.

In the case of medium voltage grids alone it is a bit different as their load may exceed 80%, depending on the scenario. The assumption of using YHAKXS 3 x 1 x 70 mm^2 aluminium cables with a capacity of 210 A[151] in accordance with

2027.

150 HELUKABEL, *YAKXS - product data sheet*, https://www.helukabel.pl/files/YAKXS-karta-katalogowa.pdf.

151 TF Kable, *Cables, Cables and power conductors* [Kable i przewody elektroenergetyczne] https://www.tim.pl/fileuploader/download/download/?d=1&file=PRODUCENCI%2F10013%2FYHAKXS%2Fkable_yhakxs.pdf.

the guidelines of the city for construction projects was adopted as the initial state of the grid. The base demand (the maximum base load on a winter business day is 65% for such cables) was taken into account as well. It was also assumed that most of the medium voltage grids would operate at the target voltage of 20 kV by 2050. In the alternative scenario, the maximum load of main MV lines increases to 86.6%, however, in the flexible scenario it is 5% higher than in the inflexible scenario. This is due to moving the peak power demand for EV charging from evening (at 8 p.m.) to business hours (11 a.m. - 12 p.m.), when the highest base load is also generated by customers on medium voltage (mainly companies). This manoeuvre slightly increases the load on the medium voltage line, but significantly facilitates the balancing of the NPS as indicated in chapter 5. Nevertheless, in both variants, the main medium voltage lines will require replacing cables with components of a higher capacity - e.g. 3 x 1 x 120 mm2. In the baseline scenario, the medium voltage grid load is also significant - 67-69%, but remains within the safety limit. It is worth bearing in mind that the initial grid load (before EV) is already high and it is very likely that the lines will have to be modernised before 2050, regardless of the demand from the transport sector.

The last of the examined components of distribution grids - HV/MV power station should not require modernisation in relation to the development of electromobility. In accordance with the methodology used in the *Assumptions for the heating, electricity and gas fuels supply plan for the Municipality of Wrocław for the years 2020-2035, it* was assumed that the demand for power at individual HV/MV stations is distributed proportionally to the transformer capacity, which means that the load is the same for all stations. It is a simplification, of course, but it is even used in urban planning documents because due to the lacking availability of accurate local power consumption data and their enormous volatility. These assumptions allow to estimate that the current maximum load of GPZ in Wrocław on a winter business day is about 51%. The construction of eight new main power supply stations is planned in the near future, and it is assumed that these will be 2 x 40 MVA stations. In addition, Pułaskiego, Swojec and Krzywoustego GPZ will undergo modernisation. This will increase the total capacity of GPZ from the current 648 MW to approximately 972 MW. At present, a winter business day peak demand is estimated at 328 MW, and it will increase to 464 MW in 2050. The increase in demand for capacity is lower than specified in the city's demand plan for the years 2020-2035 - Wrocław belongs to cities with a growing population and, therefore, overly high demand for capacity. Taking into account the modernisation and construction of new GPZ, the base load falls slightly to the value of 48%. By applying the electromobility development alternative scenario, the load of GPZ increases to 62.8% in the flexible variant. As in the case of medium voltage grids, the flexibility variant is characterised by a slightly higher peak load. The increase of 8-14% compared to the baseline scenario is negligible and the main power supply stations in large cities should not need to be modernised as a result of the development of electromobility alone.

Tab. 23. Electromobility development impact in large towns and cities on distribution grid components

	Alternative scenario maximum values		Change in relation to baseline scenario		Is modernisation necessary
	Inflexible variant	Flexible variant	Inflexible variant	Flexible variant	
Low-voltage grid load	77.16%	64.61%	26.73%	16.64%	Depending on the variant
MV/LV transformer load	37.81%	31.66%	13.10%	8.24%	No
Average load of medium voltage main lines	81.58%	86.56%	12.84%	19.35%	Yes
Maximum GPZ load	59.22%	62.84%	7.79%	14.04%	No

Source: Instrat own study.

The analysis of the impact of electromobility on distribution grids in large towns and cities has shown that an increase in the number of electric vehicles may involve additional investments. In particular, both variants of the alternative scenario require an increase in the capacity of the main medium voltage lines. The use of flexible charging makes it possible to avoid investments in the low voltage grid even in the alternative scenario.

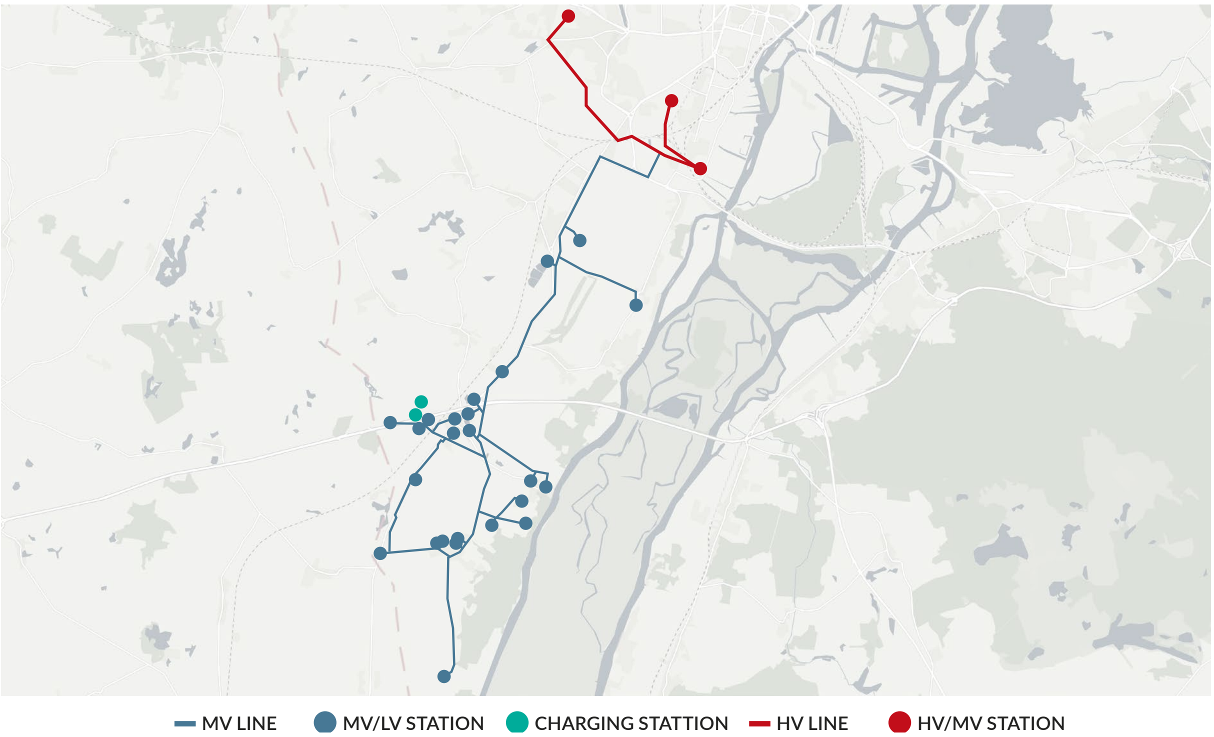
Motorways and expressways – Kołbaskowo.

In addition to the study on the impact of electromobility on power infrastructure in cities and villages, a dedicated analysis was carried out for charging EV at high-power points located along motorways and expressways. This case is significantly different from the previously discussed, as it imposes more than average requirements for available peak power in selected non-urban areas that are characterised by low base energy consumption.

The issue was illustrated using the example of Kołbaskowo municipality in Zachodniopomorskie Voivodeship. The A6 motorway runs through the municipality, with two service stations (in both directions), already including one high power electric vehicle charging point. Increasing the number of charging points to the expected in 2030 and 2050 will have a significant impact on the local power grid.

The Kołbaskowo municipality is currently supplied with an overhead medium voltage line[152] connected to Gumieńce GPZ with a capacity of 2 x 16 MVA and a load of about 40%.[153] The total distance from the charging station to GPZ is approximately 16 km (considering the current track of the medium voltage line). 26 15/0.4 transformer stations were connected to the medium voltage line. Dedicated transformer stations are already located next to the vehicle charging station- it should therefore be assumed that their capacity allows to handle the demand for electricity also at an increased number of charging points.

Fig. 36. Map of the power grid in Kołbaskowo municipality and arrangement of motorway charging stations



Source: Instrat own study based on Open Infrastructure Map, Office of Technical Inspection, Geoportal.

152 A typical for main lines AFL 70 mm2 conductor was assumed.

153 Public Information Bulletin, *Dobra municipality environment protection programme for the years 2017-2020* [Program ochrony środowiska gminy Dobra for 2013-2016 perspektywą na lata 2017-2020], 2013, https://bip.dobraszczecinska.pl/pliki/dobraszczecinska/File/srodowisko/2017/Aktualizacja%20PO%C5%9A%2017_09_2013.pdf.

In Kołbaskowo municipality, it is planned to replace the current overhead lines with cable lines[154], and it is also considered to lay a new 110 kV line along 220 kV line to power the new 110/15 kV substation in the vicinity of the motorway[155]. Such action would allow the charging station to be connected directly to the new power supply point, but no project implementation deadline has been set.

The map of distribution grid (110, 15 kV) and the arrangement of motorway charging stations for electric vehicles are presented in Fig. 36.

The municipality is characterised by a relatively small base electricity demand, the vast majority of which - 67% - is generated by households (Tab. 24). Customers in the municipality are connected to the low voltage grid. As in other areas, the municipal base electricity demand is assumed to increase from the current 14.6 GWh annually to 17.6 GWh in 2030 and 20.6 GWh in 2050.

Tab. 24. Annual electricity demand in Kołbaskowo municipality [MWh]

Public lighting	1268.5
Public administration	846.4
Housing	9815.5
Services, trade, industry	2632.4

Source: Low emission economy for Kołbaskowo municipality.

As mentioned, two charging points for electric vehicles with a capacity of 94 kW and 194 kW are located in the countryside next to the A6 motorway. In the future, it is assumed that this number will increase to the target 24 charging points - 12 per station located on two sides of the motorway (Tab. 25). Charging points use up to 34 GWh of electricity in 2050, thus accounting for more than half of the municipal demand. Energy demand comes from vehicles registered in Kołbaskowo commune, but mainly from light and heavy road vehicles travelling from other areas of Poland.

Tab. 25. Projected change in the number of motorway charging points and electricity demand for EV in Kołbaskowo municipality

	2030		2050	
	Baseline scenario	Alternative scenario	Baseline scenario	Alternative scenario
Number of charging points	2	2	6	24
Energy demand for EVs [GWh]	0.20	0.88	7.99	34.35

Źródło: Opracowanie własne.

In order to assess the impact of the growing demand for electricity generated by motorway charging points, a distribution grid model was prepared for Kołbaskowo municipality. The model includes 15 kV main grids and main power supply stations. In this case, the analysis of the low-voltage grid has been omitted as the charging station has its own dedicated transformer stations and this is a situation typical of motorway service stations and rest areas usually located far from other buildings. In places not yet equipped with EV charging stations, the current transformer stations may require expansion and adaptation.

In the case of medium voltage grids, the increase in the number of charging points and their high utilisation rate translate into a significant increase in load (Tab. 26). The current load of Gumieńce GPZ at the level of 40% increases in the baseline scenario to 49-50%, and in the alternative scenario even to 89%. Using the smart charging variant

154 Mayor of Kołbaskowo municipality, *Amendment of the spatial development conditions and directions study for Kołbaskowo municipality* [Zmiana studium uwarunkowań i kierunków zagospodarowania przestrzennego gminy Kołbaskowo], 2014, https://www.kolbaskowo.pl/attachments/article/1253/za%C5%82.%201%20do%20uchwa%C5%82y%20XXXVI.446.2014.pdf.

155 as above

allows to reduce the load to 83% in the alternative scenario, but this will still result in exceeding the limit values. It will therefore be necessary to increase the capacity of transformers - e.g. from typical 2 x 16 MVA to 2 x 25 MVA. The Gumieńce GPZ examined is located in an urban area with a high population density and thus a large (and continuously increasing) base load. Upgrade of Gumieńce GPZ is planned already for 2022, which may also include installation of higher capacity transformers. In most non-urban motorway locations, GPZ base load will not increase so heavily, which means that their upgrading would have to be carried out specifically for charging stations' requirements.

The increased load on the 15 kV main line is also a major challenge. The current load on the Kołbaskowo - Gumieńce line is estimated to be only 13%, however, it may be higher due to the creation of new housing estates in the suburbs of Szczecin, which would potentially also benefit from the line. The implementation of the baseline scenario leads to a significant increase in the load - by 34% in the inflexible variant and 28% in the flexible variant, which falls within safe limit values. However, the introduction of an alternative scenario leads to total line overload - up to 171% in the inflexible scenario and 140% in the flexible scenario. This situation requires that the current line be supplemented by a second track, which would allow for doubling the permissible capacity with limited infrastructure interference. Even then, the load on the line in the inflexible variant would be at an alarming level of 85% - it is therefore absolutely necessary to implement the flexible variant, which would maintain the load at 70%. In the inflexible variant, increasing the load from the charging station would have to involve the complete modification of the 15 kV line (including its cabling) or costly development of 110 kV infrastructure - perhaps with the planned construction of the 220/110 kV node, in the vicinity of the motorway, this would be possible, but such a huge investment for the purposes of motorway charging stations should not be expected.

Tab. 26. Impact of increasing the number of motorway charging points on distribution grid components

	Alternative scenario values		Change in relation to baseline scenario		Is modernisation necessary
	Inflexible variant	Flexible variant	Inflexible variant	Flexible variant	
Medium voltage main line load	170.97%	140.12%	123.84%	98.81%	Yes
Maximum GPZ load	89.09%	83.08%	40.49%	33.42%	Yes

Source: Own study.

To sum up, the development of high-capacity motorway chargers will pose significant challenges on the distribution grid side. In particular, it will be necessary to lay additional medium-voltage line tracks, expand 15/0.4 kV transformer stations in locations not equipped so far with charging points, and increase the capacity of GPZ when using the alternative scenario.

6.2. Necessary investments in distribution grids resulting from electromobility development

The results of the above analysis show that the scope of investments in distribution grids will depend on the area. However, the necessary measures do not constitute a barrier for electromobility development. In total, the investment costs by 2050 will amount to up to PLN 2.5 billion in the baseline scenario and PLN 11.8 billion in the alternative scenario (Tab. 27). In the latter case, the flexibility variant allows to reduce costs by PLN 5.8 billion. In the 2030 perspective, the development of electromobility will not jeopardise the operation of distribution grids, so that no additional investment costs are expected beyond the already planned activities of DSOs over that time horizon.

It is worth noting that only investments related to the development of electromobility were included in the calculations - i.e. those resulting from the increase in energy demand for EV charging, not the increase in base demand or RES development. According to the age structure of distribution grids (section 3.1.), many components of distribution grids need to be upgraded at this point- DSOs' plans in this regard have been included in the calculations (as described in section 6.). On the other hand, the considered assumption means that if the grids are not upgraded within the basic scope by 2050, the development of electromobility may entail investment costs that are higher than estimated.

Among the examined areas, by far the biggest costs are related to the development of charging infrastructure for expressways and motorways. This is due to a number of factors - primarily motorway charging stations are often distant from densely populated areas and thus from the main power supply stations. For the same reason, the existing grid infrastructure in this type of areas is not adapted to handle a high load and will need to be upgraded. The huge peak power consumption may involve the need to lay dedicated medium voltage lines to distant GPZs, which generates high costs.

Tab. 27. Cost of investments in distribution grids resulting from the development of electromobility by area by 2050

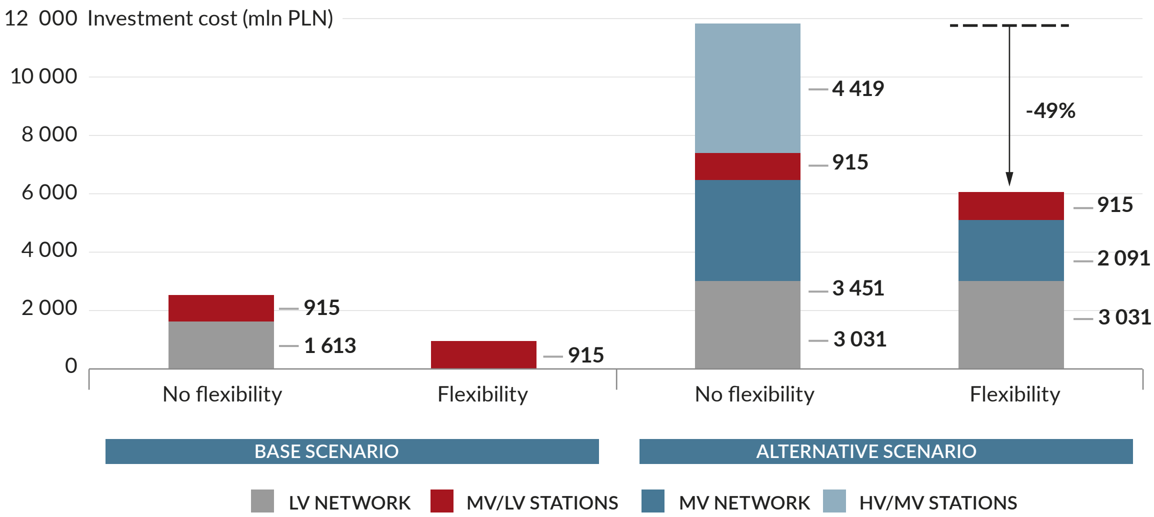
	Baseline scenario		Alternative scenario	
	Lack of smart charging	Smart charging	Lack of smart charging	Smart charging
Villages	0	0	0	0
Small and medium-sized towns	1613	0	4190	1613
Large towns and cities	0	0	3118	1275
Motorways and expressways	915	915	4509	3149
TOTAL	**2528**	**915**	**11816**	**6037**

Source: Own study.

The main cost component are main power supply stations and the medium voltage grid, which need to be adapted not only for the operation of mentioned charging stations at national roads and expressways, but also for increased power consumption in urban areas.

It should be noted that numerous investments in 110 kV grids and main power supply stations have so far been financed only partly from DSOs' own resources, in many cases most of the costs have been covered by EU subsidies. It is expected that it will be similar in the future.

Fig. 37. Investment costs depending on the grid component by 2050



Source: Own study.

In the 2050 perspective, the annual costs of adapting distribution grids to the implementation of the alternative scenario, in the scenario without flexible charging, will amount to PLN 407 million, however, when using charging flexibility it would amount to PLN 208 million. This constitutes only a fraction of annual investment costs currently incurred by DSOs, which totalled over PLN 6 billion in 2019 alone (section 3.1.). The costs on the distribution grid side should therefore not be a barrier to the expansion of the charging infrastructure, and the growing number of electric vehicles is an incomparably smaller financial challenge for DSOs than, for example, the development of RES, the need to implement smart meters or the process of cabling medium and low voltage grids, in order to provide appropriate operational safety indicators and power reliability as well as upgrading the grid resulting from the increase in basic demand.

Detailed calculations of investment costs per component by area are discussed below.

Rural areas

In rural areas, the development of electromobility does not pose a threat to low and medium voltage grids. The higher risk currently observed is the growth of PV microinstallations, which may lead to low voltage grid overload. Investments should therefore focus on adapting the grid to the development of photovoltaic installations. Importantly, the development of electromobility may contribute to reducing the scope of these investments as greater penetration of private charging points and local energy consumption within a household or company limits the flow of energy from the prosumer to the grid, reducing the LV grid load. Upgrade of the grid to the extent necessary for handling RES (and resulting from standard repairs related to the age of infrastructure) will be fully sufficient in rural areas to meet also the needs related to electromobility development.

Medium and small towns

In small and medium towns, the increase in the number of electric vehicles and the increased demand for energy to charge them may require additional investments, in particular the increase in main power supply stations' power and the potential increase in the permissible load capacity of the low voltage lines.

In the case of main power supply stations, modernisation of some of them will be required not only in the two alternative scenario variants, but also in the baseline scenario. In the latter case, the **use** of the flexibility variant allows to avoid additional costs. It is estimated that by 2050 the capacity of most GPZs in medium-sized and small towns will have to be increased to 2 x 40 MVA (from currently typical 2 x 16 MVA and 2 x 25 MVA). On the occasion of reconstruction, the stations' structure should be prepared to include 63 MVA transformers (as is the case of Wrocław). In order to meet the power demand from the electromobility sector, half of the 40 MVA transformers will require replacing with 63 MVA transformers. The replacement of transformers with bigger capacity transformers, along with the necessary adaptation of stations, is a cost of PLN 3.8-4.5 million[156]. In the case of a comprehensive reconstruction, it could even amount to PLN 10-20 million. The analysis of over 150 investment projects in the field of distribution grids financed by EU subsidies[157] showed that the average cost of modernisation/reconstruction of 110kV/MV substations in the years 2015-2018 amounted to approximately PLN 12 million, and such value was assumed in the calculations. However, it should be noted that in many cases the reconstruction of GPZs will be carried out as part of DSOs' investment projects related to energy security or RES development, and the development of electromobility will limit expenditure only to the replacement of transformers. However, assuming a pessimistic cost of single GPZ modernisation of PLN 12 million, it will be PLN 1.6 billion in total for 110 kV/SN stations in medium and small towns (the cost includes 137 stations - half of units in small and medium-sized towns).

The second cost component for small and medium-sized towns is a potential increase in the capacity of the low voltage grid, however, the use of flexible charging allows to GPZs will completely avoid it. A large number of private charging points connected to 400 V results in a load exceeding the permissible values on the main line upstream the 15/0.4 kV transformer station. This may take place even in cable grids (it is assumed that in 2050 this will concern all LV grids in cities) of 4 x 35 mm^2 class. Of course, such situation depends on the density of charging points and the grid topography. However, conservatively assuming that the grid is executed in an open structure with two tracks running from a transformer station, it is estimated that approximately 39 thousand km of LV grid will require replacing with larger cross-sectional area lines - 4 x 70 mm^2. This figure is based on the assumption that modernisation will cover 300 m long 400 V line sections from each transformer station in small and medium-sized towns (these stations are estimated to be approximately 65 thousand). The cost of replacing cables, in the existing lines, with components of higher capacity was estimated at PLN 2.6 billion, assuming unit costs of PLN 50/m (including the cable itself priced approx. PLN 16/m[158]). It is worth noting that the cost can be significantly reduced by taking into account a higher demand already at the line laying stage and introducing 4 x 70 mm^2 cables at that point. While their unit price is approx. 50% higher[159], it would allow to avoid double labour costs in the future.

The use of flexible charging makes it possible to avoid investments in the low voltage grid even in the alternative scenario.

Large towns and cities

Large towns and cities already anticipate an increase in electricity demand due to electromobility development and manage public transport electrification schemes. These changes may require an increase in the capacity of medium and low voltage lines.

In large cities, most of the medium voltage grid is cabled. The analysis of its precise topography is difficult, in particular because closed circuits with a two-way customer supply are used. However, the lines closest to transformer stations are impacted by the highest loads. These sections may even require the use of 3 x 1 x 120 mm^2 conductors in both variants of the alternative scenario. This applies to the main grid sections near HV/MV transformer stations - when analysing the grid in Wrocław, their length was estimated at approximately 5000 m around each GPZ. In total, 2346 km of MV grid in the vicinity of 469 GPZs in large cities would require modernisation. The cost of a single kilometre of a MV cable line amounts to PLN 350-450 thousand[160], whereas this includes the decommissioning of overhead lines, ground works and construction of the cable line from scratch. In the examined case, it is assumed that cables

156 EU subsidies map, https://mapadotacji.gov.pl/.

157 Ministry of Energy, *List of strategic projects for energy infrastructure as part of the Infrastructure and Environment 2014-2020 Operational Programme* [Lista projektów strategicznych dla infrastruktury energetycznej, w ramach programu operacyjnego infrastruktura i środowisko 2014-2020] 2019, https://www.gov.pl/attachment/cbaeaa34-a832-4024-8a88-7d5bb561708c.

158 tim.pl, 2021, https://www.tim.pl/kabel-energetyczny-yakxs-4x70-0-61kv-bebnowy.

159 PLN 16 / m compared to PLN 10.5 / m: tim.pl, 2021, https://www.tim.pl/kabel-energetyczny-yakxs-4x35-0-61kv-bebnowy-1 and tim.pl, 2021, https://www.tim.pl/kabel-energetyczny-yakxs-4x70-0-61kv-bebnowy.

160 Average cost of MV line cabling at PGE Dystrybucja in 2019: Biznesalert.pl, PGE Dystrybucja's record-breaking investments in power infrastructure in 2019 [Rekordowe inwestycje PGE Dystrybucji w infrastrukturę energetyczną w 2019 r.], 2020, https://biznesalert.pl/inwestycje-pge-dystrybucja-infrastruktura-rekord-energetyka/, Cabling cost estimate for Toruń: http://www.bip.torun.pl/pobierz.php?FileDir=doc&File=Informacja+WGK+z+dn+17_01.07.2007+-+dot+skablowania+napowietrznych+linii+elektroenergetycznych+%28JAR%29.pdf.

will be replaced in the existing line, which should reduce the unit cost to approx. PLN 200-300 thousand / km (the cost of YHAKXS 3 x 1 x 120 mm^2 cable alone is nearly PLN 180 / m)[161]. In total, the MV lines' modernisation costs in large towns and cities for the purposes of electromobility amount to PLN 1.3 billion.

As in the case of small and medium-sized towns, it may be necessary to increase the capacity of the low-voltage grid, although the use of flexible charging allows to fully avoid additional costs in this area. Although the low voltage grid is almost completely cabled in large cities, the popular YAKXS 4 x 70 mm^2 conductors used on the 400 V main line sections may not be sufficient if the number of EV charging points is significantly increased. Using a methodology similar to the case of medium-sized towns (modernisation of sections in the vicinity of 40 thousand transformer stations), it is estimated that 24.5 thousand km of the low voltage line will require increased capacity through the use of 4 x 95 mm^2 or 4 x 120 mm^2 cables. The cost of replacing cables in the existing lines is PLN 1.8 billion, assuming that these lines will not require reconstruction[162]. The use of flexible charging makes it possible to avoid investments in the low voltage grid even in the alternative scenario.

Motorways and expressways

In the case of high power charging points located along motorways and expressways (in so-called rest areas - MOP), the scale of the investment is significant. In the alternative scenario, it will be necessary to lay additional medium-voltage line tracks, expand 15/0.4 kV transformer stations in locations not equipped so far with charging points, and increase the capacity of GPZs when using the alternative scenario. Currently, 346 service and rest areas (the so-called MOP)[163], located only along motorways and expressways, exist or are planned to be executed in Poland (Fig. 6.2.2.) MOPs include service stations and charging stations for electric vehicles, with only 9.5% of MOPs are currently equipped with EV charging points. One (two-way) MOP covers, on average, 23 km of expressways and motorways, and these are 4000 km long in Poland[164]. It is planned to expand the network of these roads to 8117 km, which means a proportional increase in the number of MOPs to more than 700. By 2050, it is assumed that all MOPs will be equipped with high power charging points, with a target of 12 charging points per station. This is twice the number of points currently installed, e.g. at Ekoen station in Lubuskie Voivodeship[165] at a maximum capacity of 350 kW per point. The number of points per station was estimated on the basis of the total electricity demand in the road charging points sector (Tab. 4.5.2.). This demand originated mainly (85%) from the fleet of heavy road vehicles registered in cities. The light vehicle share was much smaller. Considering the charging profiles of motorway equipment (section 4.4.), the number of charging points at a single MOP has been selected so that the peak load of a single device does not exceed the nominal capacity of 350 kW. As a result, it has been proposed to deploy 12 charging points at a single MOP, with a total of 8425 charging points outside cities in 2050.

161 tim.pl, 2021, https://www.tim.pl/kabel-energetyczny-yhakxs-1x12050-1220kv-bebnowy.

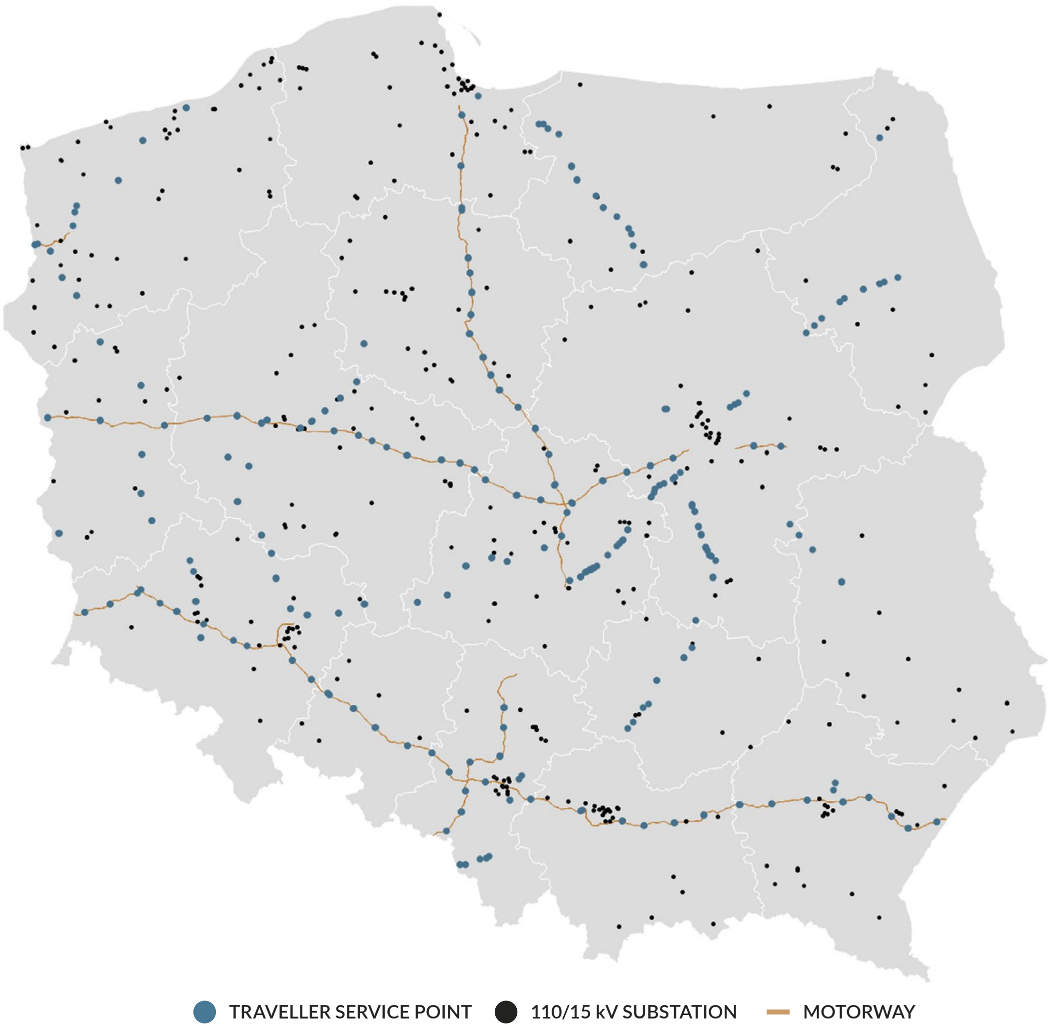
162 As in the case of small and medium-sized towns, the unit cost of cables' replacement was assumed at the level of PLN 50/m

163 GDDKiA, Map of existing and planned Service and rest areas [Mapa istniejących i planowanych Miejsc Obsługi Podróżnych]: https://www.gddkia.gov.pl/pl/2549/Mapa-istniejacych-i-planowanych-Miejsc-Obsugi-Podroznych.

164 Journal of Laws, *Regulation of the Council of Ministers of 24 September 2019 amending the regulation on the network of motorways and expressways [Rozporządzenie Rady Ministrów z dnia 24 września 2019 r. zmieniające rozporządzenie w sprawie sieci autostrad i dróg ekspresowych]*, 2019, http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20190001819

165 EKOEN, https://ekoen.pl/charging.

Fig. 38. Map of rest areas and 110/15 kV substations



Source: Own compilation based on GDDKiA and OpenStreetMap data.

Tab. 28. Electricity demand at road charging points

	2030		2050	
	Baseline scenario	Alternative scenario	Baseline scenario	Alternative scenario
Total demand from road charging points [TWh]	0.07	0.31	2.80	12.06
Demand per charging point [MWh]	8.35	36.86	332.81	1431.18

Source: Own study.

The necessary investments related to the increased number of motorway charging points include:

- GPZ power increase,
- cabling and increasing the capacity of medium voltage lines from charging stations to GPZs,
- expansion of 15/0.4 kV transformer stations.

The first component concerns approx. 120 110/15 kV substations from the total number of approx. 694 - it is assumed that charging stations will be connected to the nearest 110/15 kV substations based on Fig. 37 Obviously, modernisation concerns only existing substations. It is assumed that the newly built substations will be adapted to handling the increased load resulting from the development of RES and electromobility. Upgrading will be necessary for the mentioned stations. Based on the assumptions related to the unit cost of 110kV/MV substations' modernisation described under the section related to small and medium-sized town, the total cost of GPZs' modernisation resulting from the development of motorway charging points alone was estimated at PLN 1.4 billion.

Another required action is to increase the capacity of 15 kV lines. The peak demand for charging capacity in the alternative scenario is so high that a second 15 kV line circuit is necessary (assuming the use of the AFL-6 70mm^2 conductor). Based on the arrangement of MOPs (Fig. 38), the average distance of a MOP from the nearest 110/15 kV substation was calculated and it is equal to 15.5 km. MOPs are arranged in pairs on both sides of a road, which means that they can share a single 15 kV line (as indicated in the Kołbaskowo municipality example). This means that the number of new 15 kV line tracks built to handle charging stations will ultimately rise to approx. 351 - half of the estimated number of MOPs in 2050. In the future, grid operators will most likely seek to lay cable lines instead of increasing the capacity of existing overhead connections. The cost of a 15 kV cable line km is estimated at PLN 350-450 thousand[166], but this value depends heavily on the conditions in a given location. For an overhead line, it is PLN 100-200 thousand/km. It is worth noting that, in the inflexible variant of alternative scenario, even doubling the overhead line capacity is not sufficient to cover the power demand. Therefore, in order to ensure grid security, incurring the entire cost of line cabling is assumed. As a result, the total cost of MOP - GPZ connections will amount to PLN 2.2 billion in the inflexible variant, and it is reduced to PLN 0.5 billion in the flexible variant.

The final element of the grid requiring investments related to the development of motorway charging stations are 15/0.4 kV transformer stations. Even the existing stations need to be adapted to handle over average peak capacity demand - up to 4 MW. It is therefore necessary to use higher capacity transformers - e.g. 4 x 1000 kVA. The cost of a typical 630 kVA substation is estimated at PLN 150-170 thousand, but the cost of a single high capacity station (e.g. dedicated to PV farms) amounts even to PLN 360 thousand[167]. Assuming that such stations must be located at all MOPs not yet equipped with charging points (90.5%), the total cost of construction/modernisation of MV/LV transformer stations is estimated at PLN 915 million for both scenarios of electromobility development.

166 Average cost of MV line cabling at PGE Dystrybucja in 2019: Biznesalert.pl, PGE Dystrybucja's record-breaking investments in power infrastructure in 2019 [Rekordowe inwestycje PGE Dystrybucji w infrastrukturę energetyczną w 2019 r.], 2020, https://biznesalert.pl/inwestycje-pge-dystrybucja-infrastruktura-rekord-energetyka/, Cabling cost estimate for Toruń: http://www.bip.torun.pl/pobierz.php?FileDir=doc&File=Informacja+WGK+z+dn+17_01.07.2007+-+dot+skablowania+napowietrznych+linii+elektroenergetycznych+%28JAR%29.pdf.

167 M. Niewitała, *1 MW PV farm construction costs - analysing the share of components in the total price* [Koszt budowy farmy PV o mocy 1 MW - analizujemy udział komponentów w cenie], Globenergia, 2019, https://globenergia.pl/koszt-budowy-farmy-pv-o-mocy-1-mw-analizujemy-udzial-komponentow-w-cenie/.

7. Summary

The development of electromobility is an organisational and technical challenge for both public administrations and DSOs. It requires proper planning and cooperation between local authorities and DSOs in order to define an optimal plan for the expansion of charging infrastructure, taking into account the needs of electric vehicle users as well as grid constraints and capabilities. Secure electrification of this sector will require investments in grids to adapt them to the increased demand for electricity and to the dispersed nature of the charging system.

The amount of investment expenditure needed will depend on the development scenario, the region of the country and the introduction of mechanisms encouraging flexible charging, the so-called dynamic tariffs (they allow to reduce the costs of grid modernisation even by 49%). On the other hand, the results of the analysis show that the scale of the necessary investments in distribution grids, linked to the development of electromobility alone, is relatively small - this is not a large amount compared to the annual investment costs currently borne by DSOs and required by the growing capacity of renewable energy sources within the grid, the need of upgrading and cabling MV and LV grids, and the introduction of smart meters. Costs on the distribution grids' side should therefore not be a barrier to the expansion of the charging infrastructure.

Despite numerous concerns about the impact of an increased electric vehicle fleet on the NPS, the development of photovoltaic installations is a greater challenge in designing low-voltage grids than electromobility development. Investments related to RES development may be sufficient in many areas of the country (especially in rural regions) in terms of adapting the grid to electromobility development, which in turn may contribute to limiting the investments necessary to adapt distribution grids to the rapid RES development. The development of electromobility should be regarded as potentially beneficial to the grid and properly exploited - an increase in local energy consumption in households reduces the amount of energy returned to the grid by prosumers. It is important that grid investments are planned effectively, sufficiently in advance and take into account megatrends resulting from the changing shape and specifics of the power system.

Załącznik 1 - Tariffs and incentives

Z.1.1. Incentives for the purchase of electric cars

Country	Direct subsidies	Tax relief	Comments
Austria	EUR 1 500 (BEV, FCEV) EUR 750 (PHEV)		For cars with a maximum price of EUR 50 000 Diesel fuelled PHEV are not covered by the support scheme
Belgium	EUR 2 000-4 000		Support based on the car price.
France	For individual customers: currently EUR 6 000 and EUR 5 000 from 2022 For business: EUR 5 000, plans of reducing to EUR 1 000 in the coming years	Exemption from registration tax in many regions of the country	For BEV cars with a maximum price of EUR 45 000
Germany	BEV: EUR 9 000 for vehicles with a maximum price of EUR 40 000 and EUR 7 500 for vehicles with a price ranging 40 000 - 65 000.* PHEV: EUR 6 750 for vehicles with a maximum price of EUR 40 000 and EUR 5 625 for vehicles up to 65 000.*	BEVs registered between 2011 and 2030 are exempt from vehicle tax (German *Kfz-Steuer*); PHEV vehicles are still subjected to a lower tax than ICE, proportionate to their lower CO_2 emissions. Company car tax: reduction of taxes for private use of a company car from 1% of the catalogue price per month for ICE vehicles, up to 0.25% for BEV and 0.5% for PHEV	As part of the economic stimulus packages (1.07.2020 - 31.12.2021)
Italy	0-20 gCO_2/km: EUR 6 000 */EUR 4 000 * 21-70 gCO_2/km: EUR 2 500 */EUR 1 500 *	BEV exempt from property tax for five years after vehicle registration	*If the purchase of EV vehicle is accompanied by scrapping the old car (Euro 1-4) **If the purchase of EV vehicle is not accompanied by scrapping the old car
Netherlands	EUR 4 000 * /EUR 2 000 ** (until 2025 or use of the envelope)	BEV: Until 2024, purchasers exempt from vehicle purchase tax and property tax PHEV: the amount of tax depends on vehicle emission values - until 2024, a 50% reduction of property tax	*for the purchase or leasing of a new car **for the purchase or leasing of a used car
Norway	No subsidies	BEV exempt from VAT (25%) and three taxes on vehicle purchase.*	* Weight, CO_2 emissions and NOX emissions taxes
Portugal	EUR 3 000		Max. catalogue price of the car up to EUR 62 500
Spain	EUR 1 300-5 500 (BEV and PHEV)*		For cars below EUR 40 000; Depending on the range of the car: EUR 5500 > 72 km

Source: own compilation based on literature review

Z.1.2. Incentives for charging infrastructure

Country	Direct subsidies	Tax relief	Comments
Germany	For publicly available charging points: up to EUR 3 000 for charging stations up to 22 kW; up to EUR 13 000 for charging and DC points up to 100 kW; up to EUR 30 000 for DC charging points above 100 kW and up to EUR 5 000 for connection to the low voltage grid and up to EUR 50 000 for connection to the high voltage grid Some regions also offer additional subsidies, e.g. up to 50% (max. EUR 1000) for the purchase and installation of a private charger in Norderhein-Westfalen	Owners of private and company plug-in electric vehicles who charge their cars at the workplace are exempted from declaring this as a material benefit in the tax return Owners of company cars who charge their vehicles at home can benefit from a tax relief Employers offering free charging of electric vehicles or bicycles will not be taxed for this service until 2030.	
Netherlands	No incentives for private charging points, but incentives for the purchase and installation of chargers by companies and those available to the public. For companies: deduction of 36% of the amount invested in a charging point; possibility of amortising 75% of charging points investments costs		Public charging points: EVs users have the possibility to request the installation of a publicly available charging point. If there is no such charging point in the vicinity of their home or workplace, it will be installed by the State
Belgium		13.5% deductions from investments in charging infrastructure from corporate income tax 75% of charging costs deducted from personal income tax	
France	For individual customers: EUR 300 for the purchase and installation of a private charging point For companies: subsidies up to 40% of the costs of purchasing and installing charging points for businesses For condominiums: subsidies up to 50% of charging point purchase and installation costs For public institutions: subsidies up to 40% of the cost of purchasing and installing public charging points.*		* The charging points shall be installed at the request of electric vehicle drivers and shall be within a radius of 500 metres from their place of residence or work.
Italy		Natural persons, companies and housing communities may be granted access to a new 50% tax deduction for a total amount of up to EUR 3 000, spread over ten equal annual instalments, for the purchase and installation of electric vehicle charging points from 1 March 2019 to 31 December 2021.	
Spain	Private persons and companies may receive Moves II grants of up to 30-40% of private charging infrastructure purchase and installation costs (up to a total of EUR 100 000). Grants shall be distributed and managed by each autonomous community		
Norway			The country does not offer subsidies or tax credits, but invests in the development of vehicle charging infrastructure. The activities undertaken include: public financing of high-speed charging points every 50 km along the main streets; funds for housing cooperatives for the installation of charging points (EUR 2.1 million) etc.

Source: own compilation based on literature review

Appendix 2

The investments made by DSOs in recent years have been summarised below:

Enea Operator

In 2019 Enea Operator allocated over PLN 900 million to modernise and expand the grid infrastructure, including the execution of new entities' and RES points' grid connection process, modernisation of the grid at each voltage level and construction of smart grids. In 2019, the company implemented 29 agreements for financing investment projects and subsidies with a total amount of PLN 596 and 331 million, respectively. They will enable further investments in the construction and modernisation of substations and hundreds of kilometres of lines and will increase the grid's potential for RES adaptation as well as the construction of smart grids.

Tab. Z.2.1. Investments implemented by Enea operator in the years 2019-2020.

Year of completion	Investment	Value	Description
2019	Reconstruction of the 110 kV Morzyczyn - Drawski Młyn high voltage line	PLN 127 million (total value)	The investment led to the increase in grid length up to 240 km in Zachodniopomorskie, Lubuskie and Wielkopolskie Voivodeships. It will improve energy security in these voivodeships and increase connection possibilities, including from renewable energy sources. It also increased the total grid capacity over the summer period by more than six times, reduced energy losses generated during distribution and increased the possibilities for flexible grid traffic. It also increased the vulnerability of the line to unfavourable weather phenomena.
2020	110 kV high voltage line modernisation		Recław - Goleniów, Leszno Gronowo – Śrem HCP – Śrem Helenki, Wałcz – Mirosławiec and Gorzów - Witnica sections
2019	Station expansion and modernisation		Reconstruction of Pomorska GPZ and Dolice GPZ high voltage stations in Zachodniopomorskie Voivodeship and Czarnków Płyty in Wielkopolskie Voivodeship.
2019	Connection of RES to the grid		In 2019, 90 so-called major RES (II and III connection group) with a total capacity of approx. 80 MW and more than 12.7 thousand microinstallations with a capacity close to 90 MW were connected to the company grid. The additional installed capacity will improve energy security and continuity in these areas.
2019/2020	Connection of balancing meters		The Company purchased modern balancing meters and connected more than 30 thousand of these to the distribution grid. During the installation of meters, Enea Operator upgraded the power grids and plans to connect more meters in the following years, which will allow for mass implementation of the smart grid development project.

Source: Own compilation based on PTPiREE (2020).

Energa Operator

In 2019 Energa Operator spent over PLN 1.3 billion on investments related to the development and modernisation of grid infrastructure, i.e. increasing the potential for RES and smart grids adaption. The Company received EU support for all its proposed projects within the framework of the 2014-2020 EU perspective for a total amount of over PLN 200 million. In 2019, the company implemented projects to recover the existing assets and modernise the grid whose value amounted almost to PLN 600 million. The company also completed the conversion of 674.4 km of overhead lines, replacing them with cable lines and partially insulated conductors. It also replaced 47 km of non-grid medium voltage cables. The projects implemented have increased the connection capabilities of the company distribution grid and reduce the risk associated with the continuity of electricity supply.

Tab. Z.2.2. Investments implemented by Energa Operator in the years 2019-2020.

Year of completion	Investment	Value	Description
2019	Medium voltage grid cabling and insulation		• cabling of 14 km long overhead line at the Olsztyn 1 - Jeziorany section; • construction of a medium voltage cable line replacing the 15 kV double-circuit line at the Rosnowo Power Plant and Przemysłowy GPZ Rosnowo Power Plant section; • replacement of sections of overhead medium voltage lines with a cable line at the Drawsko GPZ - Ostrowice section – 7.14 km; • replacement of conductors with partially insulated conductors at the Rypin GPZ - Okalewo overhead medium voltage line section - 39.4 km • replacement of sections of overhead medium-voltage lines with partially insulated lines at the Borne Sulinowo and Czaplinek municipalities section– 5.99 km.
2019	Implementation of new technologies for the construction of new power lines in other areas		• Maćkowy GPZ along with Pruszcz - Maćkowy line have been built, • Oliwa GPZ, Ślesin GPZ, Ostrów Północ GPZ, Dunowo GPZ, Koszalin Północ GPZ, Kąty Rybackie GPZ, Iława GPZ, Toruń Śródmieście GPZ and Grudziądz Śródmieście GPZ have been reconstructed These projects include the implementation of the latest technical and security solutions. The additional power reserve created as a result of the investment will enable a fast realisation of the demand for connection capacity.
2019	Construction of a double-circuit high-voltage line		Construction of a new high-voltage line at the Pelplin - Starogard Gdański section
2019	Modernisation of overhead lines		Modernisation of overhead lines at the Polmo - Subkowy and Subkowy - Lignowy and Janiszew - Adamów and Płock Góry – Radziwie sections.
2019	Grid automation initiative in overhead and indoor stations		521 telecontrol switching devices were installed in overhead stations and 32 switching devices were installed in indoor stations.
2019	Investments in improving SAIDI/SAIFI indexes		Completion of the construction of the remaining telecommunication towers as well as installation and launching TETRA digital communication system base stations.
2019	Launching two distribution areas with direct customer service points		The investment was aimed at improving customer service comfort and enabling flexible coordination of grid work and shortening the response time of emergency crew services in the event of system failure. This is also aimed at enabling better identification of local needs and adapting the grid development plans.

Source: Source: Own compilation based on PTPiREE (2020).

One of the company's most important priorities for the following years is the cabling of grids in forest and wooded areas.

Innogy Stoen Operator

In 2019 Innogy Stoen Operator allocated over PLN 230 million for investments in the grid, including PLN 67.5 million for investments in connections to low and medium voltage grids, PLN 57 million for the development of the high voltage grid and PLN 18 million for projects with medium voltage grids.

Tab. Z.2.3. Investments implemented by Innogy Stoen Operator in the years 2019-2020.

Year of completion	Investment	Value	Description
2019	Nowa Towarowa GPZ station (the only 220 kV facility located in the vicinity of the city centre in Warsaw).		The grid is of key importance for the operation of the entire Warsaw 110 kV grid. The investments implemented include: • Major modernisation and replacement of most technological solutions developed in the 1990s; • equipping the substation with 220 kV switching station executed using GIS technology, H5 layout; • Installation of the second 220.110/15 kV autotransformer; The main task of the station after its modernisation and increasing the number of 110 kV lines running out of the station is to reduce the power transit and to shift a large source for the 100kV grid closer to the place of increased power demand.
2018-19	Investments in Wschodnia RPZ (District supply point)		RPZ Wschodnia station was built in the 1950s and it is the core of Warsaw's eastern medium voltage grid. In 2018, Innogy commenced works related to its complete reconstruction, and in 2019 the station was connected to voltage. In 2019, the construction of the Tarchomin RPZ station was completed in order to meet the increase in demand for electricity in the districts of Tarchomin, Żerań and Białołęka in Warsaw.

Source: Own compilation based on PTPiREE (2020).

Table Z.2.4. Innogy Stoen Operator planned projects and modernisations for the coming years

Year of completion	Investment	Value	Description
2020/21	Modernisation of Towarowa GPZ station		• two-way 220 kV grid supply, which is currently supplied with a single 220 kV line from Mory GPZ • the station is to operate within the Mora – Towarowa – Ołtarzew circuit.
2020/21 and subsequent years	Investments in RPZ station		• connection to the existing 100 kV and 15 kV grids; The purpose of the investment is to enable a high flexibility station, allowing for almost any configuration of connections between EC Żerań, EC Siekierki and Miłosna GPZ. The planned 100 kV switching stations' layout is also aimed at enabling operation in a grid divided into multiple grid areas. • construction of a new 110/15 kV Szamoty RPZ station (construction commenced in 2019). Construction is scheduled to be completed in 2021. • construction of Falenica RPZ station • modernisation and expansion of existing Imielin RPZ, Grochów RPZ stations and many RSM stations (15 kV grid switching stations).

Source: Own compilation based on PTPiREE (2020).

PGE Dystrybucja

In 2016-19, PGE Dystrybucja allocated over PLN 7 billion for investments in energy infrastructure, and in 2019 alone they amounted to PLN 2.2 billion. The investments in 2019 included, inter alia, the construction of 1,236 km of low and medium voltage lines and the modernisation of 2,673 km of lines under these voltages. In addition, the company built 838 MV/LV stations and modernised 1 409 of such stations. These investments were aimed at increasing the connectivity capabilities of the operator's distribution grid, including the deployment of more RES sources, but also at improving SAIDI/SAIFI indexes, thereby reducing grid losses and enhancing security of electricity supply continuity. In addition, in 2019, the company connected 41 996 renewable energy sources to its grid, including 41 792 photovoltaic microinstallations.

Tab. Z.2.5. Investments implemented by PGE Dystrybucja in the years 2019-2020.

Year of completion	Investment	Value	Description
2019	Construction and modernisation of HV lines (110 kV).	PLN 131 million	Construction and modernisation of 157 km long HV line (110 kV). The most important upgrades include: • modernisation of the 110 kV line at the Łódź Śródmieście – Łąkowa and Łódź Śródmieście – Drewnowska section (the cost is over PLN 14 million) • modernisation of 110 kV line at the Szczebrzeszyn – Biłgoraj section (cost of PLN 9 million)
2019	MV grid cabling	PLN 340 million	950 km of MV cable grids were executed as part of the multiannual MV grid cabling programme for 2019.

Source: Own compilation based on PTPiREE (2020).

Table Z.2.6. PGE Dystrybucja planned projects and modernisations for the coming years

Year of completion	Investment	Value	Description
2023	MV grid cabling		By 2023, the company plans to increase the share of medium voltage cable lines to at least 30%.

Source: Own compilation based on PTPiREE (2020).

Tauron Dystrybucja

In 2019, the Company allocated PLN 1.8 billion for investments in the distribution grid, including mainly projects aimed at improving the reliability of electricity supply, increasing the security of energy supply to customers and increasing the potential of RES connection. The investments involved the construction and modernisation of approx. 900 km of medium voltage lines and approx. 2 800 km of low voltage lines.

Tab. Z.2.7. Investments implemented by Tauron Dystrybucja in the years 2019-2020.

Year of completion	Investment	Value	Description
2019	Modernisation of HV lines (110 kV).		In 2019, the following multiannual 110 kV lines' modernisation works have been completed: • Skoczów GPZ - Strumień GPZ in the Bielsko-Biała branch area • in Wałbrzych • Głubczyce - Prudnik in Opole • Tucznawa – Lipówka and Bukowno – Lipówka in Będzin
2019	Reconstruction of the 110/15 kV Strusina substation (2017-2019)	PLN 15.9 million (in total in the years 2017-2019)	The purpose of the investment was to increase reliability and improve the operating conditions of the 110 kV grid. As a result, electricity supply security in Tarnów has improved.
2019	Modernisation of 100 kV switching station in Oborniki Śląskie substation		Modernisation consisted in the implementation of fully digital communication using the so-called process bus. Thanks to the modernisation, the Oborniki Śląskie substation became the first digital facility in Poland by replacing data transmission control wires and cables with optical fibre cables. Modernisation makes it possible to immediately diagnose possible errors and damages in the grid, which allows to prevent failures. In addition, as a result of modernisation, optical current transformers (sensors) were used for the first time instead of traditional 110 kV transformers.
2019	Tasks under the programmes: Regional Operational Programme of Lower Silesia and Małopolskie Voivodeships and Infrastructure and Environment Programmes	PLN 85.5 million	The activities included investments such as: • comprehensive modification of the 110/6 kV Janów substation in Katowice in order to increase energy security in Katowice and improve reliability of energy supply using smart grids. • modification of the 110/6 kV Siemianowice substation. • construction of two MV lines in cable technology at the R-37 Ręczyn section to the R-300 Mikułowa substation. These actions are to enable the connection of photovoltaic power plants, in Zgorzelec municipality, to the grid.
2020	Construction of an electricity storage unit at 110/15 kV Cieszanowice substation in Kamiennik municipality (2019-2020)		The investment's purpose is to enable a more efficient management of grid operation in the area to which a wind farm is connected. It will have a rated capacity of 3.16 MVA and a useful capacity of 774 kWh.

Literature

Bannon E., *In cities 63% support EU ban on petrol and diesel car sales after 2030*, Transport & Environment, 2021, https://www.transportenvironment.org/press/cities-63-support-eu-ban-petrol-and-diesel-car-sales-after-2030

Barone G., Brusco G., Menniti D., Pinnarelli A., Polizzi G., Sorrentino N., Vizza P., Burgio A., *How Smart Metering and Smart Charging may Help a Local Energy Community in Collective Self-Consumption in Presence of Electric Vehicles*, *Energies*, 2020, https://doi.org/10.3390/en13164163

BEZEL, *Overhead power lines* [Linie napowietrzne], 2018, https://bezel.com.pl/2018/08/01/linie-napowietrzne/#odstepy

Biznesalert.pl, GE Dystrybucja's record-breaking investments in power infrastructure in 2019 [Rekordowe inwestycje PGE Dystrybucji w infrastrukturę energetyczną w 2019 r.], 2020, https://biznesalert.pl/inwestycje-pge-dystrybucja-infrastruktura-rekord-energetyka/

Borkowski M., *Electromobility - issue or remedy for the power system* [Elektromobilność - problem czy lekarstwo dla systemu elektroenergetycznego], 2020, https://www.forum-energii.eu/pl/blog/elektromobile osc-kse?utm_source=twitter&utm_medium=post_13112020&utm_campaign=EV

Public Information Bulletin, *Draft assumptions for the plan of heating, electricity and gas fuels supply for Wołomin municipality for the years 2012-2027* [Projekt założeń do planu zaopatrzenia w ciepło, energię elektryczną i paliwa gazowe dla gminy Wołomin na lata 2012-2027], 2012, https://wolomin.bip.net.pl/index.php?c=525

Public Information Bulletin, *Heat, Electricity and Gas Fuels Supply Plan for the Municipality of Wrocław for the years 2020-2035* [Plan zaopatrzenia w ciepło, energię elektryczną i paliwa gazowe dla obszaru Gminy Wrocław na lata 2020-2035], 2019, https://bip.um.wroc.pl/artykul/859/41655/projekt-zalozen-do-planu-zaopatrzenia-w-cieplo-energie-elektryczna-i-paliwa-gazowe-dla-obszaru-gminy-wroclaw-na-lata-2020-2035

Public Information Bulletin, *Dobra municipality environment protection programme for the years 2017-2020* [Program ochrony środowiska gminy Dobra for 2013-2016 perspektywą na lata 2017-2020], 2013, https://bip.dobraszczecinska.pl/pliki/dobraszczecinska/File/srodowisko/2017/Update%20PO√C5%9A%2017_09_2013.pdf.

Bralewski P., Szabłowski ł., Badyda K., Bujalski W., *Perspectives for the development of electromobility in Poland from the point of view of the National Power System* [Perspektywy rozwoju elektromobilności w Polsce z punktu widzenia Krajowego Systemu Elektroenergetycznego], "Nowa Energia" No. 4/2018.

Bronk L., Czarnecki B., Magulski R., Pakulski T., Ścigan M., Maćkowiak-Pander J., Jędra M., *How to fill the carbon gap? 43% RES by 2030*, Forum Energii, 2020, https://forum-energii.eu/pl/analizy/jak-wypelnic-luke-weglowa.

Brown T., Hörsch J., Schlachtberger D., PyPSA: Python for Power System Analysis, 2018, https://arxiv.org/abs/1707.09913,

Bühne J.A., Gruschwitz D., Hölscher J., *How to promote electromobility for European car drivers? Obstacles to overcome for a broad market penetration*, European Transport Research Review, 2015, https://etrr.springeropen.com/articles/10.1007/s12544-015-0178-0

C40 Cities, *Fossil Fuel Free Streets Declaration*, 2019, https://www.c40.org/other/green-and-healthy-streets

Chojnacki W., *Cabling of low and medium voltage distribution grids* [Kablowanie sieci dystrybucyjnych średniego i niskiego napięcia], 2019, https://www.elektro.info.pl/artykul/kable-i-przewody/150706,cable-sieci-dystrybucyjnych-sredni]ego-i-niskiego-napiecia

Clean Energy, *Subsidies as part of the "green public transport" programme are to be launched before summer holidays* [Przed wakacjami mają ruszyć dopłaty w programie "zielony transport publiczny"], *2021, https://cleanerenergy.pl/2021/03/24/przed-wakacjami-maja-ruszyc-doplaty-w-programie-zielony-transport-publiczny/ are to start*.

Council of European Energy Regulators, *CEER Benchmarking Report 6.1 on the Continuity of Electricity and Gas Supply*, 2018, https://www.ceer.eu/documents/104400/-/-/963153e6-2f42-78eb-22a4-06f1552dd34c

Czernicki Ł., Maj M., Miniszewski M, *How to support electromobility?* [Jak wspierać elektromobilności?], ed. B. Sobik, Economic Institute, Warsaw 2019, http://pie.net.pl/wp-content/uploads/2019/10/PIE-Raport_Elektromobilnosc.pdf

Czubiński R., *Green Public Transport: local governments aim high* [Zielony Transport Publiczny: samorządy mierzą wysoko], 2021, https://www.transport-publiczny.pl/mobile/green -transport-publiczny-samorzady-mierza-wysoko-67564.html.

Journal of Laws, *Act of 11 January 2018 on Electromobility and Alternative Fuels Journal of Laws of 2018, item 317*, https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20180000317

Official Journal of the European Union, *Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure*, 2014, https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX:32014L0094&from=PL

Journal of Laws, *Regulation of the Council of Ministers of 24 September 2019 amending the regulation on the network of motorways and expressways*, 2019, http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20190001819

EDSO for smart grids, *Position paper on Electric Vehicles Charging Infrastructure*, on, https://www.edsoforsmartgrids.eu/wp-content/uploads/public/EDSO-on-Electric-Vehicles.pdf

Eltrim Kable, Conductors of overhead lines [Przewody do linii napowietrznych], 2020, https://www.eltrim.com.pl/assets/katalogi/Katalog-przewody-napowietrzne-2020.pdf

Enea Operator, 2020, https://www.operator.enea.pl/oeneioperator/aktualnosci/2020/210-enea-operator-z-kolejnym-dofinansowaniem-na-budowe-inteligentnych-sieci-elektroenergetycznych

Energa Operator, 2020, https://media.energa.pl/pr/598609/polowa-klientow-energi-operatora-z-licznikami-zdalnego-odczytu-w-2021-r

Energa Operator, *Energa summarised the third quarter of 2020* [Energa podsumowała trzeci kwartał 2020 roku], 2020 https://media.energa.pl/pr/592431/energa-podsumowala-trzeci-kwartal-2020-year

Energa Operator, *Energa Operator strengthens the power grid* [Energa Operator wzmacnia sieć elektroenergetyczną], 2021, https://media.energa.pl/pr/671715/energa-operator-Strengthen-siec-elektroener

European Alternative Fuels Observatory, 2021, https://www.eafo.eu/vehicles-and-fleet/m

Eurostat, database, http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

European Environment Agency, *Trends and projections for Europe 2020: Tracking progress towards Europe's climate and energy targets*, 2020, https://www.eea.europa.eu/highlights/eu-on-track-to-meet

Fishbone A., Shahan Z., Badik P., *Infrastructure for charging electric vehicles* [Infrastruktura ładowania pojazdów elektrycznych] *Guidelines for cities* [Wytyczne dla miast], GreenTechnica & Greenway, 2017, https://greenwaypolska.pl/wp-content/uploads/sites/7/2019/09/GreenWay_Infrastruktura_ladowania_pojazdow_elektrycznych_Wytyczne_dla_miast_www_maj_2018.pdf

GUS, Energy consumption of households in 2018 [Zużycie energii w gospodarstwach domowych w 2018 r.], https://stat.gov.pl/download/gfx/portalinformacyny/pl/defaultaktualnosci/5485/2/4/1/zuzycie_energii_w_gospodarstwach_domowych_w_2018.pdf.

GLOBEnergia, *Electric vehicle subsidy programme in the first half of 2021* [Program dopłat do samochodów elektrycznych w pierwszej połowie 2021 r.], 2021, https://globenergia.pl/program-doplat-do-samochodow-elektrycznych-w-pierwszej-polowie-2021-r-elektromobilnosc/

Grzybowski M., *Charging electric vehicles - types of chargers* [Ładowanie samochodów elektrycznych – rodzaje ładowarek], Elektryczne Autocentrum, 2019, https://www.autocentrum.pl/publikacje/porady/ladowanie-samochodow-elektrycznych-rodzaje-ladowarek/

Hampel C., France decreases electric vehicle subsidies as sales rise, Electrive.com, 2020, https://www.electrive.com/2020/09/29/france-decreases-ev-subsidies-as-sales-rise140521/

HELUKABEL, *YAKXS - product data sheet*, https://www.helukabel.pl/files/YAKXS-karta-katalogowa.pdf

International Energy Agency, *Global EV Outlook 2020*, 2020, https://webstore.iea.org/download/direct/3007

International Energy Agency, 2019, http://www.ieahev.org/assets/1/7/Report2019_Switzerland.pdf

IRENA, *Innovation Outlook: Smart charging for electric vehicles*, 2019, https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Innovation_Outlook_EV_smart_charging_2019.pdf

Jolly J., *Car industry lobbied UK government to delay ban on petrol and diesel cars*, The Guardian, 2021, https://www.theguardian.com/business/2021/mar/15/car-industry-lobbied-uk-government-delay-ban-petrol-diesel-cars

Jóźwiak D., Drechny M., *Analysis of the possibilities of using V2G technology for power system balancing*, 2019, http://pe.org.pl/articles/2019/10/12.pdf

Keay-Bright S., *Accelerating electromobility in east Europe: a how-to guide (part 1)*, 2019, https://energypost.eu/accelerating-electromobility-in-east-europe-a-how-to-guide-part-1/

Kielichowska I., Staschus K., van der Leun K., Bettgenhaeuser K., Ramaekers L., Sheppard S., Staats M., Lenkowski A., Sijtsma L., *Poland's climate neutrality by 2050* [Polska neutralna klimatycznie 2050] *Electrification and sector coupling, Forum Energii*, 2020, https://forum-energii.eu/pl/analizy/integracja-sektorow.

Ł. Kifer, *The government is preparing PLN 800 million to support electromobility* [Rząd szykuje 800 milionów zł na wsparcie elektromobilności] *Hydrogen refuelling stations and current charging stations will be built* [Powstaną stacje tankowania wodorem i ładowania prądem] 2020, https://moto.pl/MotoPL/7,170318,26631740,rzad-szykuje-800-milionow-zl-na-wsparcie-elektroMobilosci.html.

Kłos M., *Electromobility. Development of electromobility in Poland and related challenges for the power system* [Rozwój elektromobilności w Polsce i związane z tym wyzwania dla systemu elektroenergetycznego], 2020, https://www.muratorplus.pl/technika/elektroenergetyka/elektroMobilosc-w-polsce-rozwoj-elektrom

Kłos M., Marchel P., Paska J., Bielas R., Błędzińska M., Michalski Ł., Wróblewski K., Zagrajek K., *Forecast and impact of electromobility development on the Polish Electric Power System*, E3S Web of Conferences, 2018, https://www.e3s-conferences.org/articles/e3sconf/pdf/2019/10/e3sconf_pe2019_01005.pdf

KOBIZE, *CO2, SO2, NOX, CO and particulate matter emission factors for electricity* [Wskaźniki emisyjności CO2, SO2, NOX, CO i pyłu całkowitego dla energii elektrycznej], 2019, https://www.kobize.pl/uploads/materialy/materialy_do_pobrania/wskazniki_emisyjnosci/Wskazniki_emisyjnosci_grudzien_2019.pdf

Komisja Europejska, *Effect of electromobility on the power system and the integration of RES*, 2018,https://ec.europa.eu/energy/sites/ener/files/documents/metis_s13_final_report_electromobility_201806.pdf

European Commission, *Benchmarking smart metering deployment in the EU-28*, 2020 https://op.europa.eu/en/publication-detail/-/publication/b397ef73-698f-11ea-b735-01aa75ed71a1

Kwiatkiewicz P., Szczerbowski R., Śledzik W., *Electromobility - infrastructural environment and technical challenges faced by intra-regional policy* [Elektromobilność - środowisko infrastrukturalne i techniczne wyzwania polityki intraregionalnej], Poznań 2020

Maier U., Peter F., Jahn A. & Hildermeier J., *Distribution grid planning for a successful energy transition - focus on electromobility*, Agora Verkehrswende, Agora Energiewende, Regulatory Assistance Project, 2019, https://www.agora-verkehrswende.de/fileadmin/Projekte/2019/EV-Grid/AgoraRAP2019_VerteilnetzausbauElektromobilitaet_EN.pdf.pdf

Malinowski M., *Home electric car charging station: types and important parameters* [Domowa stacja ładowania samochodów elektrycznych: rodzaje i ważne parametry], 2020,https://muratordom.pl/instalacje/instalacja-elektryczna/domowa-stacja-ladowania-samochodow-elektrycznych-rodzaje-i-wazne-parametry-aa-vhiW-DQSk-Eckn.html.

EU subsidies map, https://mapadotacji.gov.pl/

Ministry of State Assets, *National Framework for the Development of Alternative Fuels Infrastructure Policy* [Krajowe ramy polityki rozwoju infrastruktury paliw alternatywnych], 2017, https://www.gov.pl/web/aktywa-panstwowe/rzad-przyjal-Krajowe-ramy-polityki-rozwoju-infrastruktury-paliw-alternatywnych-3

Ministry of Energy, *Electromobility Development Plan in Poland "Energy for the future"* [Plan rozwoju elektromobilności w Polsce "Energia do przyszłości"], 2017, https://www.gov.pl/documents/33372/436746/DIT_PRE_PL.pdf/ebdf4105-ef77-91df-0ace-8fbb2dd18140

Ministry of Funds and Regional Policy, Strategy *for Responsible Development up to 2020 (including perspective up to 2030)* [Strategia na rzecz odpowiedzialnego rozwoju do roku 2020 (z perspektywą do 2030 r.)], 2020, https://www.gov.pl/web/fundusze-regiony/informe-o-strategii-na-rzecz-odpowiedzialnego-rozwoju

Ministry of Infrastructure, *Sustainable Transport Development Strategy up to 2030*, [Strategia Zrównoważonego Rozwoju Transportu do 2030 roku] 2019, https://www.gov.pl/web/infrastruktura/projekt-strategii-zrownowazonego-rozwoju-transportu-do-2030-roku2

Ministry of Climate and Environment, *Low Emission Transport Fund*, 2018, https://www.gov.pl/web/klimat/fundusz-niskoemisgo-transport

Ministry of Climate and Environment, *Draft Act amending the Act on Electromobility and Alternative Fuels and Certain Other Acts*, 2020, https://legislacja.rcl.gov.pl/projekt/12340506

Ministry of Climate and Environment, *Polish Energy Policy until 2040*, 2021, https://www.gov.pl/web/klimat/polityka-energetyczna-polski#:~:text=PEP2040%20represents%20Light√C4%85%20wizja√C4%99%20strategii,os√C5%82abienia%20economics%20pandemic√C4%85%20COVID%2D19.

Ministry of Climate and Environment, *Draft regulation of the Ministry of Climate and Environment on detailed conditions for granting state aid for electric vehicle charging infrastructure and hydrogen refuelling infrastructure*, 2020, https://legislacja.rcl.gov.pl/projekt/12341508

Supreme Audit Office, *Information on audit results: Electromobility development support*, 2020, https://www.nik.gov.pl/plik/id,23045,vp,25751.pdf

Supreme Audit Office, *Protection of electricity consumer rights* [Ochrona praw konsumenta energii elektrycznej], 2018, https://www.nik.gov.pl/aktualnosci/ochrona-praw-konsumenta-energii.html

Nanaki E. A., Kiartzis S., Xydis G. A., *Are only demand-based policy incentives enough to deploy electromobility?*, Policy Studies, 2020, https://www.heliev.gr/wp-content/uploads/2020/02/Are-only-demand-based-policy-incentives-enough-to-deploy-electromobility-1.pdf

M. Niewitała, *1 MW PV farm construction costs - analysing the share of components in the total price* [Koszt budowy parmy PV o mocy 1 MW - analizujemy udział komponentów w cenie], Globenergia, 2019, https://globenergia.pl/koszt-budowy-farmy-pv-o-mocy-1-mw-analizujemy-udzial-komponentow-w-cenie/.

Nijhuis Ch., *Number of e-buses in German public transport doubled in 2020, fuel cell falling behind - report*, Clean Energy Wire, 2021, https://www.cleanenergywire.org/news/number-e-buses-german-public-transport-doubled-2020-fuel-cell-falling-behind-report

Piotrowski P., Baczyński D., Robak S., Kopyt M., Piekarz M., & Polewaczyk M., *Comprehensive forecast of electromobility mid-term development in Poland and its impacts on power demand system*, 2020, http://journals.pan.pl/Content/117262/PDF/06_697-709_01508_Bpast.No.68-4_27.08.20.pdf

Płuska E., Rackiewicz I., Rosicki M., Sobecki I., Szczepanik-Retka I., Załupka M., Skarbek-Żabkin A. & Matuszewski P., *Analysis of the state of development and current development trends in the area of electromobility in Poland* [Analiza stanu rozwoju oraz aktualnych trendów rozwojowych w obszarze elektromobilności w Polsce], ATMOTERM S.A. & Forum Elektromobilności, 2019, https://www.gov.pl/web/rozwoj-praca-technologia/rozwoj-elektromobilnosci-w-polsce

Polish Alternative Fuels Association, Polish EV Outlook 2020, https://orpa.pl/najnowsza-prognoza-rozwoju-elektromobilnosci-w-polsce/

Polish Alternative Fuels Association, *New Electromobility Barometer 2020/2021* [Barometr Nowej Elektromobilności 2020/21], 2020, https://pspa.com.pl/media/2020/11/barometr_nowej_mobilnosci_2020_raport_S_1.pdf

Polish Alternative Fuels Association, *Electric vehicles as an element of power grids* [Pojazdy elektryczne jako element sieci elektroenergetycznych*]*, 2018, https://pspa.com.pl/media/2020/08/V2G_raport_S.pdf

Polish Alternative Fuels Association, *Experts on the amendment of the Act on Electromobility. Many positives, but also mistakes*, [Eksperci o nowelizacji ustawy o elektromobilności. Są pozytywy, ale i błędy] 2021, https://auto.wprost.pl/aktualnosci/10435363/eksperci-pspa-o-nowelizacji-ustawy-o-elektromobilnosci.html

Portal na rzecz czystej energii i klimatu, *Polish power sector needs innovations. Not only due to excessive heat* [Polska energetyka potrzebuje innowacji. Nie tylko ze względu na upały], 2018,

https://leonardo-energy.pl/artykuly/polska-energetyka-potrzebuje-innowacji-nie-tylko-ze-wzgledu-na-upaly/

PTPiREE, *Power industry, distribution and transmission* [Energetyka dystrybucja i przesył], 2020, http://www.ptpiree.pl/raporty/2020/raport_ptpiree_druk.pdf

PTPiREE, *Energetyka, dystrybucja i przesył* [Power industry, distribution and transmission], 2018, http://www.ptpiree.pl/documents/raport_ptpiree.pdf

Polish Automotive Industry Association (PZPM), *Electromobility Meter* [Licznik Elektromobilności], 2021, https://www.pzpm.org.pl/pl/Rynek-motoryzacyjny/Licznik-elektromobilnosci/Marzec-2021

Rabiega W., Sikora P., Gąska J., *CO2 emissions reduction potential in transport sector in Poland and the EU until 2050*, Centre for Climate and Energy Analysis, 2019, http://climatecake.pl/wp-content/uploads/2019/11/CAKE_Transport_emission_reduction_potential_2050_paper__final.pdf

Ranssen van, S., *Local grid investments can make or break the energy transition*, Energy Monitor, 2021,

https://energymonitor.ai/tech/networks-grids/local-grid-investments-can-make-or-break-the-energy-transition

Shahan Z., *CleanTechnica Busts Into Electric Car Wilderness*, Clean Technica, 2015, https://cleantechnica.com/2015/10/31/cleantechnica-busts-into-electric-car-wilderness/

Smart Energy International, 2019, https://www.smart-energy.com/industry-sectors/smart-grid/23-9-billion-anticipated-substations-automation/

Stone T., *UK government announces 120 funding for electric vehicles*, TTI, 2021, https://www.traffictechnologytoday.com/news/electric-vehicles-ev-infrastructure/uk-government-announced-120m-funding-for-electric-buses.html#:~:text=The%20UK's%20Transport%20Secretary%20Grant,continues%20to%20build%20back%20greener.

Sustainable BUS, *German fundings for e-buses grow up to 650 million euros*, 2021, https://www.sustainable-bus.com/news/german-fundings-for-e-buses-grow-up-to-650-million-euros/#:~:text=Subsidies%20for%20electric%20buses.&text=of%20300%20million.-,The%20German%20aid%20scheme%20is%20valid%20until%20the%20end%20of,setting%20up%20the%20charging%20infrastructure.

Ted.tenders electronic daily, Polska-Gdańsk: *Voltage transformers 2020/S 141-347855. Proceeding results. Supplies*, 2020, https://ted.europa.eu/udl?uri=TED:NOTICE:347855-2020:TEXT:EN:HTML&WT.mc_id=RSS-Feed&WT.rss_f=Materials+and+Products&WT.rss_a=347855-2020&WT.rss_ev=a

Tomaszewski R., Power grid needs a revolution: how to transform the Polish power distribution sector [Sieć do zmiany: jak zreformować polski sektor dystrybucji energii elektrycznej], Polityka Insight, 2019, https://www.politykainsight.pl/prawo/_resource/multimedium/20182100

The Wallbox, *The ultimate guide to EV initiatives in the Netherlands*, 2020, https://wallbox.com/en_us/netherlands-ev-incentives

The Wallbox, *The ultimate guide to EV initiatives in Germany*, 2020, https://wallbox.com/en_catalog/ev-incentives-in-germany

Transport & Environment, *Roll-out of public EV charging infrastructure in the EU*, 2018, https://www.transportenvironment.org/press/only-5-percent-ev-charging-happens-public-charging-points

Transport & Environment, *How clean are electric cars? T&E T&E's analysis of electric car lifecycle CO2 emissions*, 2020, https://www.transportenvironment.org/sites/te/files/downloads/T%26E%E2%80%99s%20EV%20life%20cycle%20analysis%20LCA.pdf

Office of Technical Inspection, *Register of Alternative Fuels Infrastructure* [Ewidencja Infrastruktury Paliw Alternatywnych], https://eipa.udt.gov.pl/ [access date: 12.01.2021]

Unterlohner F.,, How to decarbonise long-haul trucking in Germany: an analysis of available technologies and their associated costs, Transport & Environment, 2021, https://www.transportenvironment.org/sites/te/files/publications/2021_04_TE_how_to_decarbonise_long_haul_trucking_in_Germany_final.pdf

Wappelhorst S., *Beyond major cities: Analysis of electric passenger car uptake in European rural regions*, The International Panel on Clean Transportation, 2021, https://theicct.org/sites/default/files/publications/Ev-europe-rural-mar2021.pdf

Wappelhorst S., Cui H., *Growing momentum: Global overview of government targets for phasing out sales of new internal combustion engine vehicles*, The International Council on Clean Transportation, 2020,https://theicct.org/blog/staff/global-ice-phaseout-nov2020#:~:text=In%20addition%2C%20the%20country%20is,Ireland%2C%20Slovenia%2C%20and%20Sweden.

Worldometer, Norway Population, 2020, https://www.worldometers.info/world-population/norway-population/

Mayor of Kołbaskowo municipality, *Amendment of the spatial development conditions and directions study for Kołbaskowo municipality* [Zmiana studium uwarunkowań i kierunków zagospodarowania przestrzennego gminy Kołbaskowo], 2014, https://www.kolbaskowo.pl/attachments/article/1253/za√C5%82.√201%20do%20uchwa√C5%82y%20XXXVI.446.2014.pdf.

Zakrzewska S., Gil-Świderska A. & Szmitkowski P., *Age structure of the Polish electrical power infrastructure* [Struktura wiekowa polskiej infrastruktury energetycznej], 2020, https://www.cire.pl/pliki/2020/str_wiek.pdf.

Zawieska J., *Development of electromobility market in Poland* [in:], Electromobility in Poland in view of European and global trends [Rozwój Rynku Elektromobilności w Polsce [in:], Elektromobilność w Polsce na tle tendencji europejskich i światowej], ed. J. Gajewski, W. Paprocki, J. Pieriegud, Warsaw 2019, Publication of the European Financial Congress, 2019, p. 9, https://www.efcongress.com/wp-content/uploads/2020/02/publikacje09__Elektromobilno%C5%9B%C4%87-w-Polsce-na-tle-tendencji-europejskich-i-globalnych.pdf

Notes

Distribution grids and electromobility
Planning and development

FORUM ENERGII
ul. Wspólna 35/10, 00-519 Warszawa
NIP: 7010592388, KRS: 0000625996, REGON: 364867487

www.forum-energii.eu