ANALYSIS OF DISTRIBUTION OF ELECTRIC VEHICLE CHARGING STATIONS IN THE BALTIC

Dainis Berjoza, Inara Jurgena
Latvia University of Agriculture
dainis.berjoza@llu.lv, inara.jurgena@llu.lv

Abstract. Fast growth in the number of electric vehicles has been observed in recent years. Possibilities to purchase electric vehicles and the availability of various structural solutions increase. The exploitation of electric vehicles requires charging stations that can be very diverse in terms of structural and technological design. In Estonia and Latvia, projects to establish electric vehicle charging stations were implemented, thus popularising zero-emission vehicles and expanding zero-emissions mobility. The paper analyses the development trends for electric vehicles and charging stations in the Baltic States. It also provides a classification of charging stations needed for electric vehicles in the Baltic and an analysis of their present locations. If exploiting a small number of electric vehicles in a country, the best option for charging vehicles is garages and technically simple and cheap charging stations, thus making the construction of charging stations cheap; however, other kinds of charging vehicles can be useful for expanding mobility by electric vehicles.

Keywords: electric vehicles, electric automobiles, charging stations, batteries, charging time, charging voltage.

Introduction

The sharp increase in the consumption of non-renewable energy resources can result in their depletion. For this reason new kinds of energy, which could be used for vehicles, are sought. One of these kinds of energy is electricity, the use of which became more popular at the beginning of the 21st century. Electromotors in automobiles is not anything new; the idea is more than a century old, as electric automobiles have been used since the beginning of the 20th century [1]. Yet, owing to their heavy batteries and small kilometrage per charge, electric automobiles lost their competitiveness against those equipped with internal combustion engines.

After inventing new, much lighter and greater-capacity batteries, the idea of electric mobility has become popular again. Initially, electromotors were used in hybrid automobiles. Toyota’s hybrid car Prius was among the first ones. Presently, hybrid automobiles are in the assortment of almost any auto manufacturer. Nevertheless, most hybrid automobiles had no possibility to be charged from a power socket. This possibility emerged only after introducing plug-in technology and a hybrid automobile can be charged from a socket and driven using only its electromotor. Plug-in hybrid automobiles and electric automobiles, as well as other electric vehicles require charging stations that can ensure full exploitation of such vehicles.

An electric vehicle charging station has to meet the following demands:

- it has to be appropriate for all vehicles exploited in the particular region. The charging station has to be relatively easy and comfortably to adapt to other charging plugs and sockets;
- its design has to be ergonomic, the charging station has to have a possibility for easy parking of electric vehicles, so that electric vehicles with charging sockets installed in various places can be charged;
- its structure has to meet the electrical safety and human protection standards;
- the charging station has to meet its owner’s requirements, for instance, payment options or free-of-charge charging;
- the structure of the charging station has to be simple and easy to understand for its users;
- geographically, the charging station has to be located where it is needed and easy to use in order to ensure relatively high mobility of electric vehicles.

What has to be done first – a comprehensive network of charging stations of various kinds has to be developed or purchasing electric vehicles has to be stimulated – it is still an urgent problem. An optimum option, of course, is to implement both these national projects simultaneously; yet, electric vehicles can do without public charging stations, for example, they can use private sector charging stations, whereas charging stations are not needed to anyone if there are no electric vehicles.

1. Researches on infrastructure for electric vehicles by other authors

Scientists of the Latvia University of Agriculture (LLU) have researched electric vehicle charging stations. They noted that 10 charging stations were operating in March 2012 in Latvia; in 7 of them their parking lot was fee-based, while in 3 it was free of charge, in 2 stations charging was priced, while in 8 stations charging was free of charge. On the whole, there were 44 charging stations in March 2012 in Latvia [2]. In the middle of 2012, only 2 electric lorries were exploited in Latvia [3]. Given the fact that a CCIF project aimed at fostering the development of charging stations was implemented in Latvia in 2014, the situation could have changed.

The LLU scientists conducted researches on potential prices of charging at various charging stations and classified charging stations as follows: charging at home, charging at closed enterprises, public slow-charging spots and public fast-charging spots. Electricity prices were analysed in 2012, and the prices were as follows: 0.1141 $EUR \cdot kWh^{-1}$ in Estonia, 0.1309 $EUR \cdot kWh^{-1}$ in Lithuania and 0.1074 $EUR \cdot kWh^{-1}$ in Latvia [1].

Electric vehicles can be charged at charging stations powered by solar photovoltaic panels, the composition and structural specifics of which have been researched by the LLU scientists. The scientists designed a 2 kW solar power station, as well as an algorithm for its placement in case it has not a solar tracking system. This is the first electric vehicle charging station in the Baltic that is powered by solar energy [4].

As regards electric vehicle charging stations, researchers mainly focus on researching charging algorithms [5], as the problem of power network load at the starting moment of charging is very acute – for many electric vehicles the charging current is very close to the socket nominal current.

Lithuanian scientists researched possibilities to introduce electric vehicles in Vilnius, designing three different algorithms. In establishing charging stations, the key criteria are as follows: size of automobile flow, population density and possibility to establish charging stations. Lithuania envisages that in 2020 electric automobiles will comprise approximately 3-10 %, while in 2030 in cities electric automobiles will account for about 40 % of the total automobiles. According to the scenarios developed, Vilnius will need 8-11 charging stations [6]. There are many researches available on whether charging a lot of electric automobiles can overload the power grid [7]. Such a situation can arise during a period when a lot of individuals start charging their electric vehicles at home after returning home at 6-7 p.m. and after their ride to work at about 9-10 a.m. With the present number of electric automobiles in Latvia, the power grid cannot be overloaded.

In-depth researches in and analyses of the geographic distribution of electric vehicle charging stations in the Baltic States have not been performed, therefore, it is useful to do it.

2. Kinds and historical analysis of charging stations

Charging stations for electric vehicles are necessary in any particular region if such vehicles are exploited in this region. A usual trend in the development of charging stations is the creation of a network of inexpensive charging stations in which charging is free of charge. With an increase in the demand for this service, a payment system may be introduced. *An electric vehicle charging station* may be defined as a parking lot for electric vehicles that provides the possibility to charge their batteries. If an analysis is done on a broader scope, not only the battery charging process for electric vehicles but also the issue of *energy replenishment* has to be considered. Energy replenishment is understood as not only this process at electric vehicle charging stations but also at battery swap stations in which this operation is usually performed by a robot. Other kinds of energy can also be used, for instance, one-phase 230 VAC, 32 A, charging time 3-4 h; three-phase 400 VAC, 32 A, charging time 1-2 h; and three-phase 400 VAC, 63 A, charging time 0.5 h. The most popular energy replenishment stations for electric vehicles are developed according to their uses:

- slow battery charging;
- fast battery charging;
- battery swap;
- medium fast charging.

Besides, the functions of charging stations may be executed at places of connection to a power network that are intended for other purposes, for instance, stations for electrical preheating of vehicle engines or electric connections at camp sites. Such electric outlets usually provide 230 VAC and a current of 16 A. In Latvia, the first electric vehicle charging stations were opened in Jurmala at the Energy Efficiency Centre on 15 May 2010 and at Riga Passenger Terminal in September. Since only electric bicycles, electric mopeds and a few low-speed electric automobiles were exploited in Latvia in that period, these stations were mainly suited for such vehicles and, globally, for tourists as well.

The first electric vehicle charging station meeting all the EU standards in Lithuania was opened by Lithuanian company Elinta next to the municipal building of Kaunas on 27 April 2011. A network of 165 fast-charging stations was officially opened in Estonia in February 2013 [8]. It was established based on a project of purchasing 500 electric automobiles for various government institutions implemented in Estonia in 2011 [8].

3. Geographic distribution and locations of charging stations in the Baltic States

As of 30 January 2015 in Latvia, charging stations were concentrated in four cities: Riga, Jelgava, Jurmala and Ogre. Presently in Latvia, there are 14 charging stations with 50 charging spots, of which 8 are intended for electric bicycles, while the rest are 16A 220 V slow-charging stations for electric automobiles. An analysis of their distribution by city reveals that 5 charging spots for electric automobiles and 3 for electric bicycles are located in the city and municipality of Jelgava. One charging station for electric automobiles is available in Jurmala and in Ogre. Riga has 33 charging spots for electric automobiles and 3 for electric bicycles. Based on the analysis, one can conclude that the charging stations are located in a radius of 50 km around the capital city of Riga and are mainly concentrated in Riga.

Fourteen charging stations are located in Lithuania. Seventeen electric automobiles can be simultaneously charged in these stations. All the charging stations provide slow charging through an outlet of 16 A 230 V, while 10 charging stations have an alternating current outlet of 32 A for fast charging. The distribution of charging stations by city is as follows: 5 charging stations with 8 spots in the capital city of Vilnius, 4 one-spot charging stations in Kaunas, 2 charging stations in Siauliai and one charging station in Klaipeda, Elektrinai and Vievis. It has to be noted that the very first charging station was opened in Kaunas rather than in the capital city.

The best distribution of charging stations is observed in Estonia. The national electric mobility programme ELMO has contributed to the fast development of stations. Estonia's government concluded a pollution quota sale contract with the Mitsubishi company in 2011. The programme involved exploitation of 507 electric automobiles Mitsubishi iMiev that were transferred to the Ministry of Social Affairs; the Ministry of Economics and Communication designed a support scheme for legal and natural persons to buy new electric automobiles. The support scheme for purchasing new electric automobiles has been in force since 2012. Five hundred electric automobiles could be bought under the programme ELMO. Since 2013, 163 fast-charging stations with 500 V 120A outlets have been available in Estonia. A financial assistance of 1000 EUR was granted for establishing a charging spot at home. In the period 2011-2014, 538 electric automobiles of various brands, using this support, were purchased in Estonia. The most popular were Nissan Leaf electric automobiles, 266 in total [9]. The average distance between charging stations is 40-60 km. A hundred of fast-charging stations were situated in cities, while 65 on main roads. Tallinn has 27 charging stations, Tartu – 10, Parnu – 5 and Narva has 2 fast-charging stations. The average charging time to reach an 80 % of the full battery capacity is 20-40 minutes.

Several payment packages are available for consumers in Estonia. The combined package costs 10 EUR. The cost per charge, which takes less than 1 h, is 2.5 EUR. With the package FLEX having no monthly fee, the cost of a 10-minute charge is 1.5 EUR, a less than 20-minute charge costs 3.0 EUR, while 4.5 EUR have to be paid for a more than 20-minute charge. The maximum package involves a monthly fee of 30 EUR for less than 150 kWh (a driving range of at least 1000 km). If the 150 kWh limit is exceeded, the cost per charge is 1.2 EUR. All charging devices have a fast-charging option, the standard CHAdeMO, as well as a slow-charging option, Type 2, with a Mennekes 22 KW plug.

One can convincingly suppose that among the Baltic States, the best coverage of charging stations is reported in Estonia. Travelling is possible in the entire territory of this country, performing fast-charging at charging stations. Based on the current technologies, Estonia has one of the best charging infrastructures in Europe. In addition, it is believed in Estonia that charging at charging stations is done from renewable energy sources.

4. Algorithm for calculating the characteristics of charging stations

An algorithm for calculating various comparable indicators has to be created to perform a comparative analysis of the infrastructure of charging stations. An important indicator is the ratio of the number of charging stations to the number of electric automobiles or the number of electric automobiles per charging station:

$$I_{EV} = \frac{N_{EV}}{N_{CP}}, \tag{1}$$

where N_{EV} – number of electric vehicles in the analysed region;
N_{CP} – number of charging stations in the analysed region.

It is useful to perform an analysis for the entire country and for individual geographic territories, for instance, a city. The smaller the indicator is, the better is the infrastructure for charging electric vehicles.

The number of people per charging station may be calculated as follows:

$$I_I = \frac{P}{N_{CP}}, \tag{2}$$

where P – the number of people in the particular region.

An important indicator is the ratio of average distance per charge to average distance between charging stations, which characterises a distance to be travelled to reach a charging station:

$$I_L = \frac{l_{EV}}{l_{CP}}, \tag{3}$$

where l_{EV} – average kilometrage per charge of electric vehicles, km;
l_{CP} – average distance between charging stations, km.

This indicator is the most important for travels outside the city and from a city to a city. If the ratio is grater than 1, travelling is possible in the analysed territory, whereas in case it is less than 1, an electric automobile will not be able to cover this road distance with one charge. The indicator $l_{CP} \approx N'_L$. Sometimes, to test the coverage of charging stations, the indicator l_{EV} is employed and circles are drawn, in scale, around the sites of charging stations. The circles have to overlap with the sites of neighbouring charging stations.

The average kilometrage per charge of modern vehicles is similar and reaches 150-160 km, yet, if electric vehicles with a different kilometrage per charge are exploited in the country, an average weighted range of electric automobiles can be calculated for the particular region:

$$l_{EV} = \frac{l_{EV1}N_{EV1} + l_{EV2}N_{EV2} + ... + l_{EVn}N_{EVn}}{N_{EV}}, \tag{4}$$

where l_{EV1} – average kilometrage of Group 1 electric vehicles, km;
l_{EV2} – average kilometrage of Group 2 electric vehicles, km;
l_{EVn} – average kilometrage of the n-th group electric vehicles, km;
N_{EV1} – number of Group 1 electric vehicles;
N_{EV2} – number of Group 2 electric vehicles;
N_{EVn} – number of the n-th group electric vehicles.

By integrating Formula 4 into Formula 3, one can obtain the following formula:

$$I_L = \frac{l_{EV1} N_{EV1} + l_{EV2} N_{EV2} + \ldots + l_{EVn} N_{EVn}}{l_{CP} N_{EV}} \qquad (5)$$

In the Baltic, 1-10 electric automobiles can be simultaneously charged in charging stations. The number of electric automobiles charged simultaneously in an analysed region is characterised by the average number of charging spots in the region charging stations:

$$N_{CPden} = \frac{N_{CA}}{N_{CP}}, \qquad (6)$$

where N_{CA} – number of charging spots in the region charging stations.

Based on the developed methodology, let us perform calculations of the most important indicators for Latvia, Lithuania and Estonia.

5. Analysis of the results

The basic data used in the calculations are summarised in Table 1.

1. table

Characteristics used in the calculations

Characteristic	Latvia	Lithuania	Estonia
Number of electric vehicles	194	69	1163
Number of charging stations	14	14	165
Number of charging spots	42	17	165
Population	2013000	2956000	1325000
Estimated distance to the nearest charging station, km	260	180	50
Average electric vehicle range per charge, km	130		

The numbers of electric vehicles per charging station and per charging spot are presented in Figure 1.

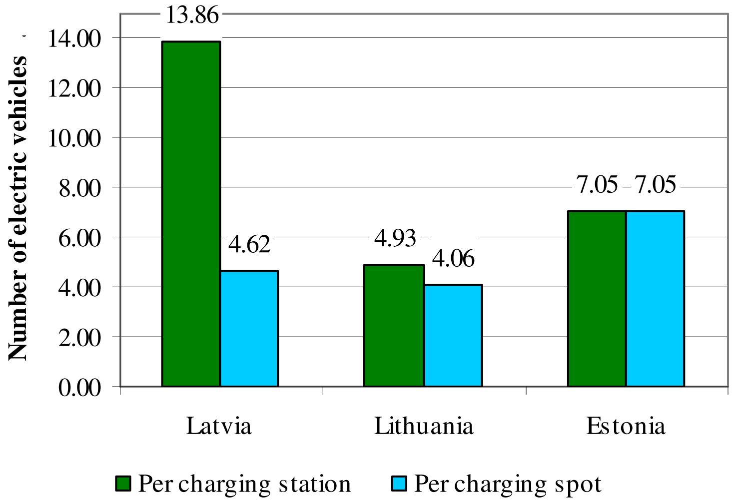

Fig. 1. **Number of electric vehicles per charging station and per charging spot**

Due to the facts that almost 200 electric automobiles were purchased within the CCIF project aimed at developing electric mobility in Latvia but the establishment of charging stations lagged behind because of inadequate standards, there were almost 14 electric automobiles per charging station in Latvia. If calculated per charging spot, the situation, just like in Lithuania, is good, i.e., 4-5 electric automobiles per charging spot. In Estonia, there are 7 electric automobiles per charging station. Yet, an analysis of an interactive map of charging stations in Estonia which shows whether a charging station is used or not reveals that the number of these charging stations is sufficient, as the number of stations being persistently used never exceeds 10 %. In Estonia, one fast-charging station can service 40-55 electric automobiles during 24 hours, while in Latvia it is only 3.

The number of population per charging station in the Baltic States is presented in Figure 2.

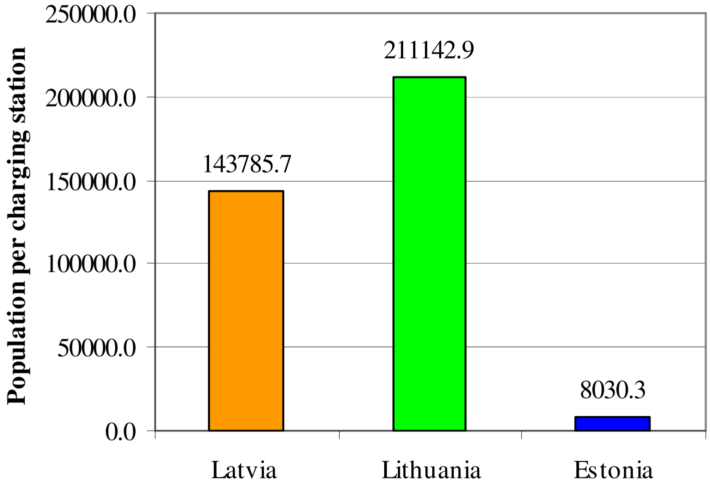

Fig. 2. **Population per charging station**

Estonia presented the best performance in terms of residents per station, 8.03 thousand, followed by Latvia with 142.7 thousand and, finally, Lithuania with 211.1 thousand. The availability of charging stations and the average number of charging spots per station are presented in Figure 3.

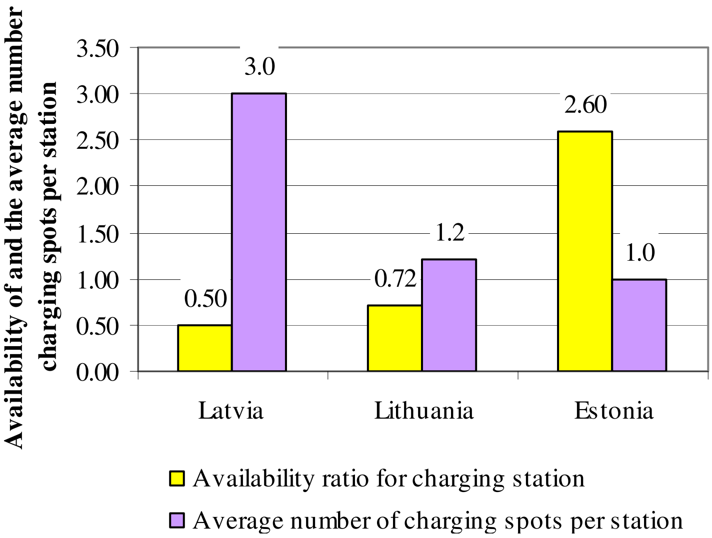

Fig. 3. **Availability ratio for charging stations and the average number of charging spots per station**

The availability ratio for charging stations in Estonia was the greatest, 2.6, in Lithuania it was satisfactory, 0.72, while in Latvia it was unsatisfactory, 0.5. This calculation assumed that the average driving distance of electric automobiles was equal to 130 km, and the possibility to get to the nearest station from the country's most remote locations was calculated; in case of Latvia – from Ludza town to Riga–, while in case of Lithuania – from Zarasai to Vilnius. Since Lithuania's charging stations are located in the vicinity of its main motor highway that stretches through the central part of the country, the availability of these charging stations in Lithuania is better than that of such stations in Latvia, and they can be actually reached from the greatest part of Lithuania's territory.

Conclusions

1. Scientists have mainly focused on enhancing the structure of electric vehicle charging stations and researching charging modes and a few researches are available on comparative characteristics of charging stations.

2. An algorithm for comparative analyses of EV charging stations in various countries was developed based on 5 criteria. The algorithm was tested in a comparative analysis of EV charging stations in the Baltic.
3. There are 7.05 electric automobiles per charging station in Estonia. The average indicators for Lithuania are better, yet, given the charging speed, Estonia presents even 15 times better performance than Latvia and Lithuania.
4. If measured in the number of residents per charging station, Estonia with 8030 residents presents the best performance. Estonia's performance is almost 17.9 times better than that of Latvia and 26.3 times better than that of Lithuania.
5. One of the most essential indicators – the availability ratio for a charging station – is excellent in Estonia, 2.60, in Lithuania it is 0.72, while in Latvia this indicator is only 0.5, which means that travelling by electric automobile is impossible in the territory of the country without establishing additional charging stations.
6. It can be considered that the charging infrastructure for electric vehicles in Estonia can fully ensure electric mobility in its entire territory, including the islands belonging to Estonia.
7. To ensure electric mobility in Latvia and Lithuania, substantial government support is needed, as well as it is necessary to simplify the procedures of granting support to natural and legal persons both for purchasing electric automobiles and for constructing charging stations, imposing no tough technical and other restrictions.

References

1. Berjoza D. Jurgena I., Vartukapteinis K. Research in electro and internal combustion engine motor vehicle energy costs. Proceedings of International Scientific Conference "Engineering for Rural Development", May 24 - 25, 2012. Jelgava: LUA, pp. 331-37
2. Putnieks U., Gailis M., Kanceviča L. Analysis on electric vehicle charging infrastructure in Latvia. Proceedings of International Scientific Conference "Engineering for Rural Development", May 24 - 25, 2012. Jelgava: LUA, pp. 400-405.
3. Reģistrēto transportlīdzekļu sadalījums pēc degvielas veida. [online] [10.02.2015.]. Available at: http://www.csdd.lv/lat/noderiga_informacija/statistika/transportlidzekli/?doc=528
4. Laceklis- Bertmanis J., Putnieks U., Mistris J., Gailis M., Kanceviča L. Composition of alternative energy battery charging station. Proceedings of International Scientific Conference "Engineering for Rural Development", May 23 - 24, 2013. Jelgava: LUA, p. 336-340.
5. Turitsyn K., Sinitsyn N., Backhaus S., Chertkov M. Roust broadcast - communication control of electric vehicle charging. [online] [31.01.2015]. Available at: http://arxiv.org/pdf/1006.0165.pdf
6. Zorskaite G., Duminyte V., Paliulis G.-M. Electric car integration in Vilnius. Proceedings of International Conference "Environmental engineering", May 19-20, 2011, Vilnius, Lithuania, pp. 1024-1031.
7. Putrus G. A. Suwanapingkarl P. Johnston D. Bentley E. C. Narayana M. Impact of electric vehicles on power distribution networks. 5th IEEE Vehicle Power and Propulsion Conference, University of Michigan, Dearborn, USA, 7-11 September 2009. [online] [31.01.2015]. Available at: http://nrl.northumbria.ac.uk/1193/
8. Elmo – Estonian electromobility programme [online] [31.01.2015]. Available at: http://elmo.ee/elmo/
9. Elektriautode toetuse statistika seisuga. [online] [31.01.2015]. Available at: http://elmo.ee/11186/ (In Estonian)