Identification of demand for electric vehicles charging stations on the example of voivodeships in Poland

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Abstract

The main purpose of the article is to identify areas where more electric vehicle charging stations should be located, on the example of Polish voivodeships. The following sections of the article review the literature on the development of electric vehicles charging infrastructure, as well as the methods and models proposed for determining the location of charging stations. Then, models were presented that identify the Polish voivodeships where more charging points should be located. The analysis was conducted on data relating to the voivodeship, due to the difficulties in finding more detailed actual data. The aim is to check whether there are voivodeships more suitable than others to have more charging points. The results can be used, for example, by the government to better direct economic resources towards this purpose. An exploratory analysis was performed using some clustering algorithms in order to find more relevant areas. In the article, a hierarchical algorithm and K-means clustering were used.

Key words

electric vehicles, charging stations, demand, model, Poland

Introduction

On the automotive market in Poland, a gradual increase in the popularity of electric cars can be observed. According to the E-Mobility Index, developed by the Polish Association of Automotive Industry (PZPM) and the Polish Alternative Fuels Association (PSPA), at the end of February 2023, 70 263 electric cars were registered in Poland, of which 66 685 were passenger cars. Within this group, fully electric BEVs, battery electric vehicles accounted for 51% (33 902 units), while the remaining 32 783 units (49%) were PHEVs, plug-in hybrid electric vehicles. Registrations of electric vans, trucks, and buses, as well as mopeds and motorcycles, are also steadily increasing [https://www.pzpm.org.pl/pl/Rynek-motoryzacyjny/Licznik-elektromobilnosci/Luty-2023, 17.04.2023].

Replacing combustion-powered cars with electric vehicles is one of the main directions of changes set by the European Union in the field of transport development. The main objectives of the European Union's transport policy include reducing greenhouse gas emissions, reducing dependence on fossil fuels, as well as introducing electromobility in transport in accordance with the principles of sustainable development [Brdulak and Pawlak, 2022]. Their implementation is intended to contribute to the achievement of climate neutrality by the European Union.

One of the main obstacles to the development of electromobility is the insufficient development of charging infrastructure. Planning a longer journey with an electric car currently requires proper route planning, taking into account the availability of charging infrastructure. This problem concerns not only Poland, but also most European countries. At the end of February 2023, there were 2 680 generally available charging stations for electric vehicles in Poland (5 266 points), of which 58 were launched in February (127 points). 30% of them were direct current (DC) fast charging stations, and 70% were slow alternating current (AC) chargers with a power less than or equal to 22 kW [https://www.pzpm.org.pl/pl/Rynek-motoryzacyjny/Licznik-elektromobilnosci/Luty-2023, 17.04.2023].

An important problem, apart from the insufficient number of charging points, is also the uneven location of this infrastructure. Considering the European Union area, the majority of charging points are located in three countries: Germany, the Netherlands, and France. As shown in Figure 1, the Netherlands is significantly ahead of other countries in terms of the number of electric car charging stations per capita.

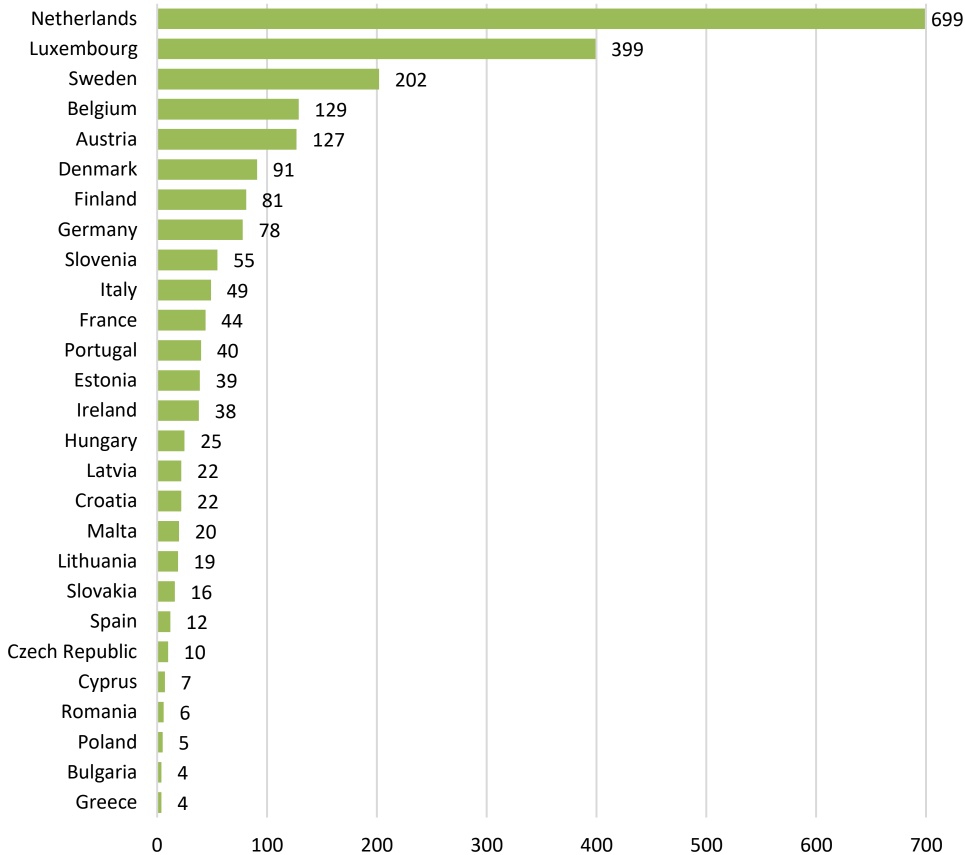

Fig. 1. Installed public charging infrastructure per 100 000 inhabitants per country in EU-27 in 2022

Source: Euronews, https://www.euronews.com/next/2022/06/20/demand-for-evs-is-soaring-is-europes-charging-station-network-up-to-speed [17.04.2023].

One of the key issues related to the development of charging infrastructure for electric vehicles is to determine the number of charging points, as well as their locations. The main purpose of the article is to identify areas where more charging stations should be located. The following parts of the article review the literature on the development of electric vehicle charging infrastructure, as well as the methods and models proposed for determining the location of charging stations. Then, models were presented to indicate Polish voivodeships in which more charging points should be located.

1. The problem of finding the best areas to locate charging stations

The development of electric vehicle charging station infrastructure is increasingly being discussed in the scientific literature. Researchers propose various methods, models, and approaches. Scientific articles on the optimal locations of charging stations are considered from three perspectives: the distribution network operator, the charging station owner, and the electric vehicle user [Ahmad et al., 2022].

Various optimization approaches are used to determine the best solution for placing the charging station. The two main techniques that scientists use to solve this problem are Genetic Algorithm and Particle Swarm Optimization. Other proposed solutions include those using Artificial Bee Colony, Teaching-Learning Based Optimization, Linear Programming, Greedy Algorithm, Gray Wolf Optimization, Grasshopper Optimization Algorithm, Branch and Bound [Ahmad et al., 2022]. Mehar and Senouci [2013] described an optimized algorithm named OLoCs (Optimized Location Scheme for electric charging stations), in which a new operator was added to the classical genetic algorithm, to improve its efficiency. OLoCs determine the necessary number of charging stations and their best placement. Miralinaghi et al. [2020] propose the use of a two-level mathematical model using an active-set algorithm to identify optimal locations for the construction of new electronic vehicle charging stations and the reconstruction of existing petrol stations. It should also be emphasised that location selection is a complex multiple criteria decision making (MCDM) problem involving many conflicting criteria [Liu et al., 2018].

Planning the development of electromobility infrastructure should take into account issues such as environmental impact and economic considerations. It is also very important to consider its impact on the distribution network [Ahmad et al., 2022]. Finding more cost-effective and sustainable solutions requires methods that integrate the spatial distribution of both the electrical distribution network and traffic flow to find optimal locations with minimal impact on the distribution network and easy access to users [Kizhakkan et al., 2019].

Research on determining the location of electric vehicle charging stations also considers the characteristics of the described areas. An example is the article by Frade at al. [2011] concerning Lisbon, the capital of Portugal, an area characterised by a strong concentration of population and employment. As the authors note, this type of area is suitable for slow charging, as vehicles are parked for several hours in a 24-hour period. A methodology based on a maximal covering model to optimize the demand covered within an acceptable level of service and to define the number and capacity of the stations to be installed was used. Due to the specificity of the area, the authors emphasise that two types of demand should be taken into account:

nighttime demand related to residences and daytime demand related to workplaces [Frade et al., 2011].

Another issue noticed by the researchers is the imbalance of demand and supply. The result is that an area with high demand cannot provide enough stations, while many stations are less used in remote areas with lower demand. A way to eliminate this imbalance may be the use of the Non-deterministic Polynomial (NP) model aiming to minimize the total vehicle service distance [Gong et al., 2019].

An interesting approach is proposed by Pagany et al. [2019], describing the user- and destination-based approach for locating the demand for electric charging. With regard to the daily activities of potential users, potential positions for charging stations are determined at the micro-location level in public spaces and semi-public spaces using geographic information systems (GIS). Depending on the time spent by vehicle users and the frequency of visits to potential points of interest (POIs), charging demand at such locations is calculated.

2. Research methodology

The purpose of this article is to find areas more suitable to have more electric charging stations in Poland. The analysis was done with data relatively to the voivodeship, due to difficulties in finding actual data in more detail. In this way, the purpose is to find if there are voivodeships more suitable than others to have electric charging stations for the vehicles. This would enable, for example, the government to better target economic resources. It has been done an explorative analysis with some clustering algorithms in order to find the areas more suitable.

Nine variables have been taken in consideration:

- Total population in a voivodeship; it will be considered areas more suitable to have electric charging stations, the most populated areas to cover a greater need than areas less populated.
- Population per 1 km^2; variable useful when it could be possible to have area populated but not so dense, and areas not too much populated but too dense that need more charging stations to cover the demand of their use [Gellrich et al., 2022].
- Average monthly receipts in PLN; variable taken in account because in areas richer it will be assumed that there will be more probability to have electric car, since electric cars are more expensive than the other types. Hence, there will be a greater need for charging stations [*How much does…*, 2021]

[https://www.fuelsinstitute.org/Research/Reports/EV-Consumer-Behavior/EV-Consumer-Behavior-Report.pdf, 17.06.2022].

- Educational level (percentage of people with higher education); it is assumed that in areas with a high educational level, people will pay more attention to the environment and its problems, people will be more motivated to buy electric cars and in these areas there will be a greater demand for charging stations [https://www.fuelsinstitute.org/Research/Reports/EV-Consumer-Behavior/EV-Consumer-Behavior-Report.pdf, 17.06.2022].
- Passenger cars per 1000 population; the assumption in this case is that in areas with more cars there will be surely more electric cars.
- Lorries per 1000 population; as electric vehicles will be important also in the transport of goods, helping to reduce the direct emissions [Zhang and Fujimori, 2020], in areas where this variable will be high, there will be more need for charging stations.
- Outlays on fixed assets serving environmental protection and water management by directions of investing; it will be assumed that in areas where this variable will be high, there will be more electric cars because of those incentives, and thus more need of charging stations; or simply more charging stations because of the investments.
- Total number of shops in a voivodeship; charging stations are often in areas like those, where people can stop their cars and use the time in the shops to charge their vehicles. It is assumed that areas, need to have charging stations, will be those with a high level of this indicator.
- Total number of petrol stations in a voivodeship; often charging stations are close to the petrol stations to have a unique station, more electric charging stations are expected to be in areas where this variable is high.

3. Models to find the voivodeships that need more charging stations

3.1. K-means

First, the clustering algorithm, K-means, was used to solve the problem [Sinaga and Yang, 2020; Jung et al., 2014]. The goal of this algorithm is to minimize the total within sum of square.

The algorithm includes the following steps:

1) fix the number of the cluster, K;
2) select K random points as centroid;

3) assigning each point to the nearest centroid and recompute them;
4) doing that until a stop condition occurs (like number maximum of iterations).

To choose the number of K, some indices were used like the "ch", "ratkowsky", "mcclain", "gap", "silhouette" [Charrad et al., 2013]. Trying with K=2 and K=3, better considerations were made with K=3. And then some measures of validation were adopted to assess the quality of the clustering. The results are shown in Figure 1.

Fig. 1. Results from K-means

Source: own elaboration.

Interesting results are obtained with K-means, fixing the K=3. There is a cluster with one element that is the element with the highest value of any variable, except for the density of the population, and it is the Mazowieckie voivodeship. This suggests that this voivodeship is very suitable to have the highest number of charging stations for electric vehicles.

Then there are other two groups, one with high value of the variables related to the population, number of shops and number of petrol stations, and the other one with low value of the same variables. The other variables are not that discriminating. In the first group there are the following voivodeships: Dolnośląskie, Łódzkie, Małopolskie, Pomorskie, Śląskie, Wielkopolskie. The second group consists of the Kujawsko-Pomorskie, Lubelskie, Lubuskie, Opolskie, Podkarpackie, Podlaskie, Świętokrzyskie, Warmińsko-Mazurskie, Zachodniopomorskie voivodeships.

In summary, it can be concluded that the Mazowieckie voivodeship should have the largest number of charging stations. Moreover, the voivodeships of the first group are also areas where it may be appropriate to locate many charging stations.

3.2. Validation of K-means

Because of to apply the supervised measure of validity a label of the data is needed, that is the real group to which the single element belongs, only unsupervised measures of validation were used.

For the K-means the following elements are analysed: the correlation coefficient between the actual similarity matrix, that is a matrix that explains the similarity between the elements, and the ideal similarity matrix, that is a matrix that contains only zeros and ones (zero if the elements are in a different group and one if they are in the same). The coefficient in the analysis is equal to 0.628, that it means a correlation of the 62.8% between the two matrices. The clustering is not so good, but it should be noticed that the dataset is limited and this influences negatively the analysis.

3.3. Hierarchical algorithm

In the next step, another clustering algorithm to find more information about the dataset was used. A hierarchical algorithm was applied that returns a hierarchy, a set of nested clusters [Murtagh and Contreras, 2011]. Then, using some indices and visualizing the results, it is possible to choose the cut level of the hierarchy. Before that, the right linkage method to build the hierarchy was selected. It was chosen the linkage method with the highest value of the cophenetic correlation coefficient. The results are shown in Figure 2.

Fig. 2. Results from hierarchical algorithm

Source: own elaboration.

For the analysis of the dataset, it was chosen to have three clusters, since some indices, like the "ratkowsky", "ch", "mcclain", "gap", "pseudot2", give two or three. Having three clusters is better than two, since with only two clusters, the algorithm gives one cluster with one element and the other one with all the elements minus one, the possible consideration would be the same of the K-means. With three clusters, the algorithm gives two clusters with one element for each and another with all the elements minus one. Practically it finds an element, the Śląskie voivodeship that is the one with the highest value of the density of population, that could get more attention, since the K-means encompassed this element with others, without finding differences with other elements.

3.4. Validation of hierarchical algorithm

For the hierarchical algorithm, the only unsupervised measure of validity is the CPCC, and it has a good value in the analysis, a value of 0.918 for the average method that was chosen to apply it.

Conclusions

The clustering algorithm applied are approaches that help to find groups in which the elements are similar among them. The K-means is well suited to tasks such as zoning [Weatherill and Burton, 2009]. But it is used in a huge number of application and different topics, achieving the same result: finding group of elements that share the same characteristics [Oyelade et al., 2010]. The main problem for every analysis of that algorithm is to find the optimal K. Looking for some indices and looking at the results obtained with different K, whoever is conducting the analysis will be able to choose the right K.

Hierarchical algorithms are also used in tasks of zoning, for example dividing maps by the main parameters of seismic activity and by the number of earthquakes and magnitudes in a certain area [Tiutiunyk et al., 2019]. Even if with other linkage method, that for sure it depends on the situation to analyse.

As shown in the article, the described methods can be used to identify areas there more charging stations should be located. Future analyses may concern the application of methods not only to voivodeships, but also to smaller areas.

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Określenie zapotrzebowania na stacje ładowania samochodów elektrycznych na przykładzie polskich województw

Streszczenie

Głównym celem artykułu jest wskazanie obszarów, na których powinno być zlokalizowanych więcej stacji ładowania, na przykładzie polskich województw. W kolejnych częściach artykułu dokonano przeglądu literatury dotyczącej rozwoju infrastruktury ładowania pojazdów elektrycznych, a także metod i modeli proponowanych w literaturze do określenia lokalizacji stacji ładowania samochodów elektrycznych. Następnie zaprezentowano modele identyfikujące polskie województwa, w których należy zlokalizować więcej punktów ładowania. Analizę przeprowadzono na danych dotyczących województw, ze względu na trudności w znalezieniu bardziej szczegółowych danych odnoszących się do mniejszych obszarów. Celem przeprowadzonych analiz było sprawdzenie, czy istnieją województwa, w których należałoby zlokalizować większą liczbę punktów ładowania samochodów elektrycznych. Wyniki mogą być wykorzystane np. przez rząd do lepszego kierowania środków ekonomicznych na rozwój infrastruktury. Przeprowadzono analizę eksploracyjną przy użyciu wybranych algorytmów grupowania. W artykule wykorzystano algorytm hierarchiczny oraz grupowanie metodą k-średnich.

Słowa kluczowe

samochody elektryczne, stacje ładowania, zapotrzebowanie, model, Polska, województwa