

Energy analysis of charging infrastructure for electric vehicles on the TEN-T road network

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Abstract. Electromobility is a European vision of future motorization. In Poland, there are plans to introduce a million vehicles of this type by 2030. Currently, their share is marginal (about 1 percent). This vision is to be made real. This is due to the fact that vehicle manufacturers are developing newer EV vehicle constructions. Increasing the number of electric vehicles requires the development of their charging infrastructure. Based on the work of the authors regarding the EV vehicle charging network on the Trans-European Transport Network road network, it was possible to extend this issue with energy calculations related to energy demand for supplying the EV vehicle charging network. This is an important topic from the point of view of the State's energy needs. The calculations made in the article present the problem of the need to increase the production of electricity, which in the case of Poland is associated with increased emissions of harmful substances and the possibility of periodic interruptions in the supply of electricity. Due to excessive domestic consumption with too little production. The second issue is the need to supply electricity to the charging station (infrastructure), as well as transmission losses, which limit the possibility of building multi-station fast charging stations. The issue presented by the authors in this article is one of the key problems relating to the introduction of electromobility in Poland. The key is to determine how large the demand for electricity in the country will be if a greater number of electric vehicles is put into operation. Considering that there are power shortages during a hot summer, this may affect the possibility of using electric vehicles in the country.

1 Introduction

The first attempts to work on electric vehicles began around 1800. Their popularity was significant until 1900. In later years they were supplanted by vehicles fueled with conventional fuels [10].

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Electric vehicles have been considered as vehicles for everyday use for about 5–6 years. This is the result of an increasing number of vehicles in the world, and thus a significant increase in emission of harmful exhaust gas, which in the end has negative impact on the natural environment and human health. These aspects combined with shrinking resources of oil-derived fuels have contributed to the intensification of works on alternative drives and fuels in transport [11–13, 17, 18].

According to the IEA report, the number of electric vehicles (BEV), hydrogen vehicles (FCEV) and plug-in hybrid (PHEV) on global roads in 2017 reached 3.1 million copies (an increase of 54% y/y). In 2017, more than 1 million electric cars were sold in total (54% more than in 2016), half of which (580 thousand) in China. The second place was taken by the United States with a result of 280.000 vehicles [14].

On the roads of the Middle Kingdom, there are currently 1.23 million electric vehicles (40% of the global EV fleet), in Europe 0.82 million, in the US 0.76 million, while in the rest of the world – 0.3 million. In 2018, the largest EV share in the new vehicle market was recorded in Norway (39.2%), Iceland (11.7%) and Sweden (6.3%). China (2.2%), Germany (1.6%), USA (1.2%) and Japan (1.0%) ranked next [14].

It is assumed that electric vehicles will be one of the most important pillars of the automotive industry. The development of this type of vehicle now allows the assumption that in the medium-term, i.e. until 2030, they are to account for around 30–35% of all vehicle sales in the world. For this plan to be accomplished their market share must be increased. In addition to convincing customers to purchase vehicles, it is also necessary to provide the right infrastructure. In the case of these vehicles, a network of vehicle charging points must be built to ensure that the vehicles' batteries are charged to 80% within 30 minutes or faster [9]. In Poland, there are currently over 300 generally available charging stations for electric cars – according to the estimates of the Polish Alternative Fuels Association (there are about 100.000 in Europe). The largest operator in Poland is Greenway. At the end of 2017, the company had 33 own charging stations (32 fast and one accelerated AC) and 4 partner stations. Now, 78 own and 15 partner stations operate in the Greenway network, which in total gives 83 [15, 19, 20, 21].

2 Electric vehicles range

Several models of electric cars are available on the market. Currently in Poland, despite an extensive promotion of electric vehicles, their sale is still insignificant. It represents less than 1% of the sales of all vehicles on the market. The number of purchased copies in the years 2015-2018 is presented in Table 1.

The vehicles offered so far have a fairly diverse range. It is largely dependent on the capacity of the batteries used. Based on the range of available electric vehicles, it is possible to determine the average mileage that vehicles can pass in a mixed cycle with fully charged batteries (table 2) [2–5]. It should be noted that the values given are those declared by the producers. In real traffic conditions, they can be much smaller.

When calculating the average range of electric vehicles available in Poland, vehicles such as Tesla Model S, Hyundai Kona Electric (extended range) and Nissan LEAF with 62 kWh battery are not included. These vehicles were rejected due to the much wider range, which would affect the overall average range of these vehicles included in the analysis. If the above vehicles had not been rejected, the average range for other available electric vehicles would increase significantly.

Based on the collected data, it has been determined that the average mileage of electric vehicles available in Poland is about 175 km. On this basis, further calculations presented in this work were performed.

Table 1. Number of electric vehicle registrations in the country in the years 2015–2018 [1].

Model	2015	2016	2017	2018	Summary
BMW i3	67	32	117	164	380
Nissan e-NV200	9	3	21	10	43
Nissan LEAF	24	8	239	269	540
Tesla Model S	21	4	40	20	85
Tesla Model X	–	–	31	33	64
Volkswagen Golf	1	3	13	41	58
Volkswagen up!	1	3	2	1	7
Renault ZOE	–	–	11	49	60
Other	–	–	10	50	60
Summary on the market	123	53	484	637	1297

3 TEN-T transport routes

The Trans-European Transport Network (TEN-T) is an instrument for coordinating and ensuring coherence and complementarity of infrastructure investments [6].

As a result of the revision of the TEN-T guidelines completed in 2013, a new agreement has been established in the territory of the EU Member States. This system includes a core network that underpins the development of the transport network on which EU activities are to focus, in particular on cross-border sections, missing links, multimodal connections and major bottlenecks, and a comprehensive network ensuring the availability and connectivity of all EU regions [6].

The trans-European TEN-T transport network includes [6]:

- road, rail, air, sea and river routes constituting the most important connections from the point of view of the development of the European Union,
- point elements of infrastructure in the form of sea, air, inland and road-rail terminals.

Its integral component is also intelligent transport systems, the implementation of which contributes to the improvement of network capacity, traffic safety and reduction of environmental pollution by transport [6].

The aim of developing the TEN-T network is to ensure territorial cohesion of the EU and to improve free movement of people and goods. An efficiently functioning transport system within the European Union is to contribute to the improvement of the operation of the single internal market, to stimulate the region's economic growth and to increase the competitiveness of individual Member States and the entire EU on a global scale [6].

The objective of EU policy in the context of the development of the TEN-T network is to create a coherent and interoperable, multimodal transport network with uniform, high technical parameters throughout the European Union [6].

Because of the nature of the work, the article focuses only on road transport. According to [7] for the TEN-T base network in Poland in 2010, roads in the Baltic-Adriatic corridor, the average traffic volume was 13,284 vehicles /day, while roads located in the North Sea-Baltic corridor 10,876 vehicle per day. On national international roads, by far the largest traffic load, amounting to over 35 thousand vehicles/day (including almost 24,000 passenger cars daily), was noted in the Śląskie Voivodship, followed by 26,513 vehicles/day (including 17,764 passenger cars/day) in the Opolskie Voivodeship. High traffic load, amounting to more than 20,000 vehicles/day (including over 13,000 passenger cars/day), was also recorded in the following provinces: Małopolskie and Mazowieckie [7].

On the remaining national roads, by far the largest traffic, with over 11,000 vehicles/day (including 8,214 passenger cars/day), was noted in the Śląskie Province. Very high load on the network of other national roads, amounting to more than 9,000 vehicles/day (including over 6,000 passenger cars/day), also occurred in the following provinces: Małopolskie and Wielkopolskie [7].

The traffic forecast for 2020 was developed for the state of the national road network in 2015. The assumption was made that no changes will take place therein and there will be no significant factors that may affect the changes in traffic behavior [7, 8].

According to [8], the highest road load according to the adopted forecast will take place around the largest urban agglomerations in Poland (including Warsaw, Katowice and Kraków, Poznań, Wrocław, Trójmiasto), where the average daily traffic volume is expected to exceed 20 thousand vehicles [7].

4 Proposal to deploy charging stations for electric vehicles at the TEN-T transport routes

On the basis of TEN-T transport routes and traffic forecasts on national roads in 2020, developed by GDDKiA, it was possible to determine road sections of the largest and most significant importance. These roads include, among others national road no. 7 (Tricity–Warsaw–Krakow), A1 motorway (Tricity–Łódź), A2 motorway (Warsaw–Frankfurt/Oder), A4 motorway (Świecko–Kraków), express road S8 – A1 motorway – national road 1 (Warsaw–Katowice) or national road 17 (Warsaw–Hrebennie).

Based on the above it is proposed to deploy fast charging stations for electric vehicles. The distance between the charging points was calculated based on the average range of electric vehicles and the possibility of charging electric vehicles. The exact calculation of the distance between the charging stations is shown in Table 2.

Table 2. Calculating the distance between electric vehicle charging stations.

	Range
The average range of electric vehicles when the batteries are 100% charged	175 km
The average range of electric vehicles when the batteries are 80% charged	140 km
Current reserve in 15% batteries	26 km
5% safety factor	~9 km
Distance between electric vehicle charging stations	~110 km

Based on the calculated distance between the charging points, it was possible to determine the minimum number of charging stations for electric vehicles on routes within TEN-T.

The suggested proposal comprises the construction of a quick charging station on the forecasted main transport routes in the country. Considering the assumptions regarding the

distance between fast loading points and analyzing the possibility of their location and considering the current road infrastructure in the country (intersections, interchanges, road type), it was possible to determine the minimum number of charging points on individual routes (Świecko–Suwałki –14; Trójmiasto–Kraków – 12 ; Trójmiasto–Łódź – 6; Łódź–Wrocław – 6; Katowice–Rzeszów – 4; Warszawa–Hrebenne – 6; Warszawa–Katowice – 6; Warszawa–Katowice – 6; Warszawa–Kraków – 6; Overall – 60).

Taking into account such variables as the location and infrastructure of given road sections, it was possible to determine the number of fast charging points for electric vehicles. Their minimum number is 60 points. With such infrastructure it will be possible to use electric vehicles on roads within the TEN-T transport routes and constituting road sections that will be heavily loaded in the perspective of 2020, without worrying about the lack of space for charging vehicles.

5 Energy demand of an electric vehicle

The demand for electricity is growing in Poland. According to the available information, in 2017 more than 170 TWh of energy was produced in the country. It is 2.2% more than in 2016. Table 3 presents the division of electricity production from various sources for years 2016–2017.

Table 3. Electricity production in Poland [16].

Specification	2016	2017	Change
	GWh		%
Total production	166 597	170 335	+2.2
Thermal power stations	140 378	140 259	–0.1
- brown coal	51 082	52 281	+2.3
- coal	80 173	79 265	–1.1
- gas	5 604	6 161	+9.9
- biomass/biogas	3 519	2 552	–17.5
Hydroelectric power stations	2 335	2 719	+16.4
- including pumped storage	482	474	–1,6
Wind power stations	2 981	3 485	+16.9
Industrial power plants	9 897	11 417	+15.4
Independent power plants – renewable energy installations	11 006	12 454	+13.2

On the basis of own tests of an electric vehicle in real traffic conditions, it was possible to determine its average energy consumption. Then it was determined with the assumption of daily runs (about 60 km), what would be the energy demand of one vehicle and energy costs related to it (Table 4).

Table 4. Annual energy consumption needed to recharge the batteries of one vehicle.

Specification	
Daily mileage on business days	60 km
Daily mileage on Sundays and holidays	60 km
Annual mileage on business days	15 060 km
Aaily mileage on Sundays and holidays	6840 km
Total mileage	21 900 km
Price 1 kWh for a household (G11 tariff)	0,55 zł/kWh
The cost of charging one vehicle a year	2529.45 zł
Annual energy consumption needed to recharge the batteries of one vehicle	4599 kWh

Next, the results of the annual electricity consumption needed to charge the batteries of one electric vehicle were referred to the assumed introduction in Poland of a million electric cars. On this basis, the annual energy consumption needed to recharge the batteries of one million electric vehicles could be determined (Table 5). Next, the percentage of energy demand in the country will be estimated.

Table 5. Energy demand for powering electric vehicles.

Specification	
Annual energy consumption needed to recharge the batteries of one electric vehicle	4599 kWh
Annual energy consumption needed to recharge the batteries of a million electric vehicles	4,599 TWh
A change in energy demand while supplying a million electric vehicles	+2.7%

Calculations show that with one million vehicles the energy demand of the country will increase by 2.7%. This is not a significant change with regard to the energy demand in the country in 2017, which amounted to over 170 TWh. One can say that the only problem is the time of charging electric vehicles. It is best for financial reasons that this process takes place at night. The tariff adopted for the purpose of the calculation is a tariff applicable to households (G11) and amounts to 0.55 PLN/kWh. With this assumption, the annual costs relating to the charging of an electric vehicle amount to PLN 2529.45. With regard to conventional vehicles, this is a significant difference at the moment.

6 Infrastructure for charging electric vehicles on the TEN-T road network

On TEN-T routes, the so-called quick chargers for electric vehicles are logical. There are currently 55 kWh variants. On this basis, it is possible to calculate the energy demand assuming that all specified stations are simultaneously used (the so-called black scenario). The above calculations showed that a sufficient number of stations on the TEN-T road network is 60 points. Considering the number of electric vehicles registered in the country (table 1), at each point there should be four stations for simultaneous charging of electric vehicles. This gives an overall ability to load 240 vehicles simultaneously in the country (table 6).

Table 6. The number of charging points for electric vehicles.

Specification	
The number of charging points for electric vehicles on TEN-T transport routes	60
Number of stands at each charging point	4
The total number of electric vehicles that can be recharged	240

With such a large number of stations and the assumption that electric vehicles on routes will be loaded within 30 minutes (battery charging up to 80%), the energy demand to power fast chargers can be determined. Once these values were determined, it was possible to determine daily and annual energy demand (Table 7).

Table 7. Energy demand for supplying fast chargers (55 kWh) for powering the batteries of electric vehicles.

Specification	Change
Hourly energy demand of fast chargers	55 kW/h
Energy demand of fast chargers for charging electric vehicle batteries in 80%	27.5 kW/h
Individual energy demand	6.6 MWh
Daily energy demand	0.3168 GWh
Annual energy demand	115.632 GWh

7 Conclusions

The proposal to build fast-charging points for electric vehicles on roads belonging to the TEN-T transport routes and constituting road sections that will be heavily loaded in the perspective of 2020, allowed to determine that to move the above-mentioned it is necessary to build 60 charging points for the type of vehicle. Other conclusions are:

- the proposal to build fast-loading points for vehicles would already allow the operation of available electric vehicles on the main transport routes,
- taking into account the proposal to build charging points on the main transport routes and the assumed development of electric vehicles (increasing their range) will enable further development of the network of charging points beyond the main transport routes,
- the development of the network of charging points can have a significant impact on the popularization of electric vehicles, and thus reduce the emission of harmful substances from transport,
- the increase in the energy load associated with the increase in the number of electric cars amounting to 2.7% will have insignificant environmental importance, considering lower consumption of petrol due to the limitation of the use of cars with an internal combustion engine.

References

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