An overview of the development of electric vehicle markets in selected EU member states

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Abstract

The aim of the work is defining the significant aspects that influence e-mobility market development, especially battery electric vehicles, within the European Union. Moreover, the development scenario was defined with elementary constraints connected to environmental issues and the power grid. The conclusions aim, consequently, at underlining areas for e-mobility development and establish the good practices for stakeholders or decision makers the most vulnerable issues for e-mobility development in terms of future sales and market share. The first part contains the assessment of the progress of electric vehicle market and support schemes in European Union with the elementary research supported by statistical analysis between market share and, i.e. policy support with a quantitative and qualitative approach. The second part deals with the impact of electric vehicles increase on the power system and environment with the life-cycle approach with visualisation of potential future implications according to various scenarios.

Keywords: e-mobility, vehicle market development, clean transportation

1. Introduction

Transport despite having a constant improvement is an industry sector which contributes to one–quarter of Europe's greenhouse gases (GHG) emissions and has an indisputable effect on the environment and human health. The Paris Agreement enforced in November 2016 aims at limiting the risk of an increase of the global average temperature by 2°C [1]. This goal could be feasible only if transport cuts down emissions. International Energy Agency (IEA) in their reports noted two scenarios managing GHG budgets and planned reduction for the 2015–2100. These scenarios are:

- 2DS (IEA *Two Degree Scenario*), providing the 50% chance that the average temperature will not raise more than by 2ºC;
- B2DS (IEA *Beyond Two Degree Scenario*), provides the 50% chance that average temperature will not increase more than by 1.75 ºC.

Electric mobility is thought to have a high impact on decarbonizing the transport therefore it is listed as one of the ways to fulfil described GHG budgets [2]. Apart from GHG emissions, it is crucial to remember about avoided emission of NOx and particulate matter (PM) if electric vehicles substituted Internal Combustion Engine (ICE) vehicles. Unfortunately, electric mobility is a technology which is hard to commercialise. Documents issued by European Parliament underline potential and the current state of affairs related to electric mobility. The papers list needs for developing sustainable transportation for the future. Apart from research and development issues, these needs are associated with the energy system in EU namely:

- a consistent approach towards development of electric mobility what includes infrastructure, incentives and new business models;
- a development of primary electricity mix and heading to less carbon-intensive solutions with capacity adjustment [3].

Referring to this statements the paper is aiming to analyze the development of electric vehicles within EU states, namely:

- to describe the current situation of electric mobility (mainly BEVs), position it within the technology life-cycle;
- to assess the market development in the European Union, point out the factors that influenced the market share value, assess them with the related incentives and choose the most crucial area of support;
- to explore the expected influence of the BEVs (and partially PHEVs) on environment and energy system capacity. Finally, the short description of the mitigation of future energy demand surplus was described [1].

2. The technology of electric vehicles and sales

Today car buyers have a choice between several different types of powertrains. Majority vehicles are internal combustion engine cars (ICE vehicles). There are also vehicles such as hybrids, plug-in hybrids (PHEVs), battery electric vehicles (BEVs) and vehicles powered by fuel cells (FCEVs). PHEVs and BEVs are the technologies that use the electric powertrain with recharging plug-in systems. BEVs are powered solely by an electric motor while PHEVs combine an electric motor with an internal combustion engine [4], [5].

As an alternative powertrain, globally in 2017, the stock of electric vehicles approached 3.1 million (including BEVs and PHEVs). BEVs accounted for around 66% of this number with the growth rate estimated at 50–60% yearly. The sales in the European Union in 2017 reached 96 thousands of BEVs, what makes it comparable to the USA market [6]. As for the end of the year 2017, there were six dominant markets regarding BEVs registrations in EU: France, Germany, United Kingdom, the Netherlands, Austria, and Sweden. The Netherlands, Austria, France, and Sweden achieved the highest market share of BEVs - above 1% [7]. According to updated data till February 2018, 1% level was reached in Portugal and Germany as well (see *Figure 1*).

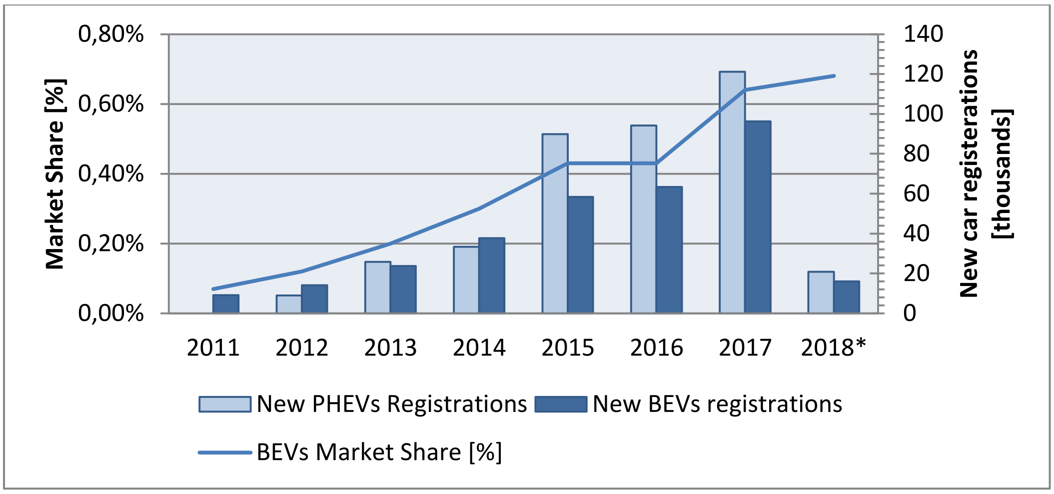

Figure 1 – BEVs and PHEVs sales and BEVs market share in EU. The *2018 new car registrations are summed till the end of February 2018 [7].

Taking into consideration the market position of electric vehicles and their technological advancement, BEVs and PHEVs should be positioned into the so-called Early Adopters stage in technology life-cycle. It forecasts the fast increase in sales in next years, combined with stable annual sales growth [8].

3. Battery Electric Vehicles market and supporting policies – assessment

The market share of BEVs and PHEVs appears to increase steadily but still it is very diverse across countries. Fluctuations can be observed between 2% to insignificant values close to 0. Analysis of the development supported by statistical analysis is the way to pick the factors that are responsible for those differences. It is presumed that factors are connected with customer concerns or inferior value proposition of BEVs. They are mainly restrained driving range, long charging time and high acquisition price, especially when comparing to ICE vehicles. There are also indirect factors that can play a role, i.e. the social or economic backgrounds: a profile of customer, income or environmental consciousness level and fuel price levels [6], [7]. The effective policy supporting every innovation should reduce the influence of these customer concerns, i.e. decrease the cost or risk attributed to technology. Therefore BEVs might adapt to market conditions at a faster pace if a right policy environment is created. The goal is to prove which incentives and measures already introduced were effective. The lesson learned can be a valuable information for markets with low BEVs deployment or with lack of appropriate polices [7].

3.1. Methodology

The methodology consists of correlation and ANOVA analysis of variance. Correlation measures the degree of relationship between mostly quantitative variables. They take values from the range *<–1,1>*, while positive correlation means that as the value of one value increases, the value of the other also increases and negative correlation means that the value of feature decreases with the increase in the value of other feature. A coefficient of *0* means that the variables are not related. In this paper rho–Spearman correlation was used because it was imposed by characteristics of data set (i.e. lack of normal distribution, the need for data ranking) [9], [10]. The formula for rho–Spearman efficient is given by:

$$r_s = \frac{\frac{1}{6}(n^3-n)-(\sum_{i=1}^{n} d_i^2)-T_x-T_y}{\sqrt{\frac{1}{6}((n^3-n)-2T_x)}(\frac{1}{6}(n^3-n)-2T_y)} \qquad \textbf{(Formula 1)}$$

Where: n – a number of observations in a group, $d_i=R_{xi}–R_{yi}$ is the difference of i–th rank for variable x (R_{xi}) and i–th rank for variable y (R_{yi}), T_x, T_y are the coefficients for tied ranks [9], [10].

Usage and reading rho–Spearman values is possible after establishing two hypothesizes (H_0: $r_i=0$; the dependence of features is irrelevant; H_1: $r_i \neq 0$; the dependence of features is important) and further validation according to the statistical significance level. Verification of hypothesises comes from the *t test*:

$$t = \frac{r_s}{\sqrt{1-r_s^2}}\sqrt{n-2} \qquad \textbf{(Formula 2)}$$

Where: r_s – rho–Spearman correlation coefficient, n – the number of observation in the group [9], [10].

For a value of *t*, value *p* is found and compared with the level of significance. Statistical works establish the usual level of significance equal *to* $p^*=0.05$. If $p>p^*$ hypothesis H_0 is verified. If $p<p^*$ hypothesis H_0 is declined in favour of hypothesis H_1 [11], [12]. Rho-Spearman was performed on the given variables:

- *Incentives;* a number of relevant incentives in use in the country,
- *PubChargers;* a number of public charging points in the country;
- *ChargersIn;* a number of public charging points per 100 000 inhabitants;
- *AvFuel;* average fuel price, being an average price of petrol and diesel fuel in the country;
- *AvSalary; net* average monthly salary in the country;
- *Ratio;* a ratio of an example electric vehicle price, in this case, averaged price of Nissan Leaf and average monthly salary [9], [10].

The ANOVA analysis of variance is used to investigate the influence of factors (which are independent variables) on the subject variable. Here it is used to examine the influence of one intergroup factor on another dependent variable. One–way analysis, namely Kruskal–Wallis was used to compare the distributions of variables due to characteristics of data set (similarly as in case of rho-Spearman correlation). Precisely for this test, to fulfil the qualitative analysis assumption, the data regarding the EU states were split into three groups. Each group showed different support level for BEVs, i.e. Group 1 consists of states with prominent purchase subsidies, circulation support like registration tax, ownership tax, VAT benefits. Group 2 consists of moderate support like circulation subsidies and local incentives. Group 3 included states with no important support or minor support locally. The ANOVA consists of the test:

$$H = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(n+1) \qquad \textbf{(Formula 3)}$$

Where: R_i – a sum of ranks in *the i–th* group, n_i – the size of the *i–th* group, n – total number of all groups.

The final value of *H* is used to assess whether there is any substantial difference between the medians in the groups according to specific *chi-square* distribution tables and significant level [13], [14]. For final approval of the ANOVA analysis, the significance level of 5% is applied [7].

3.2. Results of analysis

After performing the analysis, the variables *Incentives, PubChargers, AvSalary, Ratio, ChargersIn* variables were fitted between moderate dependence level (correlation coefficient listed in order: 0.43, 0.50, 0.59, -0.43, 0.54). *AvFuel* variable proved almost no dependency between BEVs market share and pricing of fuel in EU states. Variables and consequently impact areas are affecting simultaneously and often independently on the value of market share within EU states. There is no ultimate factor pushing BEVs market development forward. The ANOVA analysis proves that it is likely that the lower market share of BEVs is present within countries of a small degree of incentive support. This is confirmation of the idea that underlines the need for creating complex incentive program instead than one-dimensional support. Nevertheless primarily, policy should favor the measures that aim at reducing the high purchase price of vehicle and development national network of charging points.

4. BEVs impact on environment and power system

Worldwide scenarios of, i.e. IEA predict around 130-230 million EVs (not including two– and three–wheelers) of vehicle stock by 2030. This amount can significantly influence the energy systems of each country. In EU states, the market share of BEVs is thought to be between 5 and 20% [11]. To assess the influence of BEVs on an environment a brief calculation was conducted, showing the dispersion of GHG emissions under the different primary energy mix and vehicle models adoption. The most important variables of calculation were primary electricity mix (characteristic for each country, described in fuel share). The data were collected for five EU states – Poland, the Netherlands, Germany, Portugal and the Czech Republic. Also, the efficiency of different BEVs was taken into account with the discrepancies in driving schemes in the city and on a highway. The formula for this calculation is presented:

$$s_j = \sum_{i=1}^{n} p_i n_i c_j \qquad \textit{\textbf{(Formula 4)}}$$

Where: s_i – CO2–equivalent emission [g CO_{2}–$_{eq}$/km], n – a number of best–selling BEVs included in the ranking, p_i – market share percentage of i–th BEVs sold 2017, c_j – estimated amount of CO2–equivalent released from obtaining 1 kWh in j country [g CO2–$_{eq}$/kWh].

Consolidated *Figure 2* presents significant discrepancies concerning carbon footprint between all factors: the primary energy mix, driving scheme and BEVs efficiency in electricity consumption [3].

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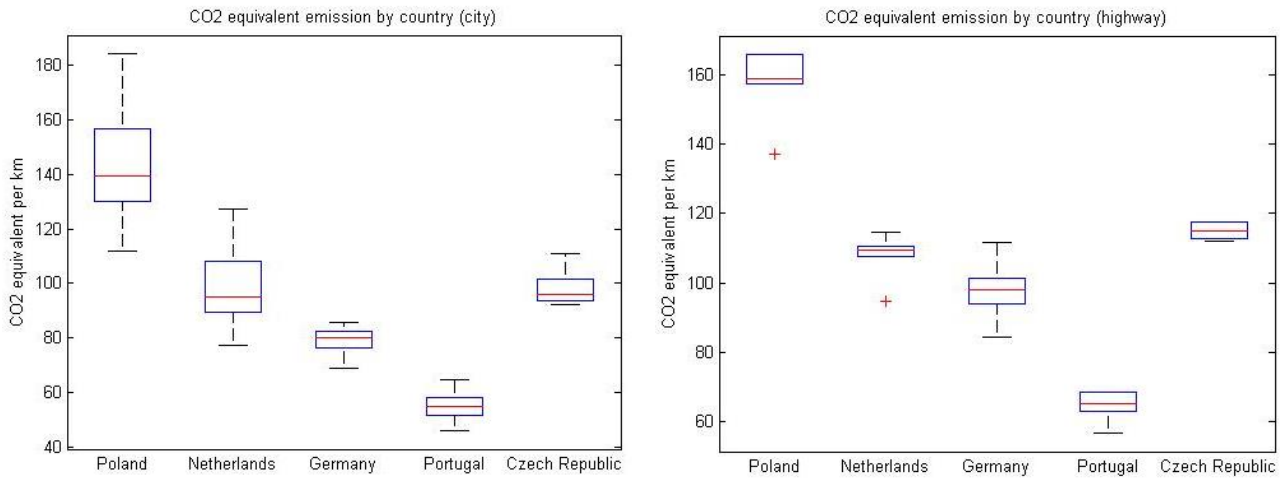

Figure 2 – CO_2–equivalent emission in city and highway driving conditions per 1 km for BEVs within five chosen EU states [7], [15], [16], [17], [18], [19].

The literature underlines the positive impact of BEVs in reducing GHG emissions (see [3]) or expresses doubts in the case of a carbon-intensive environment (see [20], [21]). In fact, BEVs have a lower impact on CO2–equivalent emissions in comparison to ICE cars considering the Tank–to–Wheels cycle. However, when summing the emissions in Well–to–Wheel cycle, which results from Life-Cycle Assessment (see *Figure 3*), these differences seem to be no longer that high. It has a crucial meaning for the future direction of energy system development – countries with diversified energy sources offer the best conditions for sustainable electric mobility development. The future policies should also include regulation addressing vehicle efficiency and support the business models gathering electric mobility in urbanised areas.

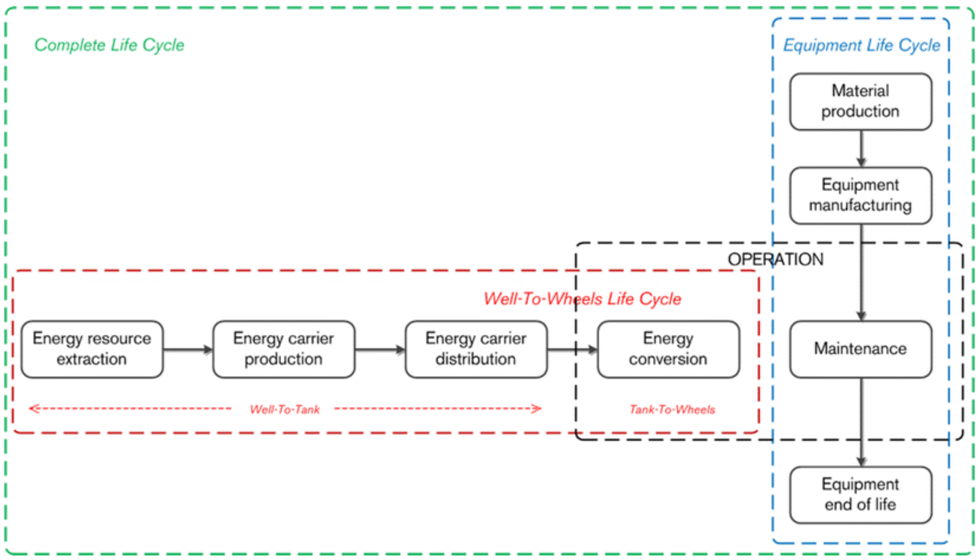

Figure 3 – Simplified scheme of vehicle life–cycle and equipment [22].

Apart from environmental issues, energy capacity is the next area which was described by the European Parliament as highly vulnerable to BEVs market expansion [3]. Globally the evolution of electric mobility can be summed up to two scenarios implemented in, i.e. IEA reports. Those scenarios are NPS (New Policies Scenario) which consolidates the ongoing and planned measures incorporated to meet most national targets of electric mobility levels; and EV30@30 Scenario, which is the result of EV30@30 Campaign Declaration and a target of 30% of the market share of electric vehicles in 2030, what is compliant with the Paris Agreement. In 2014 in EU the electricity demand attributed to electric mobility stock accounted for 0.03% of the total electricity consumption which consequently reached around 0.98 TWh [23], in 2017 this value rose up to 1.5 TWh. Scenarios indicated above, predicts the electricity demand in between 73 and 167 TWh in 2030 [6]. *Figure 4* presents possible growth in energy demand annually. Data were based on electric vehicles car stock in use till 2030 with referential values corresponding to NPS and EV30@30 scenarios. Stock number was based on average sales growth between 20–40% yearly.

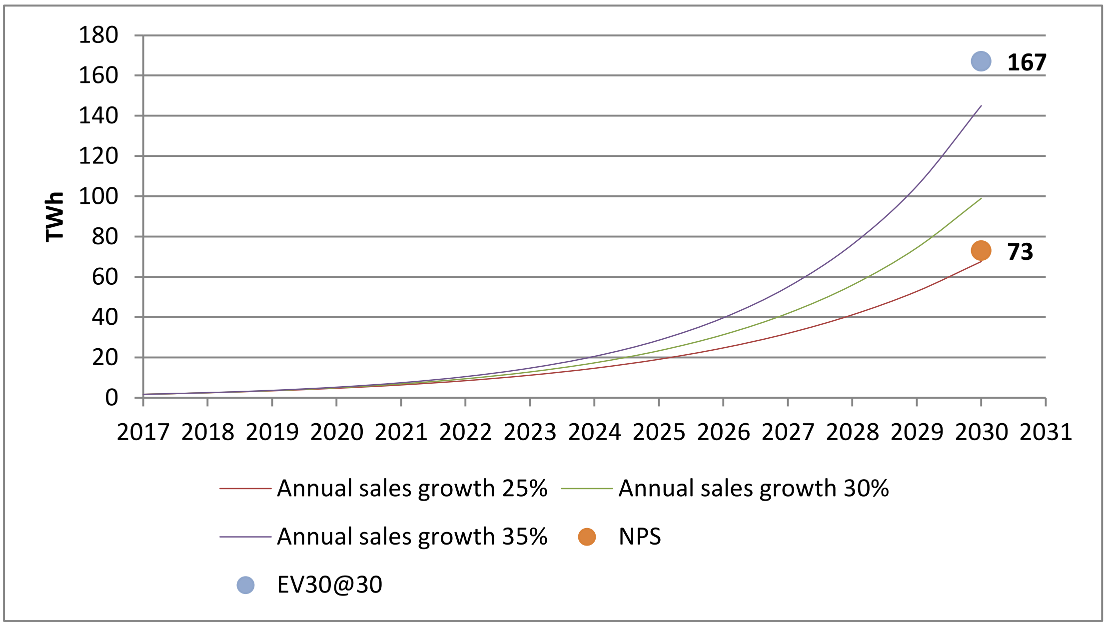

Figure 4 – Forecast of electricity demand attributed to EVs according to average sales growth till 2030 [6], [7].

From the capacity overview, the key point is that the power generation projected for 2030 can achieve 3470 TWh with 1411 TWh being produced by renewable energy sources. Electricity demand credited to electric mobility will probably consume between 2.1% and 4.8% of projected electricity generated in Europe in 2030 [24]. It is thought that electric mobility will play rather a minor role in demand increase. Probably only 6% of the general demand growth from 2015 to 2030, coming from the sectors will be attributed to vehicles [25].

The forecasts up to 2050 can be established by the backcasting method. European Alternative Fuels Observatory (EAFO) suggests the drop from 9985 Peta Joules of energy used for transport in 2016 to 2197 Peta Joules in the year 2050. That means almost 610 TWh electric power used by the car fleet. Generally, EAFO estimates the electricity demand between 600-700 TWh in 2050 what makes it a 150-350% increase compared to 2030 [26]. Additionally, it is expected that electricity consumption in EU will not exceed 5000 TWh in 2050 [27] - the electricity demand attributed to electric mobility might raise up to 12-14% in this case. The management of the extra energy coming from this increase might be a very complex process – this process should be based on three constraints:

- grid constraint, to mitigate the consequences of peak demand excess caused by recharging process, which determined by variables: time, speed and location of vehicle charging;
- energy mix constraint – as future installed capacity should involve the renewable energy sources to the most significant extent and with a certain degree of synchronisation between vehicle users and generation;
- price constraint – as a helpful tool in levelling the prices of electricity (price arbitrage) [25].

5. Conclusions

The statistical assessment highlights the significance of financial incentives and infrastructure development. The most important reason why potential BEV or PHEV customer is not buying a vehicle, is a high price of vehicle and range risk, coming from technology constrains – battery limitation or not convenient network of charging points. The crucial point for developing electric mobility markets is adapting and building the policies addressing those issues that are reducing the importance of the factors mentioned above.

Although electric mobility appeared to be less carbon-intensive, while comparing the EU averages between cars with different powertrains, discrepancies between countries or even driving patterns are still significant. Proper mobility related policy development or targeting should be based on more detailed data that include the efficiency of the electric car and Life-Cycle Assessment (LCA).

In terms of the current and future impact on the energy system - the increase in demand and capacity is thought to be manageable and feasible in next decade. It is predicted to reach the numbers between 73 and 167 TWh, what consequently corresponds to up to 5% of European electricity demand in 2030. In 2050 the demand attributed to e-mobility is expected to rise to 9-14% of total demand. According to major predictions, it is possible to cover it by the capacity that will have to install by 2030 which, at least within EU, to the high degree should be renewable energy. The problem of peak load increase coming from electric vehicles charging time demands, however, an efficient interference by grid and power systems operators. The solutions might be based on the sustainable organization of controlled charging schemes and the deployment of load management facilities with renewable energy sources and energy storage systems usage.

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