Current and future energy refilling stations in motor vehicles, problems and effects of replacing internal combustion vehicles with electric ones

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Abstract. The paper deals with changes in construction and operation that would have to take place at a petrol station located in Wrocław next to one of the shopping malls in the event of replacing internal combustion vehicles with electric ones. In addition, it was estimated to what extent the photovoltaic panels placed on the gallery roof can relieve the energy supplier's network. By modeling the expected electric vehicle system in the years 2025-2030, efforts were made to identify potential barriers to its operation on the assumed scale by referring to the operation of electromobility in countries where this system became popular. The launch of a group of a dozen large charging stations in the city will allow the operation of the electric vehicle system in the amount assumed for the years 2025 - 2030, but will force a significant demand for electricity. Generation of electricity from RES will be enough to meet the needs of charging electric vehicles in Poland in the assumed time horizon, i.e., until 2040. Demand for vehicle charging power may cause problems with its availability in the system in the absence of implementation of the incentive system for vehicle charging off-peak hours.

Keywords: electric vehicles, charging stations, energy distribution system

1. Introduction
At the end of July 2020 the 13,057 electric cars were registered in Poland, which could be charged at 1,224 charging stations [1]. Scenarios for the development of the electric vehicle market in Poland included in the "Polish EV Outlook 2020" report [2] assume, that the number of all-electric vehicle (BEV) may reach 280,000 units in 2025 and nearly 900,000 units in 2030, assuming the active support of the state. The implementation of the development of electromobility in Poland requires, inter alia, construction of charging stations for electric cars. In order to ensure the mobility of vehicles in the amounts assumed above, approx. 9,000 people would be needed to operate electric vehicle charging stations in 2025. Adopting the same relationship of the number of charging points to the number of vehicles which operate in the UK [3], the Polish EV Outlook 2019 report assumes that the number of charging points installed in public stations will increase from the current 2,100 up to 40,000 points in 2025 and 91,000 in 2030.

2. Methodology and problem to be solved
The paper tries to outline the problems related to the development of the electric vehicle market in Poland and the effects of this development on the operation of the power system. By modeling the
expected electric vehicle system in the years 2025-2030, efforts were made to identify potential barriers to its operation on the assumed scale by referring to the operation of electromobility in countries where this system became popular.

To show the scale of the problem related to the implementation of plans to replace internal combustion cars with electric vehicles, the article presents an example in a microscale. The situation of the possibility of replacing the refueling of internal combustion vehicles with the charging of electric vehicles was illustrated. The calculations assume charging the vehicle battery with a battery capacity of 60 kWh from 20 - 80% with a 150 kW charger [4].

3. An example in a microscale
The refueling of an internal combustion vehicle without payment formalities takes about 1 minute (the distributor provides the flow rate 40 [l/min]). At the same time one has to consider, that presently the charging of the individual electric car takes the long enough time to refill 30 internal combustion vehicles. That is why, among others, promoters of e-mobile solutions assume a significant increase in the number of stations and charging points in relation to the currently existing network of petrol stations of about 7,700 units [5].

Below is a simulation of the "substitutability" of a petrol station with a charging station, which may consist of charging points located in the car park of a shopping mall. The basic parameters of the charging station are summarized in the table below:

| Table 1. Charging station parameters |
|--------------------------------------|
| Parameters                            | Data   |
| Capacity of a single charging point   | 150 [kW] |
| Charging time                         | 0.3 [h]  |
| Energy stored                         | 48 [kWh] |
| Number of charging points at the station | 16 [pcs.] |
| Capacity installed                    | 2.4 [MW] |

During the charging process, approx. 5% of the energy is lost by the charger. After charging time of 20 minutes with full power, the energy gain in the vehicle's batteries will reach about 48 kWh.

3.1. The actual daily capacity of the petrol station and the theoretical daily capacity of the battery charging station

The table below shows the possible daily number of refueled vehicles (6 vehicles per hour are refueled from one dispenser x 8 dispensers; 16 charging points provided with electric connectors were established for charging stations) at an average fuel station and compared it with the possible number of vehicles being charged at the same time on the same surface. Vehicle ranges were estimated on the basis of information on fuel consumption by compact vehicles and vehicle range [6].

| Table 2. Operation of the petrol / charging station |
|----------------------------------------------------|
| Petrol station / charging station                  | Fuels | Electricity     |
| Daily number of vehicles in pcs.                  | 1152  | 1140            |
| Sale of fuel / energy per vehicle                  | 21 [l] | 48 [kWh]         |
| Daily fuel sales                                  | 24 192 [l] |
| Daily sales of electricity                        | 54 720 [kWh] |
The above list shows that to fully replace the petrol station in terms of the number of vehicles charged on the same station area, the 16 charging points are needed (8 in the station + 8 in the gallery garage). To ensure full freedom in the operation of the system for electric vehicles, we would have to assume that the necessary power capacity at such a station may be as high as 2,400 [kW]. Such high power may prove to be a difficult barrier for the energy supplier, which will force higher operating costs of the entire system. Additionally, it should be remembered that currently the average electric vehicle with batteries with a capacity of 60 [kWh] has a range of approx. 300 km, which is almost twice as short as a combustion vehicle. This will force the necessity to charge the vehicle's batteries more often than refueling a combustion vehicle.

The problem of charging the right amount of electric vehicles can be solved by increasing the power of chargers or the number of charging points. Both of these methods lead to an increased demand for power. The graph below shows the time needed to charge a vehicle at a specific charging capacity. The capacity of home chargers is 2.3kW, free charging posts for alternating current (AC) ranges from 6.6 kW to 20 kW and fast chargers for direct current (DC) from 50kW [7].

![Charge time h / battery 48kWh](image)

**Figure 1.** Vehicle charging time in relation to the used charger power, own elaboration

Only charging the vehicles with a power charger with capacity 50kW, which is becoming a standard at petrol stations and commercial charging stations, allows for a short-term 1 - 0.2 hour supplementation of energy necessary for longer vehicle operation.

### 3.2. Using the roof surface and sunny walls of a shopping mall to generate electricity

In order to support the energy distribution system with the power necessary to charge the vehicles, a photovoltaic power plant was designed in the shopping mall area adjacent to the petrol station. The area of the roof and sunny walls is approximately 16,000 m2. Basic installation parameters are presented in the table below:

| Photovoltaic power plant installation | Data                  |
|--------------------------------------|-----------------------|
| Installation area                    | 16 000 [ m² ]         |
| Number of panels                     | 2112 [pcs. ]          |
| Panel capacity                       | 350 [W]               |
| Installation capacity                | 739 [kW]              |
| Annual energy production             | 739 [MWh]             |
| Average energy production per day    | 2 025 [kWh]           |


4. Future solutions implemented now

4.1. Examples of photovoltaic power plants on the roofs of shopping malls in PL and Europe

![Photovoltaic panels on the shopping Silesia City Center roof](image1)

The largest photovoltaic power plant currently installed in Poland in a shopping mall has a nominal capacity of 40 kW. During the year, the installation produces about 40,000 kWh of electricity, which is used by ventilation and air conditioning systems. Silesia City Center.

One of the largest solar installations at a mall in Meadowhall, Sheffield, UK, produces 770,000 kWh of clean energy per year from 3,418 solar panels.

4.2. Electricity charging hub

![An example of a modern charging station](image2)

Ekoen opened the first demonstration station in Nowy Kisielin with a 1 MW connection and 350 kW quick charging points. This is an example of a concept where electricity charging hubs resemble modern gas stations, not individual stations located in many places in cities. They can play an important role in the electric car power system.

5. Operation of charging stations in a city the size of Wrocław, taking into account the possibility of energy distribution

There are 14 shopping malls in Wrocław with similar parameters to the one described above. The corresponding number of charging stations will supply up to 15,960 electric vehicles per day.
**Table 4.** Calculation of energy demand for vehicle charging stations and its share in total consumption

| Description                                      | Data            |
|--------------------------------------------------|-----------------|
| Number of charging stations                      | 14 [pcs]        |
| Daily number of vehicles                         | 15960 [pcs]     |
| Battery charging                                 | 48 [kWh]        |
| The amount of energy needed to charge the vehicles| 766.08 [MWh]    |
| The necessary charging power capacity            | 33.6 [MW]       |
| Annual use of electricity consumption for charging| 279.6 [GWh]     |
| Annual use of electricity consumption provided by Tauron SA for Wroclaw | 2388 [GWh] |
| Share of charging stations in the city's energy consumption | 12% |

Wrocław's current demand for electricity is 2,388 GWh. The amount of electricity needed to power such a number of vehicles accounts for approximately 12% of the energy supplied by Tauron SA.

The plan for the supply of heat, electricity and gas fuels for the area of the Wrocław Commune "adopted by the city" for the years 2020 ÷ 2035 assumed that the increase in electricity demand would take into account the development of electromobility in the city. The forecasted demand for electricity, covering the needs for public transport, the fleet servicing the City Hall and its related companies, and the network of publicly accessible charging points, was estimated at ~ 21MW [8]. These values are similar to those adopted in the presented model.

6. **Determination of the adequacy of the potential of energy generated from renewable energy sources for charging electric vehicles in Poland.**

The power generated in Poland from photovoltaic panels will amount to 2.5 GW in 2020, and 7.8 GW in 2025. According to the assumptions of the Polish Energy Policy, the installation potential is estimated at 16 GW by 2040. This means that in 2025 the production of electricity from photovoltaic power plants may amount to 7.8 TWh, and in 2040 16 TWh. Assuming that in 2025 there will be 1 million electric cars in Poland, the demand for energy will amount to 4 TWh. In 2040, with 10 million EV in operation, the energy demand will be 40 TWh. Adding wind farms to FV, the potential of which is currently 6.4 GW, energy production 14.3 TWh, in 2025 it will be 7.0 GW, production 15.0 TWh, and in 2040 11 GW of capacity and 24 TWh production [9]. Production from renewable energy sources is enough to cover the demand generated by electric vehicles in Poland.

7. **The problem of availability of power capacity for charging electric vehicles at the country level**

In line with the Strategy for Responsible Development in 2025 on Polish roads has to ride 1 million electric vehicles [10].

According to the authors of the study [11], from the point of view of the National Power System, the increase in energy demand caused by the commissioning of one million electric vehicles will amount to approx. 5% of electricity produced in Poland, ie 4.41 TWh. The author of a similar analysis [12] also recognizes that even a large increase in electric vehicles in road transport will result in a rather moderate demand for additional generation capacity, assuming that energy companies will have some control over the mode of charging cars. The calculations of this model assume no restrictions in the transmission network.

The lack of economic incentives to charge during off-peak hours can lead to an unstable energy system in a country by increasing the gap between peak and off-peak electricity demand in the country. A significant problem is the availability of adequate electric power capacity, which must be supplied with the use of the DSO infrastructure.
Conclusions
1. You need 16 charging points instead of 8 dispensers to handle the same number of cars. Additional charging points can be found in the parking lot of the shopping mall.
2. The power demand under the maximum load situation is 2.4 MW for one large charging station.
3. Support for a photovoltaic installation built in a shopping mall is an average of 4% of the station's energy demand, but in sunny hours it may be up to 25% of the charging station's demand.
4. The launch of a group of a dozen large charging stations in the city will allow the operation of the electric vehicle system in the amount assumed for the years 2025 - 2030, but will force a significant demand for electricity.
5. Generation of electricity from RES will be enough to meet the needs of charging electric vehicles in Poland in the assumed time horizon, ie until 2040.
6. Demand for vehicle charging power may cause problems with its availability in the system in the absence of implementation of the incentive system for vehicle charging during off-peak hours.

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