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Monika Pepłowska[1], Dominik Kryzia[2], Piotr Olczak[3]

Electric vehicles charging point occupancy at different times of the day vs. power demand

Abstract: Electric vehicles (EVs) are playing an increasingly important role in the overall vehicle mix both globally and in Poland. The article contains an analysis of the electric car market analysing the occupancy of electric car charging points at different times of the day and the demand for power based on Poland's experience in this field. Forecasts for the development of the market of broadly understood electromobility were analysed. The authors carried out research on the availability of public charging points for electric cars in Poland. The research determined the number of occupied charging points on working days and on non–working days, as well as the maximum number of single charging processes registered in individual months (September 2021–January 2022). As part of the analysis carried out in the article, the authors showed how much of a burden the current state of the electric vehicle market has on the Polish power system, taking into account the existing number of vehicles and their demand for charging power at publicly available stations. In addition, a simulation was carried out to determine how big changes in the load on the power system will mean an increase in the number of electric vehicles. Moreover, the authors indicated the hours of

✉ Corresponding Author: Monika Pepłowska; e-mail: monika@meeri.pl

[1] Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Poland; ORCID iD: 0000-0001-9150-7525; e-mail: monika@meeri.pl

[2] Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Poland; ORCID iD: 0000-0003-0639-3485; e-mail: kryzia@meeri.pl

[3] Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Poland; ORCID iD: 0000-0002-4926-0845; e-mail: olczak@min-pan.krakow.pl

occurrence of a higher number of electric vehicle recharges per day and the number of occupied charging points. These data were collated and compared with the average power demand values in Poland. The study also explored potential strategies to mitigate the strain on the power grid, such as optimising charging times and enhancing grid capacity. The results underscore the need for proactive measures to ensure that the growth of electric vehicles does not compromise the reliability of the national power system.

Słowa kluczowe: Poland, energy demand, EV, charge points, EV energy demand

Introduction

Cars are a major part of road transport in many countries, especially in those in the developing world. Their popularity is due in part to their versatility, enabling them to travel both short and long distances, in a variety of terrain conditions and with different transport needs. According to available estimates, electric passenger car sales will quadruple to 4.5 million units in the next two years alone, or 5% of the total market (Gajewski et al. 2019).

Given the targets the European Union has set to achieve zero-emission and climate neutrality by 2050, new tools and investments are still needed. One way of enforcing change on a large scale in the Member States is to bring vehicles to the markets that run on clean fuels (EU European Green Deal). European countries, which include Poland, are taking steps towards achieving this goal (Komorowska et al. 2023). As technology advances and environmental awareness increases, alternative energy sources for transport are receiving increasing attention. The conversion of combustion cars to electric vehicles is one of the key developments in this field. Electric vehicles are more efficient in energy consumption and generate significantly lower or even zero emissions of greenhouse gases and other harmful substances than combustion vehicles. The move towards electrification of transport aims not only to reduce negative environmental impacts but also to improve urban air quality and reduce dependence on fossil fuels (Kryzia and Pepłowska 2023). An assessment of the potential of electric cars to reduce greenhouse gas emissions to curb global warming is provided by author (Vitta 2021) and (Hirz et al. 2022). At the same time, the Polish experience is described by the authors (Majchrzak et al. 2021) and (Kryzia D. and Kryzia K. 2023).

At the same time, year after year, due to the ever-increasing development of civilisation, more and more energy resources are required to meet social, economic, and production needs. Although electric vehicles are more energy–efficient and environmentally friendly than internal combustion vehicles, their operation requires access to a suitable charging infrastructure, which also generates additional energy requirements. Hence, there is an upward trend in electricity consumption, which is partly driven by the growing number of electric vehicles and increasing energy demand in other spheres of social and economic life. According to projections in the US Energy Information Administration's International Energy Outlook 2021 (IEO 2021)

report, global electricity consumption will increase by almost 50% between 2020 and 2050 (EIA 2021). According to the EIA's projections and energy trends based on current laws and regulations, the strongest growth considering energy sources until 2050 will be in renewable energy consumption. It is important to note that liquid fuels will remain the largest source of energy, driven mainly by the industrial and transport sectors. Renewable energy sources will be the main source of new electricity generation, but it will be hydrogen, along with natural gas, coal, and increasingly deployed energy storage systems that will be used to stabilise and support existing loads on the power grid. According to IEO2021 projections, the number of registered electric vehicles (EVs) will contribute to emissions reductions and account for 31% of the total passenger vehicle fleet by 2050 globally. At the same time, the above report estimates that the expansion of electric–powered road transport will contribute to a projected increase in energy consumption of at least 79%. According to a recent report by EY and Eurelectric *Six essentials for mainstream EV adoption* – the number of electrically–powered cars will increase in 2022 and worldwide to 26.8 million (EY Six Essentials...). Forecast to reach 14.3 million sales in 2023, BEV and PHEV sales will account for more than half of all new car sales worldwide by 2030. The availability of charging infrastructure and the cost of purchase are still the biggest barriers to the development of electromobility. Currently, according to the International Energy Outlook 2024, electric cars account for around 20% of new car sales, though they make up less than 5% of the total number of cars on the road. Factors such as tight profit margins, high inflation, the phase-out of purchase incentives in some countries, and insufficient public charging infrastructure have raised concerns about the pace of further EV adoption. Nonetheless, global sales data remain strong. In 2023, around 14 million electric vehicles (including both battery electric vehicles and plug-in hybrids) were sold globally, with projections suggesting this will rise to approximately 17 million in 2024, representing over one in five cars sold. In the first half of 2024, electric car sales increased by about 25% compared to the same period in 2023, largely driven by growth in China, which accounted for 60% of global sales. In August 2024, more than 1 million electric cars were sold in China, with total annual sales projected to exceed 10 million units by year-end. It is anticipated that by the end of 2024, nearly half of all cars sold in China will be electric (IEO 2024).

There are also several forecasts for the development of the global and European electric car market (IEA 2024). Figures presented by ING show that in 2035 all new passenger cars sold in the European market will be electric cars (ING Economics... 2017). Car manufacturers in Europe are increasingly serious about electromobility according to the KPMG Global Automotive Executive Survey, by 2030 sales of new battery electric vehicles (BEVs) in Europe are expected to account for 30% of total vehicle sales (KPMG Global... 2024).

It should also be noted that the European Parliament has approved CO reduction targets2 for new cars. The new guidelines envisage zero emissions from new cars and vans in 2035. This is part of the *Fit for 55* package of measures *The European Green Deal* (Gheuens 2023). However, the assumptions, described in the EU *Fit for 55* document, are being protested by the automotive industry, indicating that transport after 2035 must combine both combustion and electric vehicles. Manufacturers are concerned about the high costs of switching production directed solely

towards electric vehicles, as well as the lack of sufficient charging infrastructure. This situation is expected to result from the specific objective in the 2011 *White Paper on Transport, Roadmap to a Single European Transport Area–Towards a Competitive and Resource–Efficient Transport System,* which aims to halve the number of conventionally fuelled cars in urban transport by 2030 and exclude them from cities by 2050 and to achieve essentially CO_2 – free logistics in major urban centers by 2030 (European Commission... 2011).

The uptake of electric cars and vans in Europe increased significantly in 2020, according to the European Society of Motor Manufacturers (ESPS). Electric car registrations in 2020 totalled nearly 1,325,000 units, up from 550,000 units the previous year. Analysed as a percentage, this is an increase from 3.5% to 11% of total new car registrations during the year. The use of electric vans has also increased, as evidenced by an increase in the volume of new registrations from 1.4% of total new registrations in 2019 to 2.2% in 2020 (European Environment... 2024).

In connection with the EU regulations, a set of documents was presented in Poland The Electromobility Development Programme is one of the flagship projects of the Strategy for Responsible Development (SOR). The implementation of the objectives of the SOR about the Electromobility Development Programme became the basis for the creation of a regulatory package, consisting of the following strategic documents:

- Plan for the Development of Electromobility in Poland "Energy into the Future", adopted by the Council of Ministers on 16.03.2017,
- National policy framework for the development of alternative fuel infrastructure, adopted by the Council of Ministers on 29.03.2017,
- Law on Electromobility and Alternative Fuels of 11 January 2018,
- The Act establishing the Low Emission Transport Fund, i.e. the Act of 6 June 2018 amending the Act on bio–components and liquid biofuels and certain other acts.

The Electromobility Development Plan for Poland defines the benefits associated with the widespread use of electric vehicles in our country and identifies the economic and industrial potential of this area. Electromobility development must be included in the most important document of the Polish economy, i.e. the Energy Policy of Poland until 2040 (Ministry of Climate... 2021). Electromobility development is one of the specific objectives of the Polish Energy Policy. Thus, the development of and investment in green transport is one of the priorities of the national authorities.

At the end of January 2022, there were 39,328 electric passenger cars on Polish roads. Fully electric vehicles accounted for 49% of this number, while the remainder (51%) were plug-in hybrids – 19,898 units. At the end of January 2022, there were 1,992 publicly accessible electric vehicle charging stations in Poland, providing 3,893 charging points. Of these, 28% were direct current (DC) fast charging stations and 72% were slow alternating current (AC) chargers of 22 kW or less. In January, an additional 60 new public charging stations were launched, increasing the number of charging points by 109. Currently (2024), Poland has 6490 electric vehicle charging points. According to data from the end of July 2023, a total of 47,018 registered electric cars were recorded in Poland, comprising both passenger vehicles and commercial vehicles that run entirely on electricity (BEV). During the first seven months of 2023, an increase

of 13,293 units was recorded in this number, an increase of 57.7% compared to the same period in 2022. This information comes from the Electromobility Counter, which was launched by the Polish New Mobility Association (Polskie Stowarzyszenie Nowej Mobilności) (DailyDriver How many... 2024). At the end of March 2024, the number of registered electric passenger cars in Poland is 108,331 units (Electric Market Electric Vehicle... 2024). At the end of 2021 and the beginning of 2022, almost three times as many public charging stations were launched in Poland as in 2021–2020. Despite the existing system barriers, operators are also initiating activities to increase the capacity of existing points and to increase the number of chargers in already occupied locations. According to the Polish Alternative Fuels Association (PSPA), the charging infrastructure support programme launched by the National Fund for Environmental Protection and Water Management (NFOŚiGW) will contribute to the expansion of the network. According to the PSPA, the first effects of the implementation of the support scheme, translating into an increase in the number of points launched, may be visible in the second half of 2022.

Research into electric car charging point occupancy and power demand at different times of the day has been conducted by authors to date. Lee (2017) found that demand for chargers is highest from 9 am to 9 pm, with an increase during holiday periods (Lee et al. 2017). Bryden (2018) predicted that the use of fast charging points for long-distance travel peaks in the evening, with 45% of daily fast charging taking place between 3 pm and 7 pm (Bryden et al. 2018). Santini (2012) highlighted the potential for charging during the day, particularly ahead of summer afternoon peak loads (Santini etal. 2012). Moon (2018) further highlighted a preference for evening charging, with a shift to public fast charging during peak load hours (Moon et al. 2018). Together, these studies suggest that electric car charging point occupancy and power demand are influenced by factors such as time of day, vehicle type, and consumer preferences. In contrast, the authors of this article examined the case of Poland. Therefore, this article aims to quantify the occupancy of electric car charging points at different times of the day in Poland and to estimate its impact on the load on the power system. The authors hypothesised that the occupancy of electric car charging points at different times of the day in Poland has a significant impact on the magnitude of the load on the power system/power demand in Poland.

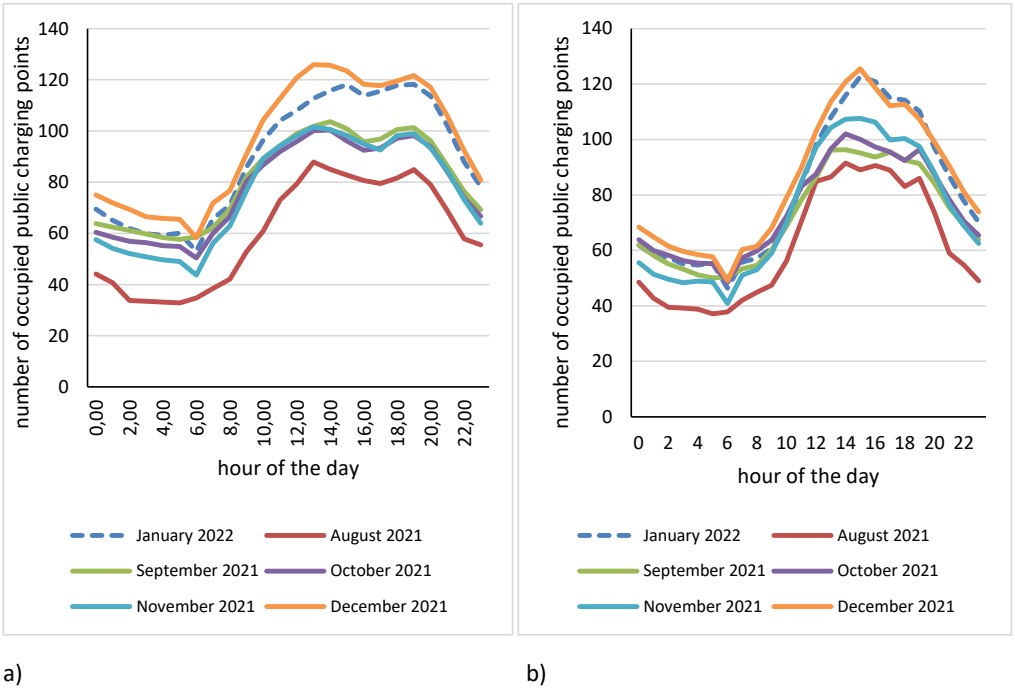
1. Materials and methods

1.1. Identification of charging points

The Alternative Fuels Infrastructure Register (EIPA) is a public registry maintained to provide EV and natural gas vehicle users with information to facilitate the use of EVs. The registry contains information on the location of natural gas stations and charging stations, current prices

for alternative fuels, and the current state of use of EV charging equipment (active, damaged, available, occupied installed at publicly accessible charging stations. In addition, the registry provides electronic services that allow the registration and updating of data, concerning a compressed natural gas (CNG) refuelling point, a liquefied natural gas (LNG) refuelling point, or a charging point installed at a public charging station, and the transmission of current information on the availability of a charging point installed at a public charging station and current prices of alternative fuels (Office of Technical Inspection... 2024). Thus, using the EIPA database, the user can check the availability of charging stations throughout the country, as well as in the area where he or she is currently located. Using the map provided on the website, we can identify in which city and on which street it is currently possible to charge the batteries in the vehicle. Using the data collected in the EIPA database, the authors prepared an input data analysis to simulate the load on the National Electricity System (NPS).

Figure 1 shows the daily number of electric vehicle recharges at public charging stations in Poland, assuming the study period from August 2021 to January 2022. Analysing the prepared summary and starting from August 2021 (orange line), we notice that the number of electric vehicles recharges is increasing about the preceding month, which is a result of an increase in the number of electric vehicles in Poland as well as the number of vehicle charging points.



a) b)

Fig. 1. Number of occupied charging points on (a) working days and (b) days off

Rys. 1. Liczba zajętych punktów ładowania w (a) dni robocze i (b) dni wolne

The anomaly in January 2022 may be due to holiday breaks, a large number of non–working days falling, and long weekends. The highest number of recharges was recorded in December 2021, which may be due to the movement of people over the festive period, and increased energy needs per km of route travelled. The figures quoted by the authors are the number of charges of electric cars at publicly accessible stations, private chargers are not included. The term "public charging station" is defined as a charging station available on an equal basis to any owner of an electric vehicle and a hybrid vehicle (Chancellery of the Sejm...). It is estimated that charging at public access stations only accounts for around 10–20% of the total number of charges. It should also be noted that the chargers at charging points vary in power, voltage, and amperage of the current applied (charged), which affects the charging time of the battery located in the vehicle and its cost. On weekdays from Monday to Friday, the highest number of recharges at public charging points occurs in the afternoon between 12 noon and 6 p.m. By contrast, on public holidays, the peak hours of use are between 2 p.m. and 6 p.m.

There are the following types of charging stations in Poland:

- direct current (DC): These are superfast stations that allow vehicles to be charged in around 20–30 minutes. Their power output typically ranges from 50 to 350 kW.
- alternating current (AC): These are publicly accessible public stations that offer charging over a longer period. The capacity of these stations typically ranges from 3.7 to 22 kW.

In Poland, there are currently a greater number of alternating current (AC) charging stations compared to direct current (DC) charging stations. This is mainly because AC stations are cheaper to build and can be more easily installed in various locations, such as shopping centres car parks, restaurants, or petrol stations. However, DC stations, especially the high–powered (super–fast) ones, are also increasingly popular, especially along major traffic routes and motorways. Their charging speeds are attractive to drivers who want to charge their vehicles quickly during long journeys.

As a result, the analysis in the article assumes that the average charging power at chargers located at public points is approximately 20 kW. It was also assumed that the highest instantaneous number of vehicle recharges is 200, resulting in a power requirement of 4.0 MW. In the context of this, it can be concluded that the power needed, at the times of peak charging at public stations, of the highest charging demand is only a few MW. This value appears to be a negligible size of the power demand at the national level (PSE System Data).

An important parameter for the NPS is the maximum number of charges by hour per month (Fig. 2). The NPS needs to identify the hours of occurrence of extreme values and it is important to identify them because they are difficult to manage (between regulated and unregulated supply and difficult to change demand).

The observed increasing number of charges is also due to the increase in the number of EVs in Poland. Hourly minimum values among the monthly maximum numbers occur between 1 and 5 o'clock. In contrast, the maximum values occur during the afternoon hours of 2pm to 7pm and the volumes reached are approximately twice the daily minimum values.

The level of consumer demand for electric car charging with the increasing rate of electric vehicles in the country will be able to have a significant impact on the organisation of work in

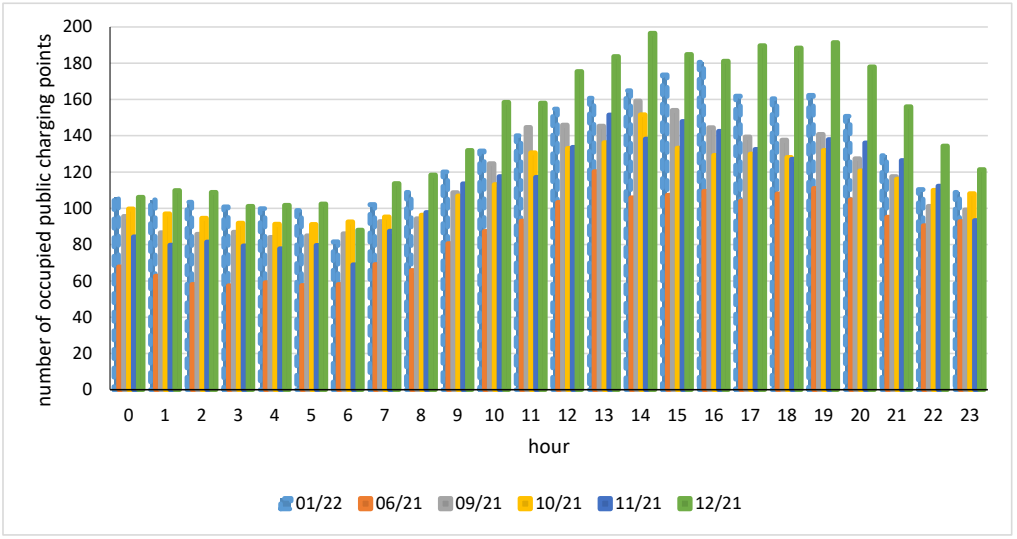


Fig. 2. Maximum number of charges by hour per month

Rys. 2. Maksymalna liczba opłat za godzinę w miesiącu

the national electricity system. Thus, it becomes reasonable to analyse how much impact the above–mentioned consumption may have on energy demand. Generally speaking, more energy is consumed in the electricity system during the winter season than in the summer. The same is true for electric cars, as energy consumption for heating the vehicle increases in winter, as well as the efficiency of the battery. Consequently, more electricity is needed to cover the same distance than in the spring and summer months.

1.2. Energy demand in Poland

The power demand by National Electricity System is presented in the graphs (Figs 3 and 4) and is:

1. On working days
2. On weekend days

There is an increase in demand for electrical power in particular months, which is due to seasonal trends. In the winter months, especially when temperatures are low, demand is higher than in the summer months. This is due to the increased use of electric heating and other electrical appliances for thermal comfort. Therefore, the highest power demand is usually recorded in December, which is one of the coldest months of the year. For example, the highest load on the electricity grid was recorded in December 2021, as people made more intensive use of heating systems and other electric–powered appliances to maintain adequate indoor temperatures.

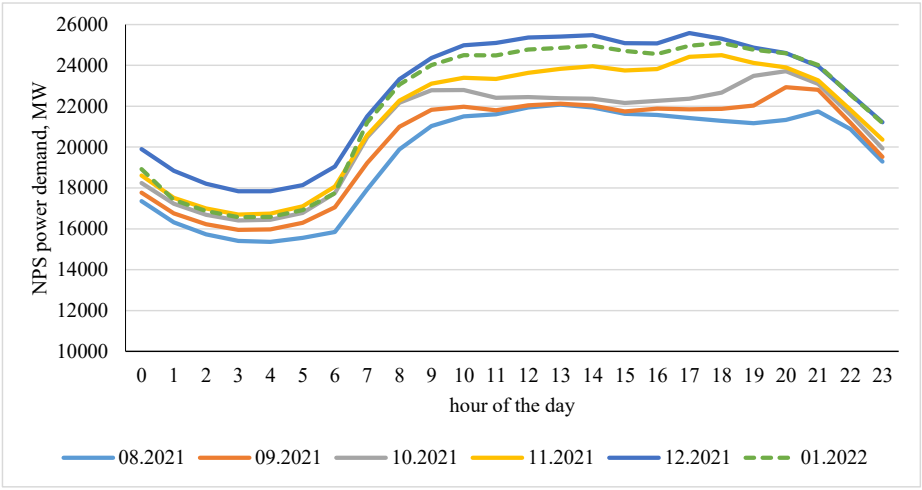


Fig. 3. Average power demand in the NPS by month, working days [MW]

Rys. 3. Średnie zapotrzebowanie na moc w KSE według miesięcy, dni roboczych [MW]

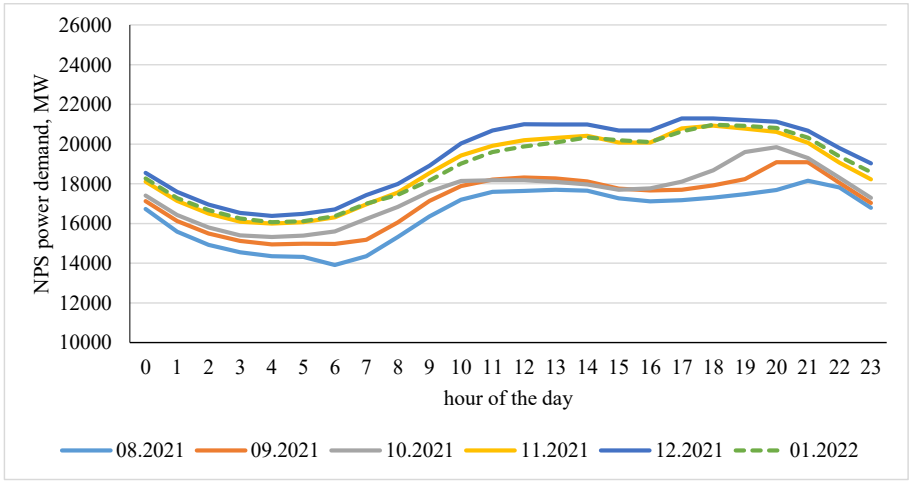


Fig. 4. Average power demand in the NPS by month, weekend days [MW]

Rys. 4. Średnie zapotrzebowanie na moc w KSE według miesięcy, dni weekendowe [MW]

The energy demand over the years is presented in the graph (Fig. 5).

It can be seen that, when analysing the whole year, there is a clear trend towards higher electricity demand in the winter months and lower demand in the summer months. This is due to natural changes in people's energy needs, which are related, among other things, to the intensity of the use of heating systems in winter and the lower consumption of energy for air conditioning

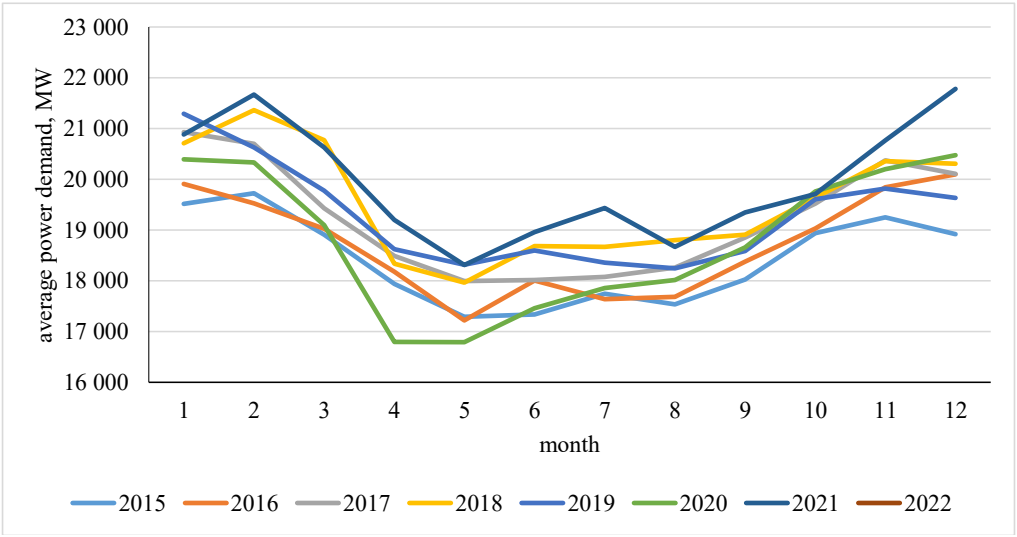


Fig. 5. Average power demand in Poland by month and year 2015–2022 [MW]

Rys. 5. Średnie zapotrzebowanie na moc elektryczną w Polsce według miesięcy i lat 2015–2022 [MW]

and cooling in the summer months. Annually, there has also been an overall increase in the country's electricity demand. The exception to this trend was in 2020 when an unusual situation of a decrease in energy demand was observed. This is a phenomenon related to the global COVID–19 pandemic, which affected many aspects of social and economic life, including electricity consumption. This was particularly evident in April 2020, which marked the beginning of the pandemic in Poland. At that time, lockdown restrictions, reduced economic activity, and remote working resulted in a significant decrease in electricity demand compared to similar periods in previous years (Kaczmarzewski et al. 2022; Onmedia Record of... 2024).

2. Results and discussion

Considering the data from December 2021, the volume of power demand on the national electricity system reached a significant level of 22,000 MW, with the highest hourly demand occurring mainly between 12 and 8 pm (see Fig 5).

At the same time, it is interesting to note that the demand for EV charging at public chargers peaked at 2 pm, when a maximum of 180–200 active EV charges were recorded (see Fig. 2). Assuming that the capacity of the chargers averaged 20 kW, the total demand of the electromobility supply system was then around 4,000 kW (4 MW). This means that the load from publicly available EV chargers represented a small 0.018% of the power demand of the national electricity system.

Although this share seems relatively negligible, analysing the growth and development forecasts for the electric car market and assuming only a 100–fold increase in the number of vehicles, it can be predicted that demand at its peak could rise to 400 MW. In such a scenario, the share of load would increase to almost 2%, a significant increase compared to current levels.

Similarly, if the number of electric vehicles is a thousand times higher than today, the share of load will increase significantly to 18%, which is a very significant share of the power demand on the national electricity system, assuming no significant increase in power demand. It is also necessary to take into account the impact of demand resulting from energy consumption by home or non–publicly available chargers, which may further affect the load on the electricity system.

Conclusions

Based on the data collected so far, the authors presented the current state of electromobility development in Poland. However, given the projected continuous increase in the number of electric cars in the country, as a final result of the article, a situation in which the number of vehicle charges is a hundredfold or even a thousandfold higher was simulated. The authors analysed whether the projected increase in the number of electric cars and the expansion of the electromobility system would have an impact on the demand for power during peak periods and, consequently, on the operation of the national electricity system.

The results of the analyses carried out showed that the country's electricity system will be significantly burdened if the number of electric vehicle charges increases. In the context of EU policy and national actions and strategic documents being prepared, we are moving towards a low–carbon economy. Electric vehicles, which are considered environmentally friendly, are being developed all over the world, and the increasing awareness of consumers is leading them to choose environmentally friendly vehicles. As a result, the number of electric vehicles is increasing year on year.

As the number of electric vehicles increases, the share of power demand in the national electricity system increases. This situation necessitates the search for new power sources and an increase in peak generation.

Therefore, this paper aimed to carry out a quantitative assessment of the occupancy of electric car charging points at different times of the day in Poland and to estimate its impact on the load on the power system. The authors hypothesised that the occupancy of electric car charging points at different times of the day in Poland has a significant impact on the magnitude of the electricity system load/power demand in Poland.

The results of the analysis confirmed the hypothesis, showing that the increased occupancy of electric car charging points at certain times of the day leads to a significant increase in the load on the electricity system. Particularly during peak hours, when the number of active charges is

highest, the load on the system can reach significant values, which may require additional measures to ensure the stability of the electricity supply.

In conclusion, the results of the analysis show the need for further research into optimising the management of electric car charging points and expanding the electricity infrastructure to meet growing demand. Furthermore, the analysis highlights the need to integrate electromobility with the electricity system in a way that takes into account changes in user behaviour and changes in electricity demand at different times of the day.

The approach proposed within the framework of this article is a universal proposal for proceeding, which can be successfully applied to the analysis and assessment of the situation related to electromobility in other countries. The results and conclusions of this analysis are not only applicable in the context of the Polish electricity system but can also provide valuable guidance for other countries that are also seeking to promote and develop electromobility.

By adopting this approach, it is possible to tailor the methodology and parameters of the analysis to the specifics of a country, taking into account local factors affecting electromobility and electricity infrastructure. In this way, the results of such studies can provide important information and decision–making tools for governments, institutions, and companies working in the field of electromobility worldwide.

Among others, the authors observed that during the afternoon hours of 2 to 7 pm, the number of charges achieved is approximately twice the minimum daily values. This, in effect, translates into the statement that the level of consumer demand for electric car charging with the increasing rate of electric vehicles in the country will be able to have a significant impact on the organisation of work in the national electricity system.

Further work planned includes an analysis of the impact of energy consumption by home EV chargers on the stability of the National Power System as well as including influence of the increasing share of RES in Poland.

The Authors have no conflicts of interest to declare.

DTA DigiTAl electromobility simulator for conventional vehicles. Projekt finansowany przez Narodowe Centrum Badań i Rozwoju w ramach Programu Operacyjnego Inteligenty Rozwój, poddziałania 4.1.4 „Projekty aplikacyjne". Project financed by the National Centre for Research and Development under the Smart Growth Operational Programme, Sub-measure 4.1.4 „Application projects".

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Monika Pepłowska, Dominik Kryzia, Piotr Olczak

Zajętość punktów ładowania samochodów elektrycznych w różnych porach dnia a zapotrzebowanie na energię

Streszczenie

Pojazdy elektryczne (EV) odgrywają coraz ważniejszą rolę w ogólnym miksie pojazdów zarówno na świecie, jak i w Polsce. Artykuł zawiera analizę rynku samochodów elektrycznych, analizując zajętość punktów ładowania samochodów elektrycznych w różnych porach dnia oraz zapotrzebowanie na energię na podstawie doświadczeń Polski w tym zakresie. Przeanalizowano prognozy rozwoju rynku szeroko rozumianej elektromobilności. Autorzy przeprowadzili badania dostępności publicznych punktów ładowania samochodów elektrycznych w Polsce. W ramach badań określono liczbę zajętych punktów ładowania w dni robocze i dni wolne od pracy, a także maksymalną liczbę pojedynczych ładowań rejestrowanych w poszczególnych miesiącach (wrzesień 2021–styczeń 2022). W ramach analizy przeprowadzonej w artykule autorzy pokazali, jak duży wpływ na polski system energetyczny ma obecny stan rynku pojazdów elektrycznych, biorąc pod uwagę istniejącą liczbę pojazdów i ich zapotrzebowanie na moc ładowania na ogólnodostępnych stacjach. Ponadto przeprowadzono symulację mającą na celu określenie, jak duże zmiany obciążenia systemu elektroenergetycznego będą oznaczać wzrost liczby pojazdów elektrycznych. Ponadto autorzy wskazali godziny występowania większej liczby ładowań pojazdów elektrycznych w ciągu doby oraz liczbę zajętych punktów ładowania. Dane te zestawiono i porównano ze średnimi wartościami zapotrzebowania na moc w Polsce. W badaniu zbadano również potencjalne strategie łagodzenia obciążenia sieci energetycznej, takie jak optymalizacja czasów ładowania i zwiększanie przepustowości sieci. Wyniki podkreślają potrzebę proaktywnych działań, aby zapewnić, że wzrost liczby pojazdów elektrycznych nie wpłynie na niezawodność krajowego systemu elektroenergetycznego.

Słowa kluczowe: Polska, zapotrzebowanie na energię, EV, punkty ładowania, zapotrzebowanie na energię EV