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

Analysis of observed trends and supporting policies

Paweł Siara

Thesis to obtain the Master of Science Degree in

Energy Engineering and Management

Supervisors: Prof. Rui Manuel Gameiro de Castro

Dr. Artur Wyrwa

Examination Committee

Chairperson: Prof. Edgar Caetano Fernandes

Supervisor: Prof. Rui Manuel Gameiro de Castro

Member of the Committee: Prof. Paulo José da Costa Branco

October 2018

Abstract

The work aims at defining the factors that influence electric vehicle market development within the European Union. Furthermore, the growth scenario was defined with the conclusions related to primary constraints connected to the environment and the power grid. The conclusions aim at underlining areas for e-mobility development and establish the good practices for stakeholders or decision makers pointing out the most vulnerable issues for e-mobility development in terms of future sales and market share. The first part contains the assessment of the development 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. The second part of the paper is dealing with the impact of electric vehicles increase on the power system and environment with a life-cycle approach.

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

Resumo

O trabalho visa definir os fatores que influenciam o desenvolvimento do mercado de veículos elétricos na União Europeia. Além disso, o cenário de crescimento foi definido com base nas conclusões relacionadas com as restrições primárias ligadas ao ambiente e à rede elétrica. As conclusões do trabalho visam sublinhar áreas para o desenvolvimento da mobilidade elétrica e estabelecer as boas práticas para os decisores políticos apontando as questões mais vulneráveis para o desenvolvimento da mobilidade elétrica em termos de vendas futuras e quota de mercado. A primeira parte contém a avaliação do desenvolvimento do mercado de veículos eléctricos e dos esquemas de apoio na União Europeia, com a investigação elementar apoiada por análises estatísticas entre a quota de mercado e, por exemplo, o apoio político. A segunda parte do artigo trata do impacto do aumento de veículos elétricos no sistema de energia e no ambiente com uma abordagem de ciclo de vida.

Palavras-chave: e-mobilidade, desenvolvimento de mercado de veículos, transporte limpo, política energética

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2DS, *2 Degree Scenario*
AC, *Alternating Current*
B2DS, *Beyond 2 Degree Scenario*
CAGR, *Compound Annual Growth Rate*
CO_2, *Carbon dioxide*
DC, *Direct current*
EFTA, *European Free Trade Association*
ESS, *Energy Storage Systems*
EU, *European Union*
EV, *Electric vehicle*
FCEV, *Fuel cell electric vehicle*
GHG, *Greenhouse Gases*
ICE, *Internal Combustion Engine*
LCA, *Life cycle assessment*
MPPT, *Maximum power point tracking*
NEDC, New European Driving Cycle
NPS, *New Policies Scenario*
OEM, *Original Equipment Manufacturer*
PM, *Particulate matter*
PV, *Photovoltaics*
RES, *Renewable Energy Sources*
TCO, *Total Cost of Ownership*

1. Introduction

Transport is one of the pillars of the economy and society. Despite constant improvements in a technological area, this is still a sector that contributes to a quarter of Europe's greenhouse gases (GHG) emissions and has an undeniable impact on the environment and human health. European Union set constant objectives to develop solutions reducing the impact of fossil fuels and increase efficiency in their consumption. The transport sector's targets regarding a reduction of GHG emission are one of the major ones since it is the only sector of the industry that did not reduce the amount of pollution emitted since 1990 [1]. This sector presently accounts for around 23% of global energy-related emissions of GHG, and it grew by 17% in comparison to 1990 level [2]. This rise is alarming because currently, European Union uses not accurate methods of measuring vehicle's emission to the atmosphere. Real–life CO_2 emissions might be 30–40% higher than it is officially declared [1].

In 2011 *Transport White Paper* outlined the way to achieve 60% reduction of GHG by 2050 in comparison with 1990. To do so, the paper includes a condition of 50% reduction of conventionally fueled cars in usage by 2030 and their complete abandonment till 2050. Later on, these targets were followed by European strategy for low–emission mobility published by the European Commission in 2016, which underlines the importance of low and zero–emission vehicles as a part of decreasing oil dependency [1]. The Paris Agreement announced in December 2015 and later enforced in November 2016 aims at limiting the chance of an increase of the global average temperature by 2°C. Transport as an industry sector has to cut down emissions to achieve these goals. The International Energy Agency in their report listed two scenarios managing GHG budgets and outlining trajectories of planned reduction for the 2015–2100 period. Those scenarios are:

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

The critical point of these scenarios is that the energy sector will have to reduce the CO_2 net emissions to zero in the second half of the century to meet the Paris agreement ambitions. Decarbonisation of energy industry within this time is not possible without electrification of transport. 2DS scenario, for example, projects 1.2 billion electric cars by 2060 in circulation, while B2DS force electrification at a faster pace [2].

Followed by GHG emissions one has to remember of the importance of NO_x and particulate matter (PM) presence. These pollutants are significant in urbanised areas, where the direct emissions are highly dangerous for human health and the environment. As the PM presence might not be caused mainly by vehicles, NO_x limits are repetitively exceeded in European Union in locations with intensive road traffic. Vehicles might be responsible for 60%–80% of NO_x emission in that case. Direct emission can be reduced to the great extent by applying electric vehicles as the primary mean of transportation in the cities [1].

Another issue which should support electric vehicle deployment is the noise pollution. It also affects human health and well–being. The noise pollution has two sources – first is the engine noise, second is the noise coming from contact of the tires and the road – the friction. As the engine noise predominates at speeds up to 50 km/h, electric vehicles would reduce it significantly in urbanised areas where average speeds are below 50 km/h, and cars are exposed to frequent acceleration and deceleration [1].

As presented electric mobility might have a high impact in decarbonising the transport industry and making it more environmentally focused. In the available European Parliament documents, namely *Challenges for a European Market for electric vehicles* (see [3]), there is a significant review on the current state of affairs related to electric mobility. The paper lists needs for developing sustainable transport market models in the future. Apart from research and development of technology connected with batteries and automotive industry, there are other vital necessities stated:

- A consistent and homogeneous approach towards development of infrastructure, business models, pilot projects and incentives for supporting the electric mobility development;
- Primary energy mix development (related to electricity production) towards less carbon intensive solutions, capacity is not listed as an issue, however, grid system and production adjustment to charging schemes are recommendable [3].

A situation in the European Union is very diverse in terms of either primary energy mix, incentive support level for electric mobility and consequently their deployment. The good strategy in keeping consistent electric mobility sales growth among European countries is to analyse its development so far. Specifically to find and analyse the factors that directly speed or slow the sales and consequently, market growth, assess their influence and adjust supporting solutions. Simultaneously it is important to find out the areas in which the market development will influence in the future. Precisely, in this case, it is essential to be conscious about the impact of electric mobility on energy system and environment. Electric mobility is likely to generate an increase in electricity demand, the exact value is not known but can be predicted by applying certain assumptions (i.e. forecasting using trends in annual sales growth, or backcasting using given targets to achieve), what was included in this paper. This energy surplus will directly influence the shift towards sustainable transport system, and it can be a so-called technology push to cause changes in the transport and energy industry in general [1].

The European Commission notes the specific issues to develop in further studies, such as the impact of electric vehicles market on CO_2 emissions, electricity demand and efficiency as well as assessing the potential of current and intended support schemes, especially on the national level, which still are uneven among EU states [3]. Market development analysis is a useful tool for reviewing those issues, as it aims at determining and assessing potential technological, political, economic or environmental drivers in development and forecast the market growth, i.e. sales or impact on the associated industries in future [4].

1.1. Objectives of the thesis

Considering the findings from the literature and articles referenced above, the paper will address the current problems and potential development of electric mobility within EU states. The main objectives of the thesis are to evaluate supporting mechanisms for BEVs and PHEVs market development and formulate some conclusions in which measures and incentives to invest, as well as to calculate the spread of energy needed to fulfil the BEVs and PHEVs consumption in EU and evaluate its impact on environment and energy system.

1.2. Structure of the thesis

The four objectives were realised and structured in the following chapters:

- Chapters 2 aims at giving an idea what the fundamentals of BEVs and PHEVs powertrain to describe further the sales and market share within EU are and in relation to the rest of the world in Chapter 3. It is done to fulfil the objective of evaluating the current status of the electric mobility market development with detailed market share numbers in EU states and globally.
- Chapter 4 refers to the need of a consistent and homogeneous approach towards development of electric mobility. The chapter 4.1 points out the factors influencing the sales of BEVs mainly focusing on customers tendencies and technology constraints. By performing analysis in chapter 4.2 factors were collocated with corresponding incentives and it was stated which measures or incentives appeared to be the most successful. The methodology of the research consists of correlation test (chapter 4.2.1.) and analysis of variance (chapter 4.2.2.) for several factors considered to be crucial in shaping the market development. The results were presented in chapter 4.3.
- Chapter 5 refers to the issue of the future primary energy mix. In Chapter 5.1. scenarios for electric mobility market development were described with the predicted future market share. In 5.2. the BEVs impact on GHG emissions was shortly described using energy sourced from different primary electricity mixes (chapter 5.2.1.), while later the findings are collocated with the conclusions from Life Cycle Assessment sourced from literature (chapter 5.2.2). Finally, fulfilling the assumption of sustainable energy development approach, constraints are established for energy production to avoid counter-productive increase of indirect GHG emission (chapter 5.2.3.). Chapter 5.3. aims at estimating the increase in energy consumed by BEVs and partially PHEVs up to 2030 using forecasting method and probable annual sales growth. Predictions to 2050 were made using the backcasting method with specific targets scheduled for this year. The demand growth is positioned within the general demand growth coming from industrial development. Furthermore, some propositions of decreasing the impact of energy surplus are presented with the focus of RES and energy storage technologies.
- Chapter 6 presents the conclusions of the work.

2. Electric vehicles and recharging – current technology

The car buyers nowadays have a choice between several different types of powertrains. Currently, the majority of car bought is the internal combustion engine cars (ICE vehicles) which include both diesel and petrol engine powered cars. There is also a choice within alternatively powered vehicles such as hybrids, plug-in hybrids (PHEVs), pure battery electric vehicles (BEVs) and vehicles powered by fuel cells (FCEVs). The vehicles that use the electricity drawn from the grid are PHEVs and BEVs, both technologies have plug-in systems for battery recharging. BEVs are being powered solely by an electric motor that runs on energy chemically stored in batteries while a controller manages the performance of the electric motor. PHEVs presents a very similar system, but powertrain combines a internal combustion engine with electric motor that might run simultaneously or individually. Thanks to the engine controller, part of the distance might be driven by electric motor and another by petrol depending on the speed or driving style – usually at low average speed or frequent braking and accelerating, electric motor works exclusively. Simple scheme including parts of a drive system for BEVs and PHEVs was presented in *Figure 1* [5], [6].

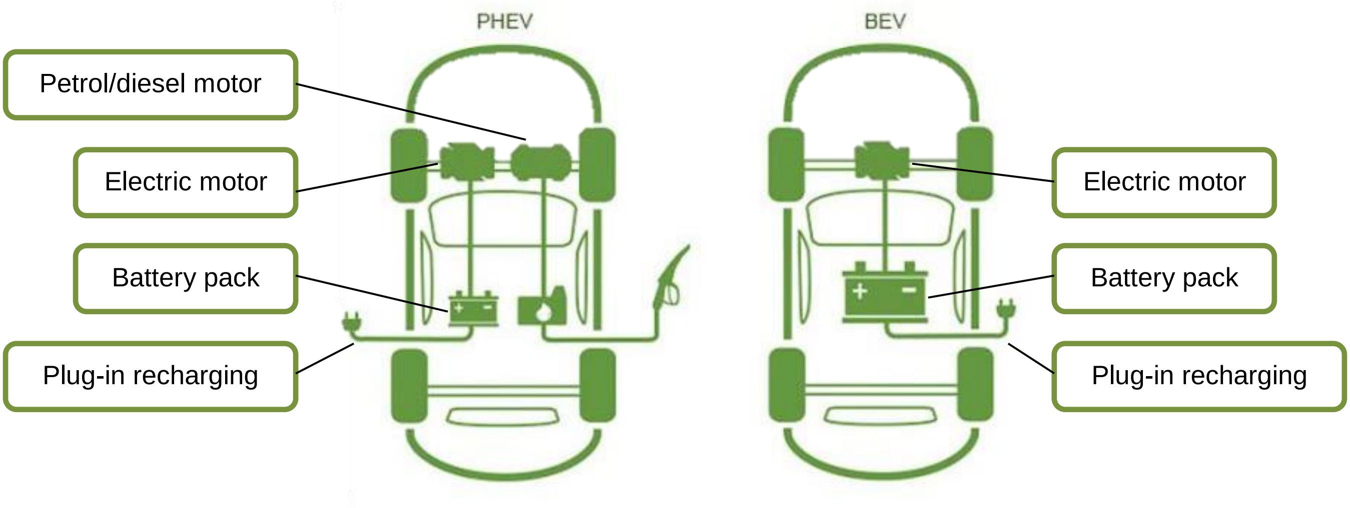


Figure 1 – Scheme of BEVs and PHEVs drivetrain [7]

The great advantage of electric powertrain is higher efficiency up to 80% in transferring the electric power to mechanical, which is way higher than conventional, internal combustion engines (20–30%). The energy consumption of electric motor depends directly on the type of vehicle, it is usually between 20–27 kWh/100 km with a driving range between 80 to 400 km [1]. Moreover, electric motors are characterised by high reliability and low noise generation. Most electric vehicles use lithium-ion battery technology as it offers high energy storage capacity and long lifespan. The main disadvantages are the cost, weight and gradual loss of capacity through the time. The cost of batteries significantly increases the Total Cost of Ownership. Total Cost of Ownership (TCO) is the total cost of acquiring, installing, using, maintaining and finally getting rid of assets over a specified period [8]. Presently, the gap in the Total Cost of Ownership of the BEV compared to ICE vehicle can vary from 5000 EUR upwards per vehicle. However cost of the battery pack is thought to drop to USD 200/kWh by 2020 and further to USD 160/kWh by 2025 due to manufacturing and supply chain improvement and technology progress [5], [9]. The aim to develop lighter, cheaper and better, in terms of energy storage capacity, materials especially cathode is the major target for improving electric mobility value proposition [1].

The limitation of short driving range makes BEVs reliant on recharging infrastructure. The charging seems to be crucial for further development of electric mobility market in Europe. However, the effective development of charging infrastructure depends on the cooperation of electricity suppliers, automakers – OEMs and local or state policies. Currently, only plug-in charging is commercially available. It can offer several modes of charging a battery which uses a different combination of power level supplies, AC or DC electric current and the plug construction. Typical times of charging in household conditions are between 3–8 hours for standard 230 Volt AC socket. Charging time can be reduced by applying direct current to 20–30 minutes [10]. The important disadvantage of fast, high–power charging infrastructure is the transfer loss due to stronger current. It decreases the efficiency of transfer, increases the peak load in energy demand and leads to a drop in battery lifetime, meaning less total charging cycles. Fast recharging points, which are based in DC, are almost three times more expensive as a simple AC charger when it comes to installing costs [1]. Making the recharging process less time–consuming and problematic for the grid, is one of the challenges for researchers. Apart from the plug-in charging method, there are two other ways of charging the battery: battery swapping and wireless charging. The battery swap can be done by replacing a discharged battery with charged one at the special station. This is not practised in Europe since no BEV available on the market nor infrastructure support this technology. The possibility of wireless charging by induction uses electromagnetic field around a charging pad. As the vehicle is positioned on the pad, charging can occur. The technology has pilot projects, mainly for buses in Belgium, Germany or Sweden [5].

Nearly all major OEMs have included in their short and long-term strategic investments in the development of various powertrains. The reason is the uncertainty of the market. An estimated value of 46 new BEV models was confirmed to be released in Europe up to 2020 [5].

3. Market share and sales of BEVs in Europe

In 2017 the global stock of electric vehicles reached 3.1 million (BEVs and PHEVs combined) while BEVs accounted for two–thirds of this number. It consequently follows the growth rate by 50–60% yearly. Taking into consideration only BEVs, the main market is China where new car registrations in 2017 exceeded correspondingly 460 thousand, with an overall stock of 951 thousands of BEVs (summing 2005–2017 registrations). The sales within EU states in recent year is comparable with the USA market; it reached 96 thousands of BEVs (2005-2017 stock around 300 thousand) while in the USA reached 104 thousand. If we take into account normalised data according to the population of China, USA and EU, it is observable that China's market might develop at the fastest pace. EU market seems to develop constantly, but there is the lower amount of registrations per capita than in comparable USA market (see *Figure 2*).

The countries with the most significant BEVs stock so far (summing 2005–2017 registrations) within EU states are so far France (92.95 thousand), Germany (59.09 thousand), Netherlands (21.12 thousand) and United Kingdom (45.01 thousand). Those countries contributed the most in the development of BEVs market in EU in terms of sales within the last decade and still maintain at leader positions in 2017 [11].

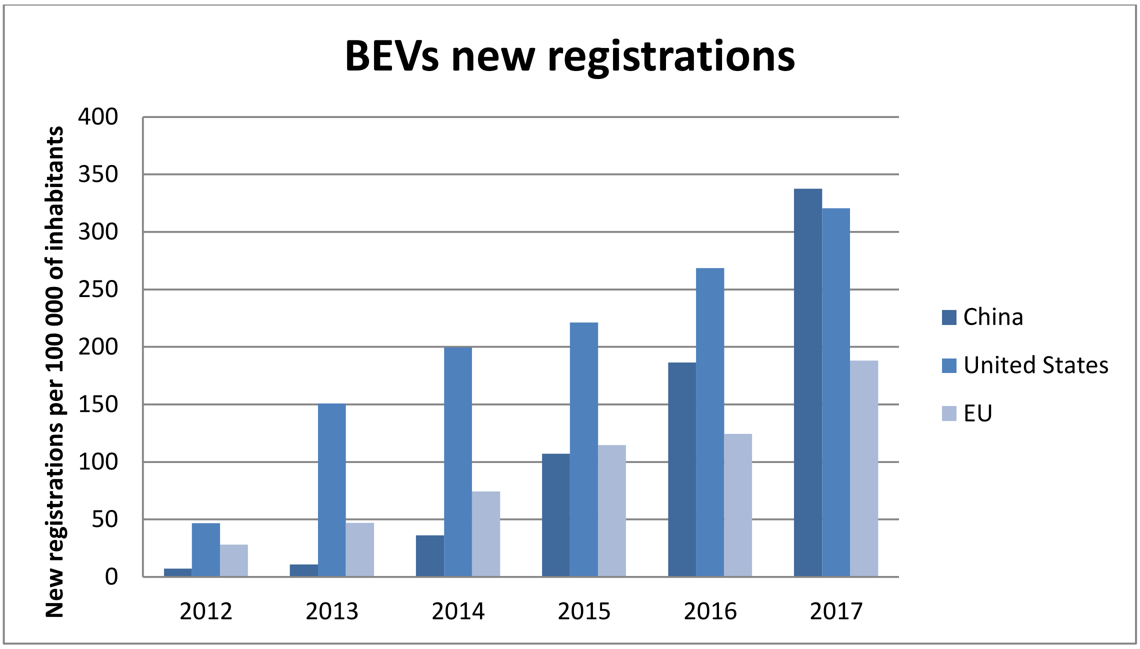


Figure 2 – Comparison of numbers of new BEVs registration between 2010–2017 in China, the United States, and the European Union [2], [12].

The market for electric mobility was solely based on BEVs until PHEVs being massively introduced in 2012. Since that time a decrease in BEVs market share in comparison to PHEVs was observed. Still, the European market is still a growing market and BEVs volume of sales is extremely variable among countries. Looking closer to European statistics (see *Figure 3*) in recent years there was observed a steady increase in BEVs market share up to 2018. The slowdown in 2016 was probably due to the policy changes associated with a reduction of BEVs related incentives in major European markets, i.e. Denmark. In 2017 in European Union new BEVs sold reached value of 96.349 thousand registrations with 0.64% market share [12].

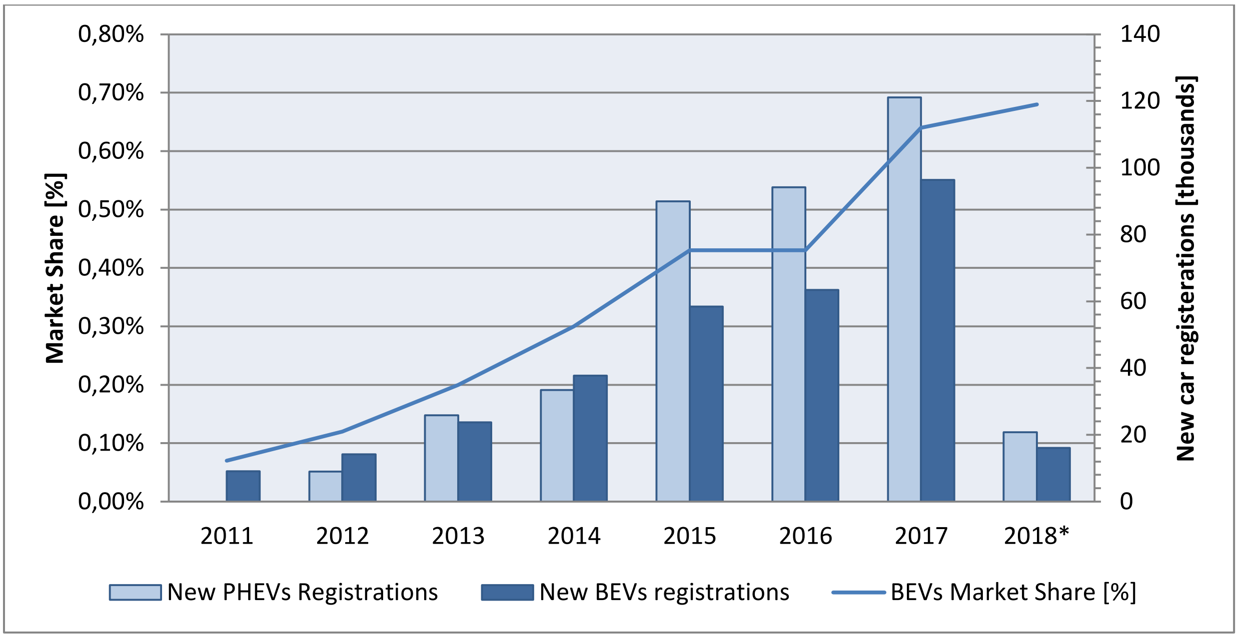


Figure 3 – BEVs and PHEVs sales and BEVs market share in EU; *2018 new car registrations are summed till the end of February 2018 [12].

In 2017 and 2018 in Europe around 44% of electric cars sold are BEVs (see *Figure 3*) [2], [12]. As for the end of the year, 2017 six dominant markets in terms of BEVs registrations in EU were France, Germany, United Kingdom, the Netherlands, Austria, and Sweden. The highest market share of BEVs above 1% was achieved in the Netherlands, Austria, France, and Sweden. Considering data till February 2018, 1% level was reached in Portugal and Germany, also the overall increase of market share in EU was registered at 0.75% for BEVs and 1.65% for PHEVs (see *Figure 4)* [12].

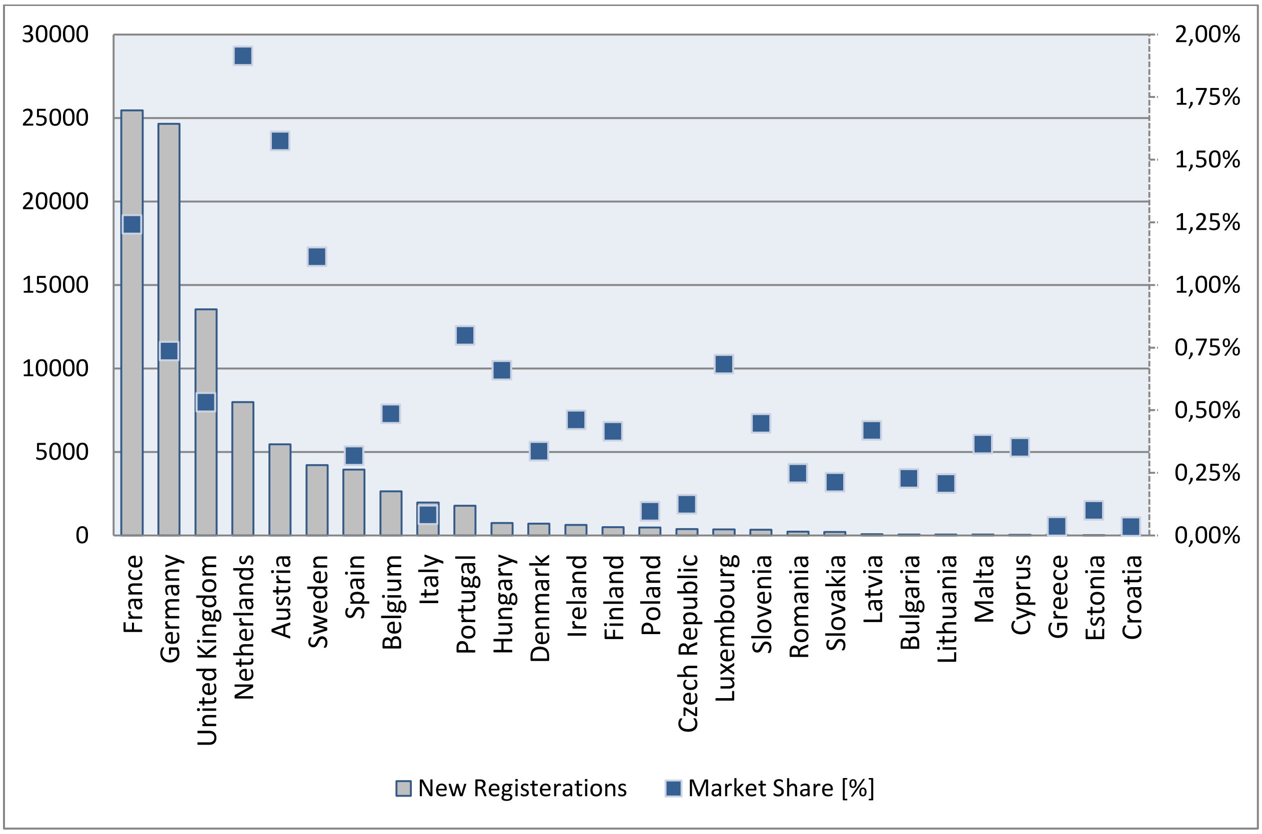


Figure 4 – BEVs sales and market share within EU states in 2017 [12].

As for EU and EFTA countries, the undeniable leader is Norway with 15.67% share of BEVs in 2016 and 20.82% in 2017. It might be a result of a favourable policy including incentives like tax reduction as well as exclusions from road toll and ferry waivers and charging infrastructure [12].

In terms of technology life-cycle, as there is much area for battery pack improvement (see *Chapter 2 Electric vehicles and recharging – current technology*) and uneven sales distribution, one might to position technology of BEVs and PHEVs in so-called Early Adopters stage what suggests the rapid increase in sales in further years, with stable annual sales growth [13]. Electric mobility seems to leave its innovation phase, and it is listed as one of the megatrends that play a major role in decreasing the impact of global warming [14].

4. Monitoring the development of BEVs market and support schemes in EU

4.1. Factors influencing the BEVs sales

As presented in the *Figure 4* BEVs market shares in EU states are very diverse. Analysis of the development of BEVs market has to point out the factors that are responsible for those differences. The final decision whether it is BEVs, PHEVs or ICE vehicle purchase is on the customer side – their choice is what has the direct impact on sales. Therefore what slows down the market development is primarily connected with customer concerns or poor value proposition – for BEVs, those are, i.e. the limited driving range, long charging time or high purchase price in comparison to ICE vehicles. These come directly from technology constraints like battery limitation. Indirect factors mainly come from the social or economic backgrounds like a profile of customer (his income or environmental consciousness level) or fuel price levels [15], [16].

The good policy towards the BEVs market intake growth is reducing the influence of these customer concerns [16]. Policies aimed at encouraging customers, investors or manufacturers to develop large-scale market mainly by decreasing the cost or risk attributed to technology. If there is a supportive policy environment, technologies like BEVs might adapt to current market conditions faster. Also if the specific activity led by government appeared to be essentially successful, it could only underline the importance of this policy and area of support - this is extremely important within countries with low BEVs market share, which are in the starting point of such policy development [2].

Supporting policy background might be categorised into:

- Research and development grants and supports affecting the improvement of technology directly, i.e. battery cost and performance;
- Financial incentives like purchase subsidies, tax deductions or exemptions that help lowering the high expenses of BEVs purchase [1], [2];
- Public expenditure in, for instance, charging infrastructure affecting the range anxiety by faster and convenient way to charge the car whenever and wherever the driver is [16];
- Law regulations and others, i.e. limiting the mobility of ICE vehicles in cities to broaden the value proposition of BEVs [2].

Financial incentives are mainly controlled and introduced on the national level. They reduce the cost of purchase and total cost of ownership. Incentives depend on the market size and characteristics. They can take the form of rebates, exemptions of tax payment, or other financial reprieves that favours BEVs in comparison with ICE cars. In the case of Scandinavia where the taxes appear to be high, differentiation of taxes was introduced based on the fuel economy and CO_2 emissions performance [2]. Certain countries use so-called one-off grants, which take the form of registration tax reduction (depending, i.e. on a price of a vehicle, technology, category of vehicle) or total exemption. France or Portugal offered the possibility when BEV buyer might obtain a fixed grant, if he replaces the old car that may be scrapped. Many countries impose the annual circulation tax for the use of public roads. For BEVs, those taxes are exempted during the first five years of usage in Sweden and Italy and ten years in Germany. Latvia offers exemption from car tax and operation tax, Austria also exempts BEVs owners from monthly imposed vehicle taxes. In Belgium and Portugal deduction from corporate income tax might be obtained if using low–emission cars [2], [11], [17].

The infrastructure development in terms of charging station might take the form of pricing scheme of charging or direct activity like ELMO programme in Estonia where fast-charging stations were subsided by the government. Pricing schemes are based on the peak and off-peak pricing system and reward consumers which tend to charge the vehicle during off-peak hours. It was introduced or is planned in, i.e. Czech Republic, Finland, France, Germany, Poland and Spain. Moreover, a program of free charging at public stations has been introduced in Bulgaria, the Czech Republic, Denmark and is being piloted in Portugal [1]. Often policies are usually adapted to local mobility characteristics. Examples of these measures comprise of:

- Public purchasing of BEVs by municipal authorities. For instance, around 30% of local councils in the United Kingdom operate at least one BEV. In the Czech Republic municipalities can obtain around 25% subsidy for buying alternatively fueled car [1].
- Exclusion from urban area access restriction, where only vehicles meeting certain environmental standards are let in certain urban zones. These exclusions are introduced, i.e. due to Ultra Low Emission Zone in London. Every vehicle used in the central area of London has to meet the agreed exhaust emission standard. The exemption was announced to be introduced in urban areas in Paris in France [2] as well as in municipalities in Greece and Germany.
- Exclusion of fees for infrastructure usage (i.e. parking fees, road tolls). Examples outside EU might be Norway where BEVs are exempted from road tolls and public ferries.
- Dedicated parking spots or allowance of using the bus lanes. The idea was implemented in certain municipalities in Estonia, Germany, Latvia and the United Kingdom. The councils of Amsterdam impose the priority rule for BEV owners when applying for parking permission [2].

4.2. Policy support and market share – assessment and methodology

As stated before a consistent and effective approach towards incentives for supporting the electric mobility development should address the needs and concerns of potential customers. Thanks to a variety of incentives supporting BEVs in EU decision makers, by observing trends in sales, can choose incentives that appeared to be most effective in real market conditions. Every incentive might be associated with certain customer concern (i.e. risk of limited range or high purchase price). Observation of sales and market growth can lead to an answer what are the most significant factors speeding up or slowing down BEVs market intake.

Below BEVs market share within years 2013–2018 were described and confronted with the introduction of supporting policies. Point A in *Figure 5* shows a great increase of BEVs market share in the Netherlands where purchase grants get on average 30% of BEVs price [18]. Such subsidies bring BEVs closer to the point when they can become more price competitive with ICE cars. Moreover, since 2015 zero-emission cars are being exempted from paying road tax, this incentive was followed by introducing in 2016 the exemptions of registration tax, circulation tax and the possibility for BEVs to be tax deductible investments for companies. They recuse the total cost of ownership of the car favouring BEVs over ICE vehicles [2].

In France and UK subsidies are slightly below 20% of BEVs price. In those cases, there is almost linear growth in BEVs market share (see point C in *Figure 5*) which correlates in time with i.e. introduction of tax credits and electricity tax exemptions in France (2016) or exemptions from congestion charging, free parking or reduction for company taxation in the United Kingdom [2].

Introduction in Germany similar subsidies for BEVs like in France and UK might have caused doubling BEVs sales and increase in market share (see point B in *Figure 5*) especially since before 2016 there was a scarcity of BEVs supporting policies [18]. In 2017 in Germany strong focus was put to offer rebates for purchasing BEVs that were provided both by automakers and government [2].

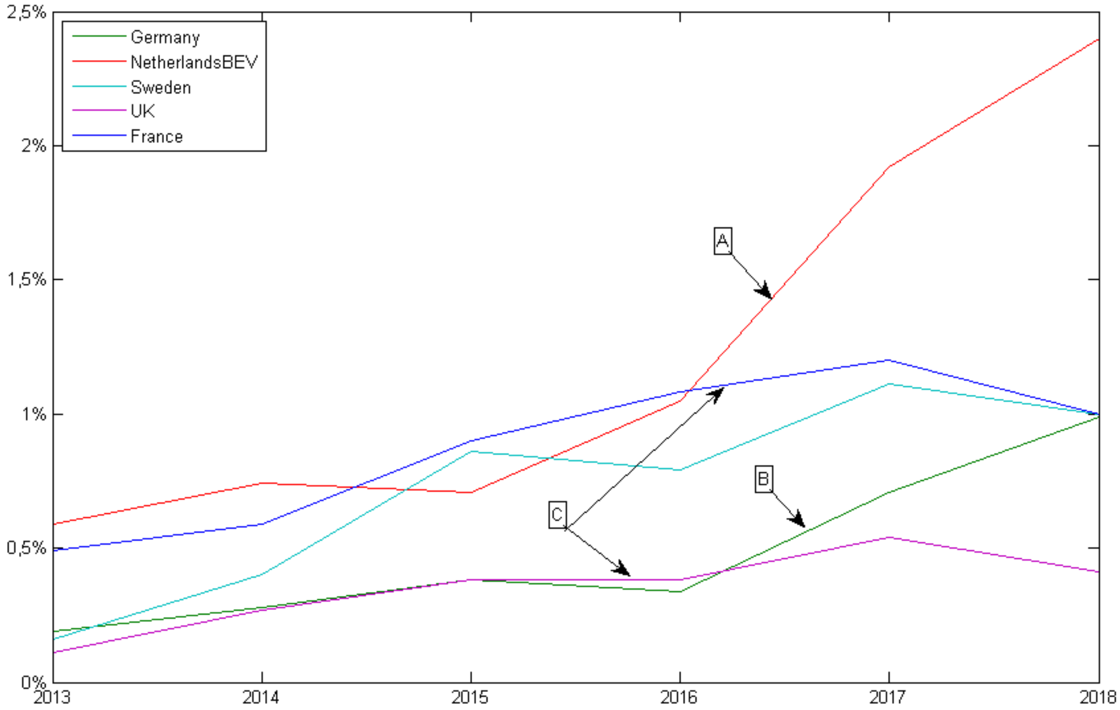


Figure 5 – Market share of new BEVs in selected EU countries [3].

This simple dependence and findings available in the literature suggest the possible relationship in which incentives play a significant role in BEVs market evolution. Considering only on market share growth, it is observable that majority of BEVs are sold in countries that designed throughout the last years a lot of very structured yet simple incentives. Incentives available to all group of consumers are supposed to be the most successful, considering the fact that vehicles buyers now fit into many groups: companies, private owners, car rentals, leases, car–sharing utilities or taxis [19]. The example of country outside of EU that offers simple incentive system with decreasing Total Cost of Ownership of BEV to ICE vehicle levels is Norway where i.e. initial grants can range between 40–45% of the car's price, which clearly attracts customers to invest in BEVs and justify the large market share for this technology in national mobility.

Correspondingly slowdown of market development might also be correlated with changes or withdrawal of certain policies. In the case of Denmark reintroduction of registration taxes in 2016 for BEVs after years of exemption and discontinuing of public procurement program could significantly influence the drop in BEVs sales by –68% (see point E in *Figure 6)* [2]. Fast increase of BEVs market share in Estonia between 2012–2014 was due to a public procurement program for the purchase and further management of so-called ELMO quick charger network. Funded by state ELMO was scheduled to come to an end in 2017 and be privatised [20]. As for 2017, there was 193 quick chargers and 191 normal power charging points. Estonia's further low figures of market share could be attributed to only one–dimensional support – lowering risk of range limitation for BEVs, instead of sustainable policy support comprising, i.e. purchase subsidies (see point F in *Figure 6*). In Poland, there are no official incentives supporting BEVs. It may have been the reason why the market share and consequently stock is deficient compared to other European countries (see point G in *Figure 6*) [12].

Even for PHEV technology, which can be associated with minor range limitation risk, lack of policies addressing customer needs can withhold potential buyers from deciding to purchase PHEV. From 2016 the Netherlands reduced their incentives for PHEVs along with differentiation of CO_2–based scheme of taxation. Registration tax for cars directly emitting CO_2 will increase stepwise in future years three times. Similarly, the increase will also apply to taxes for private use of company cars. The income tax on the private use of a company car for PHEVs and ICE cars will level off. It might have caused a drop in PHEVs sales between 2015 and 2016 by 50% (see point D in *Figure 6).*

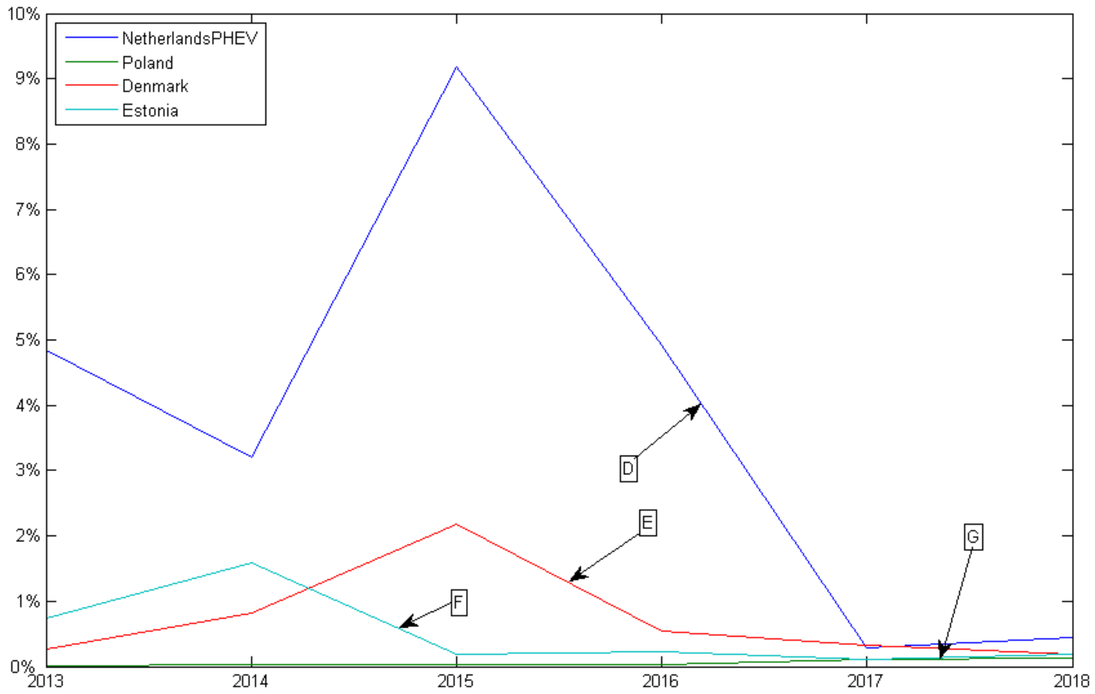


Figure 6 – Market share of new BEVs in selected EU countries and Netherlands PHEV market share [3].

Summing up European vehicle markets seem to be very multidimensional and complex. Figures above inform about specific tendencies for each country. As they cannot be a basis for formulating any further conclusions to indicate the aspects that influence the BEVs market development, it is convenient to perform statistical analysis. Assessment of market share between countries towards, i.e. incentive level or charging infrastructure development can give an idea of which area of supporting activities could have a determinative meaning. Moreover, it can answer the question of what activities and undertakings are crucial for the homogeneous development of electric mobility in EU. The following analysis was divided into two parts – quantitative part using correlation test and qualitative using Kruskal–Wallis one–way ANOVA test.

4.2.1. Correlation test

Correlations measure the degree of relationship between mostly quantitative variables. Correlation coefficients can take values from the range *<–1,1>.* The positive correlation means that when the value of one feature increases, the value of the other also increases. The correlation coefficient of *1* is the strongest positive correlation. Negative correlation, on the other hand, can be obtained when the value of feature decreases with the increase in the value of other feature. A correlation coefficient of *–1* means the strongest negative correlation. A coefficient of *0* means that the variables are not related in any way. One can distinguish two basic correlation tests. The r-Pearson linear correlation with obtained coefficient measures the strength of a linear relationship between two measurable features *X* and *Y*. A linear relationship means that an increase in the value of one of the features implies proportional changes in the mean values of the second characteristic (increase or decrease). The rho–

Spearman correlation is a nonparametric equivalent of the r–Pearson test. As in the case of parametric correlation, rho–Spearman coefficient also measures the strength of interdependencies between variables, however, in this case, a variable with a normal distribution is no longer required. In the case of the rho–Spearman coefficient, ordinal variables are used, so if quantitative variables are present in the test, they should be ranked. It is important to rank variables that stick to one convention of the scale, sorted in the right order – the increase or decrease of a given trait as successive rank parameters. However, if during the ranking the same observations are come crossed, i.e. for *k*-values there is the same rank in the group, the average value of the position is assigned to both (tied ranks). One of the additional benefits of rho–Spearman correlation is the reduction of the influence of outliers on the test result, which is an advantageous feature in small groups. Additionally, a ranking is necessary when the correlation between the quantitative variable (i.e. BEVs market share) and ordinal (i.e. a level of governmental support: low, medium, high) is checked, where the r–Pearson solution is not able to give us the correct answer for such issues [21], [22]. The general solution for rho–Spearman coefficient is given by:

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

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 [21], [22].

As in the case of parametric correlation r–Pearson, while using rho–Spearman it is also imperative to check the statistical significance of the dependence obtained. To perform it the hypotheses are made (see *Table 1*).

Table 1 – rho – Spearman correlation hypothesizes [21]

Null hypothesis	H_0: $r_i=0$; the dependence of features is irrelevant
Alternative hypothesis	H_1: $r_i\neq0$; the dependence of features is important

Where: r_i for i=1,..,n are the rho–Spearman correlation coefficient for n variables.

We use the test *t* to verify the hypothesis:

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

Where: r_s – rho–Spearman correlation coefficient, *n* – the number of observation in the group.

For a given value of *t*, value *p* is associated. The test statistics have a t–Student distribution with *n–2* degrees of freedom. The value *p* determined from test statistics is compared with the level of significance. Usually, in statistical analyses, the level of significance $p^*=0.05$ is adopted. If $p>p^*$ hypothesis H_0 is verified as true. If $p<p^*$ hypothesis H_0 is rejected in favour of hypothesis H_1 [21], [22].

In this work correlation test was used to indicate what influence BEVs market development in the highest degree. In line with what was stated in chapter *4.1 Factors influencing the BEVs sales* the chosen variables for assessment towards BEVs market share were presented in *Table 2.*

Table 2 – Description of variables used in test

Variable used in correlation test	Description
Incentives	a number of relevant incentives in the country, unlike in Kruskal–Wallis test when countries were divided qualitatively, here the ranking was made based on a number of existing incentives, which were summed up and categorised by source [12]
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 income per inhabitant
Ratio	a ratio of an electric vehicle price and average monthly income (in this case, averaged price of Nissan Leaf)

These variables are related to direct and indirect factors influencing the BEVs market development: the limited driving range along with long charging time, the high purchase price in comparison to ICE vehicles, society wealth level, and fuel price. For correlation, quantitative values were assembled from the year 2017 and to calculate the correlation between the variables rho–Spearman correlation coefficient was used, as the data do not have to be close to a normal distribution. Rho–Spearman uses the rank system so as data were limited to EU countries the influence of outliers on the test result was reduced [21]. The numerical value of rho–Spearman correlation gives the numerical coefficient describing the strength of dependence according to correlation force scheme for $|r_s|$:

- < 0.2 – no line relationship;
- $0.2 – 0.4$ – weak dependence;
- $0.4 – 0.7$ – moderate dependence;
- $0.7 – 0.9$ – quite strong dependence;

- *> 0.9* – very strong dependence [22].

4.2.2. Kruskal–Wallis one–way ANOVA test

The ANOVA analysis of variance is one of the most commonly used statistical analyses. There are several groups of ANOVA, for this research one-way analysis of variance was chosen. In this case, the goal is to check whether a single independent variable (different for each the sample groups) influence the level of the dependent, intergroup variable. Analysis of variance is the ratio of the variance that was calculated between the studied groups and the average variance that was observed inside the groups [23], [24], [25].

Since the aim of the research is to examine the impact of one intergroup factor on a dependent variable, one–way analysis of variance might be used. One–way analysis of variance, as the name implies deals only with one factor to check if it affects the measured dependent variable. The results obtained by the one–way analysis of variance can be considered true if the following assumptions are met:

- each population must have a normal distribution;
- samples taken for analysis are independent;
- samples taken from each population must be random simple trials;
- variations in populations are equal

If the assumptions of variance analysis are not met, the Kruskal–Wallis test should be used. This test is used as it does not require the fulfilment of, i.e. classic analysis of variance. Distributions of variables do not have to be close to a normal distribution. There is no requirement for the same number of samples as well as the equality of variance in groups is not required. The only requirements for the Kruskal–Wallis test are:

- dependent variable should be measured on an ordinal or quantitative scale;
- observations in the analysed groups should be independent of each other [23], [24].

With this test, one ought to compare the distributions of several variables (*k*) (see Table 3).

Table 3 – Kruskal–Wallis ANOVA hypothesizes [23], [24]

Null hypothesis	H_0: $F_1 = \ldots = F_k$ (all samples come from one population)
Alternative hypothesis	H_1: $F_1 \neq \ldots \neq F_k$ (not all samples come from the same populations)

The point of the test it to rank all the values investigated together, assigning the biggest value to the rank 1, the next 2, and the largest rank *n*. The repeated values have a rank that is equal to the arithmetic mean of ranks that would be assigned to them if they were different. Then the test is defined:

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

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 rank sum is calculated, and the Kruskal Wallis test determines whether these sums differ so much that it is unlikely that all of them will come from the same populations. If the all (k) variables come from the same population, test H has approximately the *chi-square* distribution with $k–1$ degrees of freedom, assuming that the sizes of the samples are not too small (i.e. $n_i \geq 5$). The null hypothesis is rejected at the significance level (described as α) if the statistic value H is not less than the critical value of the chi-square distribution for $1–\alpha=0.95$ and $k–1$ degrees of freedom [25]. In practice for the determination if there is any substantial difference between the medians of each group, significance level is used as the main assessment tool. Usually, a significance level of 0.05 is used in literature and was used in this case as well. The significance level of 0.05 gives a 5% risk of that the conclusion was badly interpreted – the hypothesis that not all samples come from the same populations were accepted whereas all samples come from one population. Significance level then shall be compared with computed from ANOVA table *p-value* (*p-value* determines the probability of obtaining the data assuming the null hypothesis). The general interpretations should be made as follow:

- *a p-value* is less than α: the differences between groups' medians are statistically significant, the null hypothesis can be rejected;
- *a p-value* is more than α: the differences between groups' medians are not statistically significant, the null hypothesis cannot be rejected [23].

Specifically for this test, to complement the quantitative analysis of correlation, the data were presented qualitatively. EU states were split into three groups by the level of incentive support for BEVs. Group 1 consists of states offering strong support with purchase subsidies, circulation subsidies like registration tax, ownership tax, VAT benefits. Group 2 consists of moderate support offering mainly circulation subsidies (taxes exemptions) combined with other, i.e. local incentives. Group 3 consisted of states with no significant support or with small local support or minor tax exemptions. A split was presented in the table below [12].

Table 4 – EU states divided into three groups based on a level of BEVs incentive support [12].

Group 1	Group 2	Group 3
Austria	Belgium	Croatia
Denmark	Finland	Cyprus
France	Greece	Czech Republic
Germany	Hungary	Lithuania
Ireland	Italy	Bulgaria
Malta	Latvia	Estonia
Portugal	Netherlands	Poland
Luxembourg	Slovakia	
Romania	Slovenia	
Spain		
Sweden		
United Kingdom		

4.3. Results of correlation and analysis of variance

After performing analysis Rho–Spearman coefficient for variables: *Incentives*, *PubChargers*, *AvSalary*, *Ratio*, *ChargersIn* (description in *Table 2*) were estimated to fit between moderate dependence level (see *Figure 7).* On the contrary, *AvFuel* variable describing average showed that almost no dependency exists between BEVs market share and pricing of fuel in EU states. Variables and consequently impact areas affect simultaneously and independently on the value of market share. None of them is a factor that ultimately pushes BEVs market development.

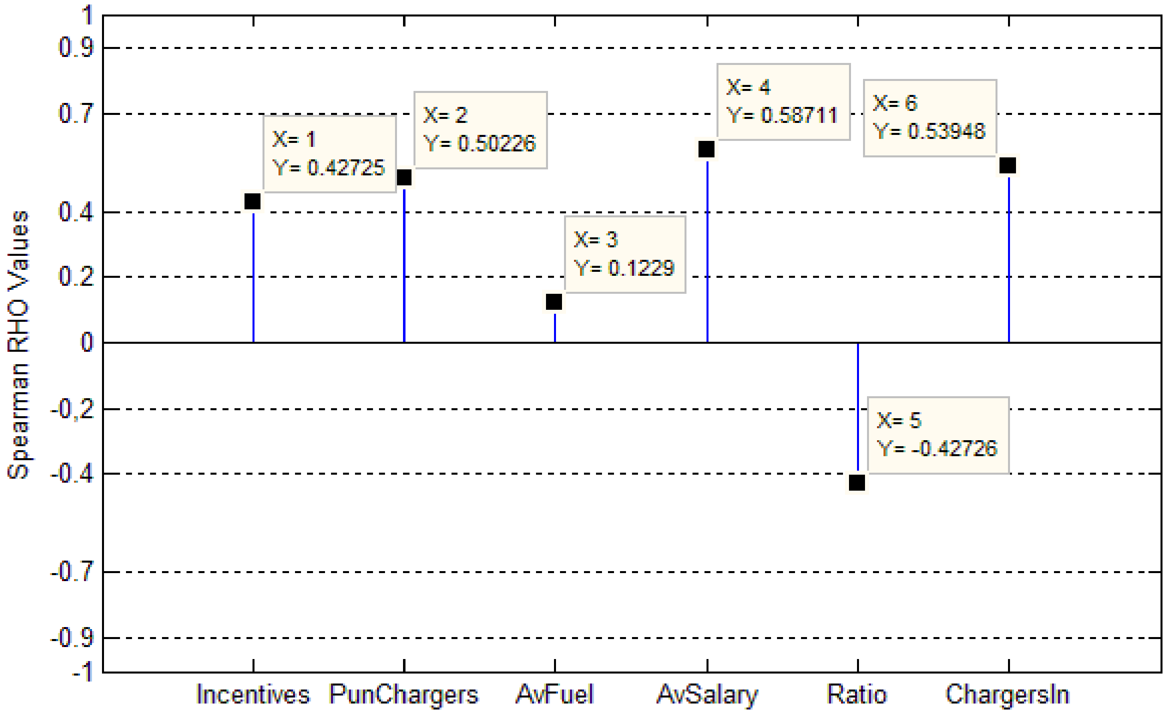


Figure 7 – Rho–Spearman correlation coefficients for variables [12].

As in the case of each parametric correlation, in this case, also checking the statistical significance of the obtained dependence is obligatory. As seen in *Figure 8* the only correlation with no significant value is the correlation between market share and average fuel price. Remaining values were classified within the significance level, especially the correlation between market share and public charging system (described by variables *PubChargers* and *ChargersIn*) and average income level per capita (*AvSalary*) appeared to be significant statistically.

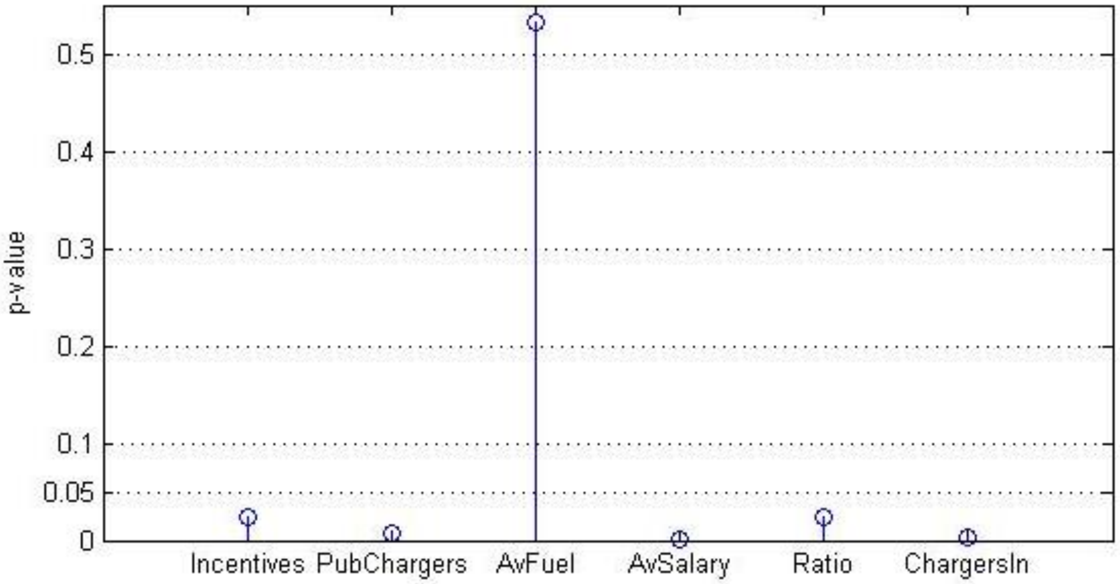
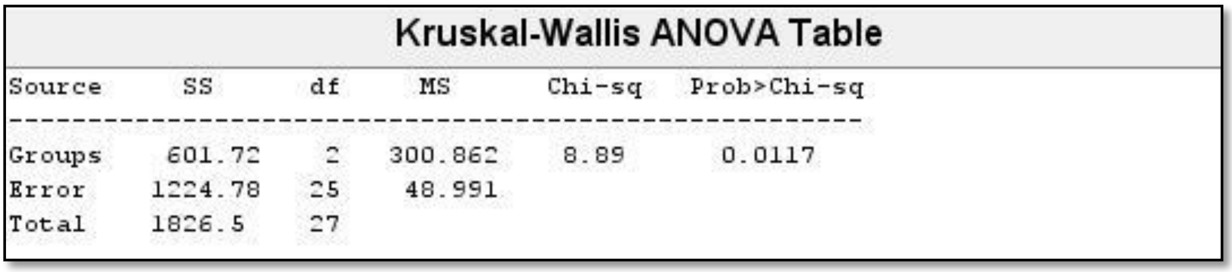


Figure 8 – Levels of statistical significance (*p-value*) for each variable [12].

Kruskal–Wallis test returned the ANOVA table (see *Table 5*) which consist of *p-value* (described as *Prob>Chi–sq*) of 0.117 which allows rejecting the null hypothesis. Three country groups have significant differences in the market share values at 5% significance level [24].

Table 5 – Kruskal–Wallis ANOVA Table [12].



Kruskal-Wallis ANOVA Table

```
Source     SS      df     MS      Chi-sq   Prob>Chi-sq
------------------------------------------------------
Groups    601.72    2   300.862    8.89      0.0117
Error    1224.78   25    48.991
Total    1826.5    27
```

The box plot below (see *Figure 9*) presents the summary of statistics for each country group visually. As the countries were divided into three groups, it is possible to observe the decrease in market share of BEVs along with the lower degree of incentive support. Each groups' result were labelled with median (red), upper quartile (25% of data greater than corresponding value) and lower quartile (25% of data lower than corresponding value) (blue) along with minimum and maximum (black). The first group consists of outlier value which corresponds to a high level of BEVs utilisation in Sweden. This qualitative assessment matches the qualitative one done for the correlation test.

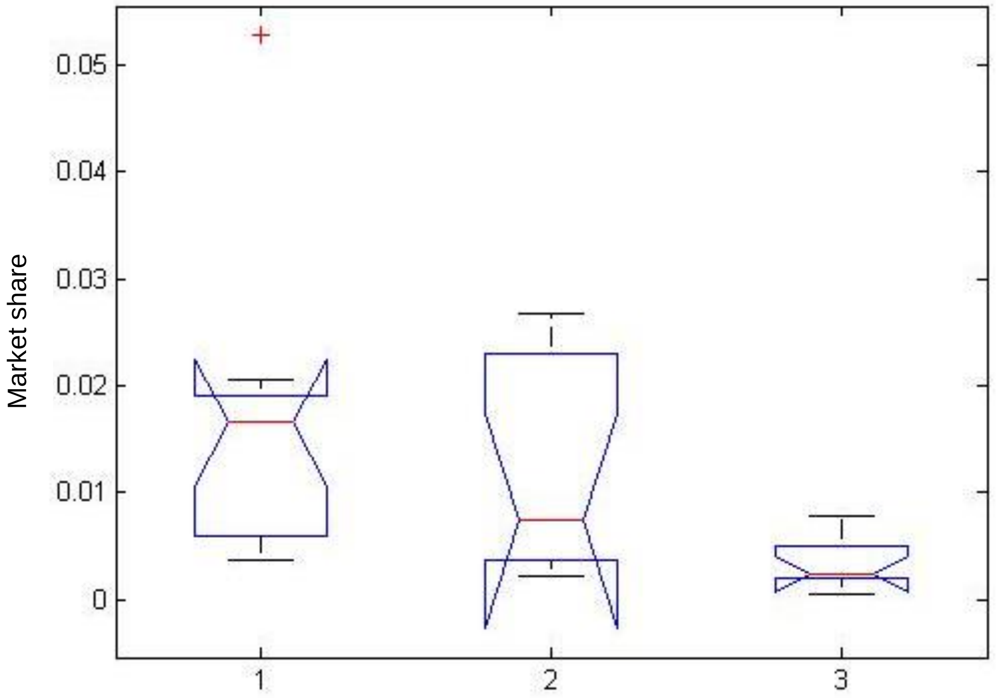


Figure 9 – Kruskal–Wallis box plot describing market share within the three countries group [12].

Results confirm the complexity of factors influencing BEVs market development. Due to a high association between financial incentives, society wealth and level of market share, the customer concern related with a high purchase cost of BEVs appears to be dominant. At the same time, a high level of market development is also conditioned by other circumstances like the number or density of charging point in the area. The results match the conclusions and lessons learned for publications based on data from past years (see [15], [26]) where charging infrastructure was stated as the best predictor of a BEVs market share in country followed by incentive and BEVs pricing levels. Similar results coming from the correlation test in this paper underline the key importance of charging infrastructure, however it also means that support mechanisms cannot be limited only to one way of support. This one dimensional approach is not sufficient to realise the EU goal to create the homogenous, consistent electric mobility intake.

The conclusions might be useful for the countries where the electric mobility market is low developed (i.e. group 3). The results outline the direction in which new policies should be established. They should primarily aim at reducing Total Cost of Ownership (especially the entry price of the vehicle) and guaranteeing well-planned charging point distribution. Building policy around customers concerns, in theory, guarantees the success although the decision–making process in energy policy proves to be a complex process. For instance, direct ways of increasing the BEVs competitiveness towards ICE cars, like incentives or supporting infrastructure, might not be reached effectively without rethinking the business model and mobility system [27]. The business model in case of mobility, is a plan for service or facility that describes how it will create revenues and make a profit. It clarifies what is the placement of the service within a market, establish the value offered to customers based on their needs and concerns and describes the workflow, partners, activities and estimate expenses [28]. The countries with well development electric mobility market (i.e. group 1) should invest in testing new business models to maintain the consistent increase of EVs market – as the grants and incentives cannot be constantly funded as it would create major expenditures in countries budgets. There are some estimations as well, saying that 10% of cars sold in 2030 will be shared cars falling into the category of *mobility–on–demand* service. The future support schemes should deal with the trends in business models innovation in transport and attitude change towards car ownership idea [29], [30], [31].

5. Impact analysis of BEVs increase on the power system and environment

5.1. Scenarios for electric mobility market development

As the electric mobility is regarded to have a major influence on decarbonising the transport industry – surely it will note the increase of the market share and stock in all regions of the world [32], [11]. A review of the literature on the BEVs market development is mainly built on the countries plans and targets and OEMs plans. Globally it can be summed up to two scenarios implemented in, i.e. IEA reports. Those scenarios are:

- NPS (New Policies Scenario), established by IEA in World Energy Outlook. Scenario incorporates the policies and ongoing or planned measures that governments plan to put into practice to meet imposed targets of electric mobility levels;
- EV30@30 Scenario, which describes the ambitions of Electric Vehicle Initiative countries to meet the EV30@30 Campaign Declaration. The campaign aims at achieving a target of 30% of the market share of electric vehicles at the global level in 2030. This campaign, if coordinated with decarbonisation of the energy industry can be compliant with the Paris Agreement.

Worldwide the EV30@30 Scenario predicts 228 million EVs (excluding two– and three–wheelers) of vehicle stock by 2030, while the New Policies Scenario forecasts around 100 million less [11]. This forecast seems to be valid in terms of OEMs plans. Throughout the recent years, nine global OEMs have publicly announced the desire to create or considerably expand the range of electric powertrain models within the next 5–10 year. Therefore BEVs stock resulting from OEMs targets can range from 9 to 20 million by 2020 [2] and 50 to 100 million in 2025 worldwide. Those fit between NPS and EV30@30 scenarios [11].

On the European scale, the market share of light-duty passenger BEVs is thought to be between 5 and 20%. The shares of other types of vehicles can be seen in *Figure 10* [11].

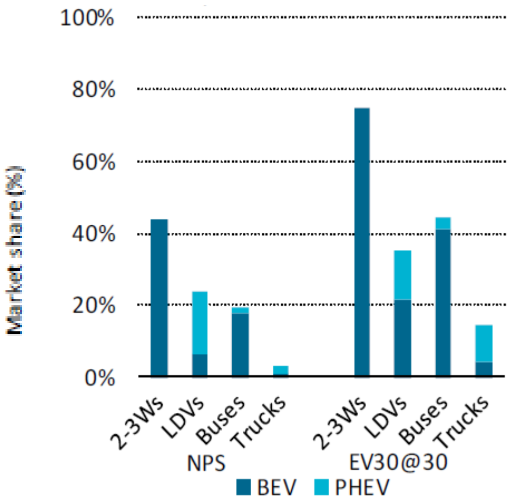


Figure 10 – EV market share by type of vehicle and scenario in Europe in 2030, according to NPS – The New Policies Scenario and EV30@30 – the EV30@30 Scenario. 2–3Ws are two or three wheelers and LDVs are light-duty vehicle [11].

According to *Bloomberg New Energy Finance* in the case of Europe, BEVs and PHEVs market shares could reach almost 5% of new car sales in 2021. In the long term, statistics say about achieving 30% of market share in 2030 (what is compliant with EV30@30 scenario), 50% in 2035% and 67% in 2040 being the fastest growing market exceeding China and USA [33]. The market growth CAGR rate within next years, according to various sources is estimated on around 20–25% (see [34], [35], [36]). CAGR is the compound annual growth rate, which is described as a mean annual growth rate of the market worth over a specified period [37]. What is more, recently EU experienced the 38% increase in sales of EVs between 2016 and 2017 while currently between 2017 and 2018 (May as the reference month) there is a 48% increase of sales [12].

Such fast yet uncertain deployment of electric mobility is the important challenge for the power sector. It can create new opportunities in terms of electricity sale, building new infrastructure and other services but also cause the problems related to the energy system on a local and national level [38]. European Parliament listed the areas that are highly vulnerable to BEVs energy capacity, those areas were briefly investigated in following subsections as they were summed to two major impacts:

- influence of an electric mobility market development on energy efficiency and CO_2 emissions in EU scale,
- influence on the change in energy demand, influence on capacity installed and electricity load within specific hours [3].

5.2. Impact of BEVs on the GHG emissions

5.2.1. BEVs exploitation under different primary electricity mixes

ICE cars undoubtedly are responsible for the largest lifecycle GHG emissions during the drive. Whereas BEVs are considered to be zero-emission cars (see, i.e. Nissan Leaf advertisement [39]) while driving, however, their electricity supply might cause significantly more emissions than fuel supply for ICE vehicles. The environmental benefit of BEVs usage strictly depends on the type of fuel used to generate electricity – primary energy mix [3], [40]. EU documents (see: [3]) estimate that with average energy supply, BEVs could generate up to 50% less GHG than conventional ICE vehicle. Consequently, most of the countries, not only within EU, set an ambitious goal to achieve high EV deployment within the 2020–2030 timeframe, i.e. 30% market share [11]. Although the targets set by EU seems to be strict but feasible, they were often generalised for all countries. Therefore the most important policy issue stated by EU is BEVs market development coordination, which depends on primary energy mix and BEVs impact on energy efficiency and CO_2 emissions for each country. EU Policy Department underlines the importance of creating additional reviews and studies of the environmental impact based on the very recent field data [3].

Studies mentioned above might be used for creating the environmental constraints for development of electric vehicle market and mark out the framework for energy management – in which direction should primary energy mix develop (i.e. in which renewable technology to invest or if the fossil fuels are really worsening the GHG emissions and to what degree). Moreover, they would be an important contribution to energy and transport management – which business models to support and how to adjust the policies. This chapter consequently reviews those issues through the better understanding the current impact of BEVs on environment taking into account the different profiles of the primary energy mix of EU states. To analyse this issue, a short calculation was performed. It aims to obtain the dispersion of GHG emissions of BEVs under the different primary energy mix and vehicle models to underline the need of providing the impact of BEVs presence on emissions. The most important characteristics of calculation were:

- primary electricity mix (described in fuel share) were taken into account, in five EU countries with different fuel mix profile (electricity share mix in 2017 [41] and CO_2–equivalent emission for each electricity generation technology [42])
- the efficiency of BEVs in two driving schemes: city and highway (specific efficiencies for each car in city and highway conditions (kWh/km) [43], [44], [45])
- citizens preference in buying BEVs, based on top-selling BEVs models in 2017 [12].

Five countries were chosen, each representing different electricity generation mixes – Poland with the majority of fossil fuel share, the Czech Republic with fossil fuels being slowly displaced, Netherlands with oil and gas dominated share, Germany which electricity mix is the most relevant to European average and Portugal with the high amount of renewable energy sources. The formula established for this calculation is presented below and estimates CO_2–equivalent emission while driving:

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

Where: s_i – CO_2–equivalent emission [g $CO_{2\text{–eq}}$/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 CO_2–equivalent released from obtaining 1 kWh in *j* country [g $CO_{2\text{–eq}}$/kWh].

The results were obtained and showed in *Figure 11* and *Figure 12*, they present big discrepancies in terms of carbon footprint, between the primary energy mix, driving scheme but also the BEVs efficiency in energy consumption. The box graphs were applied for showing the dispersion and closer analysis of BEVs emissions not relying only on arithmetical averages. The most significant impact of BEVs is logically present in fossil fuel-based energy generation in countries like Poland (mainly coal-based) or the Netherlands (mainly natural gas). BEVs are expected to reach the lowest efficiency while driven in highway conditions. The averages and conclusions were presented in chapter *5.2.3. Conclusions and environmental constraints for BEVs market development*.

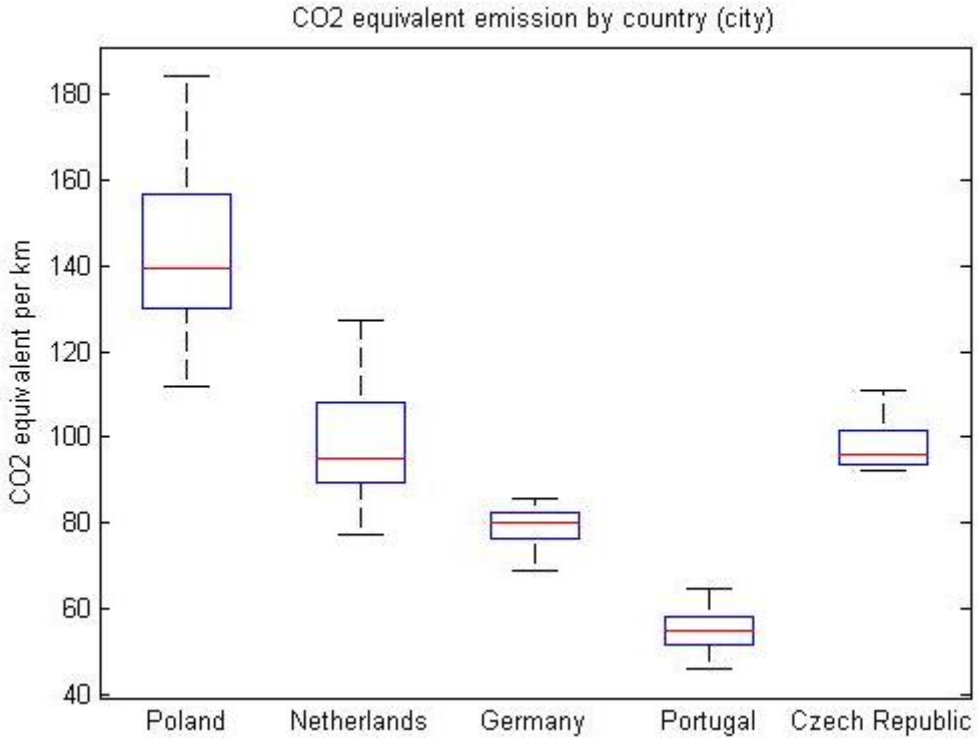


Figure 11 – CO_2–equivalent emission in city driving conditions per 1 km for BEVs within five chosen EU states [12], [41], [42], [43], [44], [46].

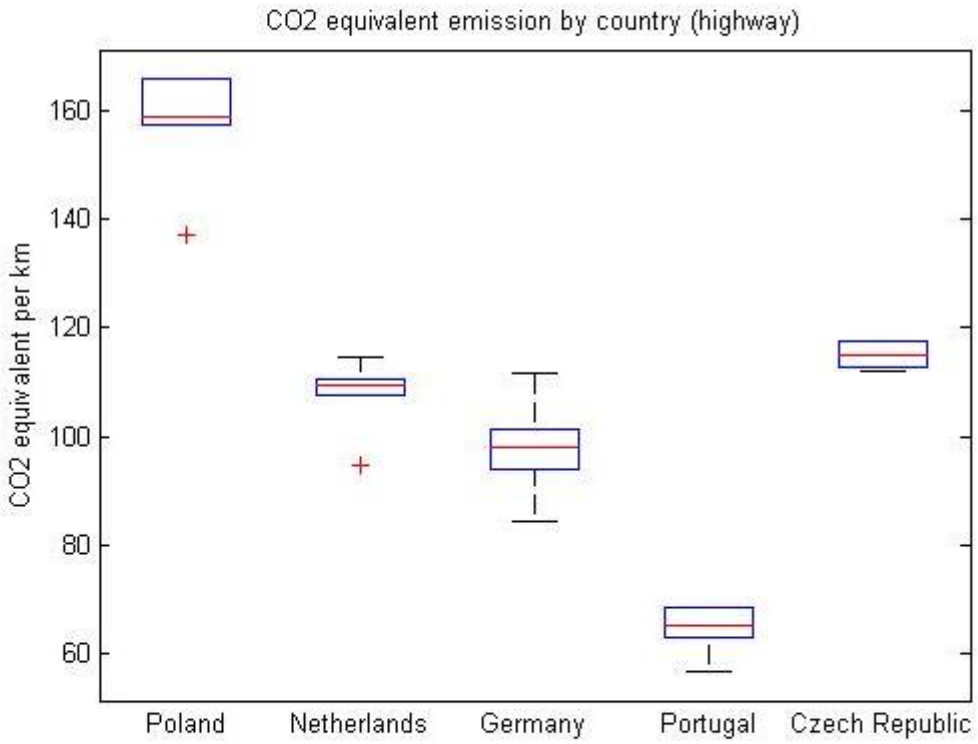


Figure 12 – CO_2–equivalent emission in highway driving conditions per 1 km for BEVs within five chosen EU states. The medians were marked with the red line, blue box fits the samples between 25th and 75th percentiles, minimum and maximum values were marked as black “whiskers”, the red crosses ticks “outliers” – the values that are more than 1.5 times away than the top and bottom of the box range [12], [41], [42], [43], [44], [46].

5.2.2. Lessons learned from Life Cycle Assessment of BEVs

For better fulfilment of the need of assessing the impact of BEVs market development of GHG emissions, it is imperative to supplement the data from the previous chapter with the data about the emissions attributed to a whole life cycle of the vehicle [3], [47].

Life cycle assessment (LCA) contains a specific methodology that is used for environmental assessment of any product or service. It deals with all processes that are connected with the product even for its creation until utilisation [48]. LCA of BEVs is done by analysing the product mass and energy fluxes throughout the life cycle. Usage of LCA proved itself to be a very suitable method for analysing and computing the environmental impact of given product. Over the last two decades, it became vastly accepted and approved on an international level. LCA has also been standardised to International Organization for Standardization norms, i.e. ISO 14040 or ISO 14044. Typically it is summed up to four successive steps: definition of goal and scope; analysis of inventory; assessment of impact, results interpretation. By definition of goal and scope, it is understood as a clear description of system boundaries and functional unit. Inventory analysis is aiming at understanding the input and output flows observed within the described system as well as pointing out the interaction with the environment (the input-output balance described in the functional unit). Impact assessment is the review of potential environmental impacts that come from extracting resources and from released pollutants. Emissions should be classified in terms of contribution and expressed in impact equivalents, i.e. in CO_2–equivalents ($CO_{2–eq}$). Finally, results should be presented in a way that it is possible to derive clear conclusions and perform future sensitivity and uncertainty analyses [49].

As previously stated ICE cars and BEVs have their maximum GHG emission at different life–cycle levels. While BEVs might have scarce emissions in operation cycle, emissions related to energy and equipment production, combined together, might exceed ICE vehicles if the unfavourable primary energy mix is used for electricity production (i.e. based on the previous chapter, such energy mix might be based on major usage of fossil fuels). To better explain the life cycles one can use the *Figure 13* for their placement in a complete life cycle.

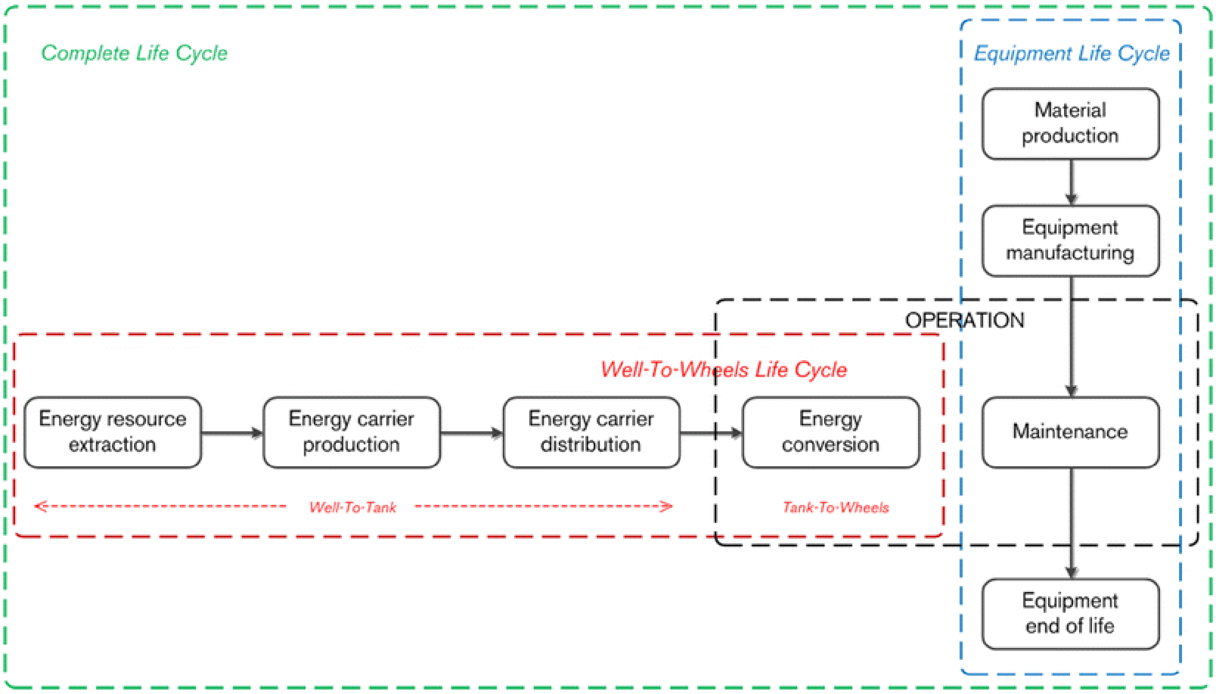


Figure 13 – Simplified scheme of vehicle life–cycle and equipment [40].

Taking into consideration life-cycle emissions presented on *Figure 13*, environmental footprint of Well-To-Tank and Tank-to-Wheels cycles were presented on *Figure 11* and *Figure 12.* Those cycles deal with energy resource extraction, production, distribution and conversion according to primary electricity mix, and also final conversion according to car efficiency and driving scheme. *Figure 14*, on the other hand, deals with the so-called equipment life–cycle. They aim at showing the GHG emissions values that should complement the *Well–to–Wheels* emissions. The summed emissions altogether should be the base on which the BEVs could be compared with ICE vehicles. As glider and powertrain do not appear to cause a notable difference in emissions, a surplus is generally created by battery pack production (it adds an average of 12 g of CO_2–equivalent to overall life–cycle emission under certain constraints (see *Figure 14*). The emissions breakdown was presented for the LMO battery. The LMO battery comprises of lithium manganese spinel cathode which is widely used by passenger car producers like Renault-Nissan-Mitsubishi Alliance.

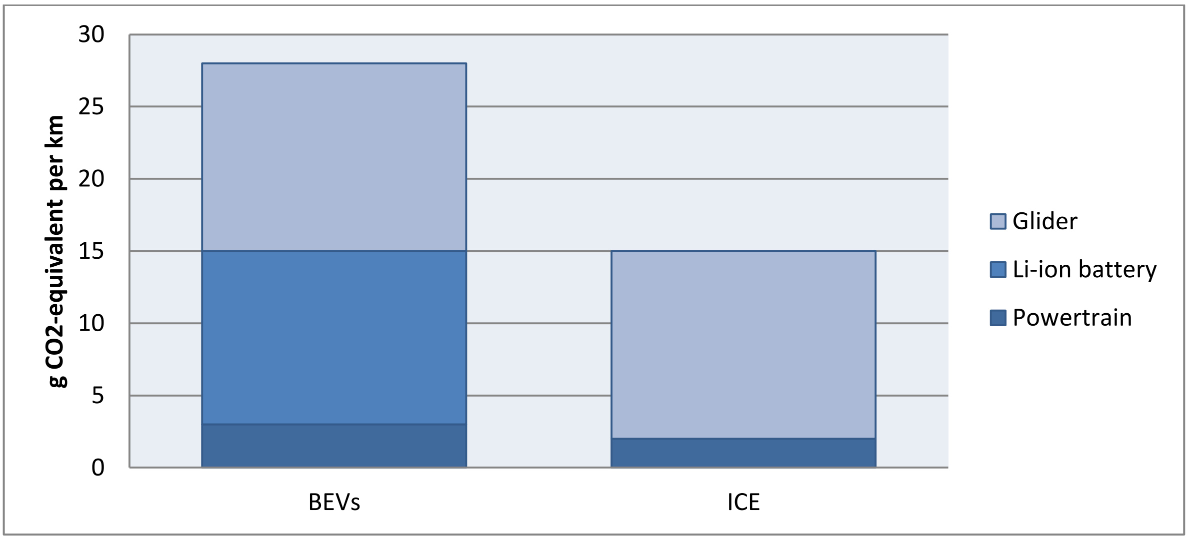


Figure 14 – Emissions of the glider, powertrain, and Li-ion battery packs (material production and further manufacturing) on the life–cycle carbon footprint of vehicles. The lifetime of 200 000 km is taken into account, an average weight of the glider equal to 1200 kg and 30 kWh LMO Li-ion battery (average of 55 kgCO_2/kWh) with electricity consumption – 0.2 kWh/km. Battery replacement after 150 000 km driven is included [48].

The Equipment Life Cycle attributed emissions is sensitive to the lifetime of the vehicle, more precisely to driven distance. Shorter lifetime such as 150000 km increases the impact of the equipment up to 46 g CO_2–equivalent/km. As the production of equipment is not done under homogenous primary energy mixes, this amount can raise even to 80 g CO_2–equivalent/km if applying energy intensive condition [46], [47]. As it is seen in *Figure 15*, there is a tendency for carbon footprint to drop along the increased total mileage of BEVs.

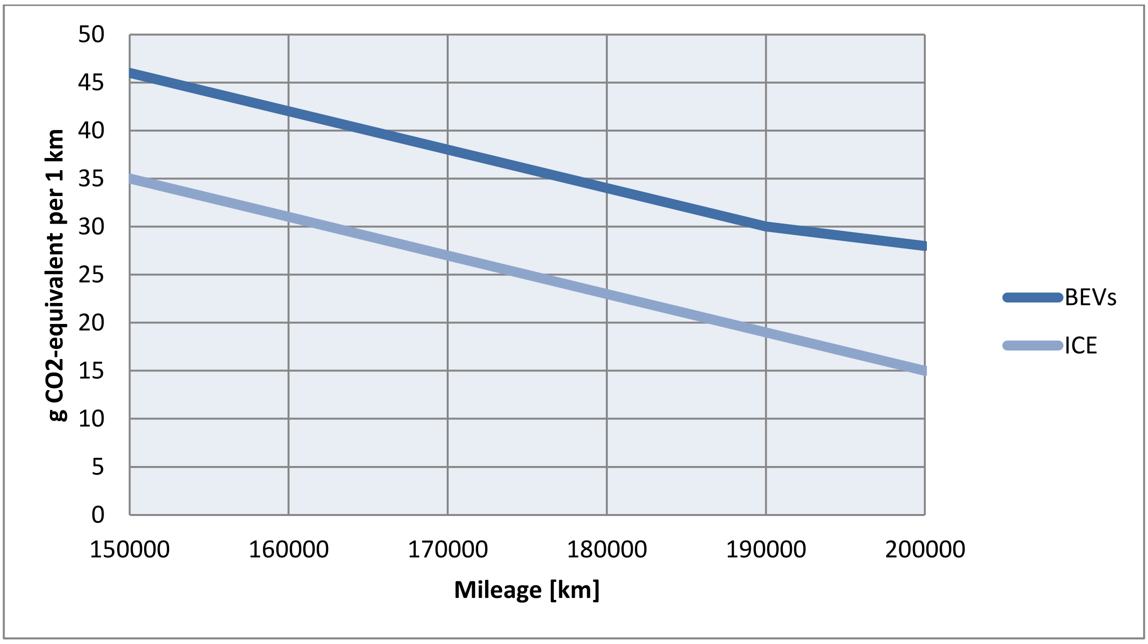


Figure 15 – Sensitivity analysis of carbon footprint within the different mileage of vehicles [47], [48].

5.2.3. Conclusions and environmental constraints for BEVs market development

The need for developing additional reviews and studies of the environmental impact of BEVs based on the recent field data were expressed, i.e. in EU papers [3]. The two previous chapters consequently aimed at understanding the present impact of BEVs on an environment that might also work as an indicator and constraint for current and future BEVs market development [2]. The hypothesises coming from the literature stated the positive attitude towards BEVs potential to reduce GHG emissions (see [3]) or expressed the doubt about the carbon footprint of BEVs (see [47], [49]). The simple calculations based on current available data ([43], [46], [44], [42], [12], [41]) proves the uncertain carbon footprint of BEVs but can be base for formulating some conclusions.

The key environmental constraint for the development of electric vehicles market lies in CO_2 and CO_2–equivalent emission which varies depending on several factors. Although BEVs seems to have a lower influence on CO_2–equivalent emissions than ICE cars in *Tank–to–Wheels* cycle, summed emissions in *Well–to–Wheel* cycle are no longer that much superior. BEVs market development needs to meet improvement of primary electricity mix with renewable energies introduction and improvement of fossil fuel generation efficiency what would significantly lower CO_2–equivalent emission. Data in *Figure 11* and *Figure 12* suggest that intensive application of certain types of BEVs in fossil fuel-based energy generation countries like Poland might pose a slight counterproductive effect or in certain cases be neutral like in the Netherlands. In those countries, emissions values change remarkably depending on the type of vehicle and driving conditions. On average they reached correspondingly 147.8 and 103.9 g CO_2–equivalent/km. These values plus additionally averaged 12 g of CO_2–equivalent coming from battery pack can give, in some cases, the comparable or exceeding values with average emissions from ICE vehicles (see *Table 6*).

In comparison, the average level of emission for a new (ICE) car that was sold in 2017 was 118.5 g of CO_2–equivalent per kilometre (*Tank–to–Wheels*) [50]. Specifically for countries listed in this paper, the data for ICE cars were presented and compared in *Table 6*. Similarly to calculations for BEVs, new passenger cars were taken into consideration, that is why there are differences between emissions coming from car buyer preferences in each country.

Table 6 – Average emissions from new passenger cars by selected countries. BEVs emissions are city and highway emissions combined in g CO_2–equivalent/km based on the data presented in *Figure 11* and *Figure 12.* Data for ICE vehicles are described in grams of CO_2/km due to lack of specific data for the CO_2–equivalent unit. However for instance for a petrol engine, the value of g CO_2–equivalent/km might be up to 2–3% higher [12], [41], [42], [43], [44], [46], [51], [52].

Country	Average emissions from new passenger cars (g CO_2–equivalent/km)	Average emissions from new passenger cars (g CO_2/km)
	BEVs	ICE vehicles
Poland	147.8	141.4
Netherlands	103.9	109.1
Germany	87.8	136.1
Portugal	56.8	108.8
Czech Republic	105.8	134.6

In general, the main conclusion is that countries with fossil fuel-based profile of primary energy mix should establish market penetration strategy which is focused on complementary usage of electric vehicles (i.e. exploring the business model of car sharing or fleets operated in cities) rather than direct substitution of existing combustion engine cars. Such countries represent the primary energy mix with a presence of renewables in share with less than 15%. The Czech Republic renewable share achieved 12% nevertheless the fossils like coal are highly substituted by nuclear power (29%). Neutral impact in the Netherlands (15% renewables) is achieved by applying clean fossil fuel technologies and pilot projects supporting this energy branch and surely usage of natural gas as less carbon-intensive fuel. Germany has the sustainable policy with highly differentiated sources of energy. Along with Portugal represent a level of renewables above 25%, what guarantees low impact of BEVs car in comparison with ICE vehicles even with the added value of CO_2 coming from battery pack production [53].

However worldwide projections for 2030 tell that CO_2 emissions linked with the use of electric mobility will be significantly lower (29% less) than those of ICE vehicles even if the neutral scenario is applied and electricity generation does not decarbonise further. The decarbonisation according to NPS scenario would lead to a reduction of CO_2 emissions by 42% [11].

Furthermore, it is worth to mention that many data regarding CO_2 emissions from ICE vehicles are determined using the New European Driving Cycle (NEDC) which does not give the real driving results. For instance, the average fuel consumption and consequently emission might increase even to 160% with reference to base value what proves the high potential of BEVs market development even in fossil fuel-based countries. Moreover, the market development of BEVs can be successfully done under sustainable primary energy mix with differentiated sources of energy [54].

From policy and business side, discrepancies within data in *Figure 11* and *Figure 12* also suggest that BEVs supporting policies should be focused not exclusively on the numbers of electric cars in stock or electrification degree but also on the type of vehicle since not every vehicle present the same environmental impact. Moreover, BEVs driven on highways emitted 9–24% more of g CO_2–equivalent. BEVs prove in this case their benefits towards ICE cars in terms of urban driving. The electric engine performs better in an environment with many stops, congestion, and traffic due to regenerative braking system which recovers energy and the fact that engine is not working during stops, unlike in standard ICE vehicles. As EU stated the need for "*the new mobility patterns supporting the use of electric vehicles"* [3], these conclusions confirm the strong point in BEVs utilisation in cities and trials to implement business models fitting the urban driving and commuting schemes seems to be valid from environmental side. Especially in the cases when ICE cars, solely in city driving, can achieve values of emissions more than 200 g CO_2–equivalent [48]. Another constraint for mobility patterns is intensifying BEVs usage what brings the benefits in decreasing CO_2–equivalent emissions from equipment life cycle (see *Figure 15*).

5.3. Impact of BEVs on the power system

In 2014 the EVs stock in Europe reached around 85.8 thousands vehicles. The electricity demand attributed to them was around 0.03% of the total electricity consumption that year [55], which corresponds to around 0.98 TWh [56]. Although the stock rose in recent years almost threefold (see *Figure 2*) in 2017 the electricity demand for EVs combined did not exceed 1.5 TWh within European countries [11]. The electricity demand trajectory for the electric mobility is also defined by NPS and EV30@30 Scenario that were described in *5.1 Scenarios for electric mobility market development.*

Scenarios indicate an increase in electricity demand that can be positioned between 73 and 167 TWh in 2030 (*Figure 16*) [11]. For better understanding, 167 TWh is comparable to electricity generation by Polish energy system in 2017 [41].

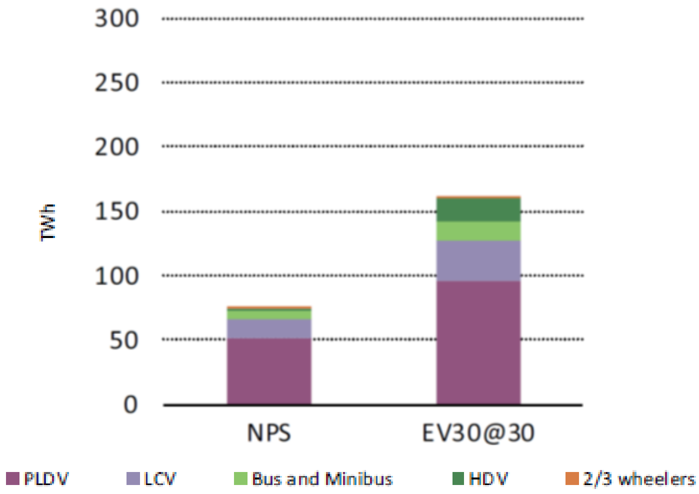


Figure 16 – Electricity demand attributed to electric mobility by two scenarios (NPS and EV30@30) by 2030 in Europe. Description: PLDV – light-duty passenger vehicle, LCV – light commercial vehicle, HDV – Heavy duty vehicles. Assumptions like average range and fuel consumption were taken for each vehicle category, charger losses assumed to reach 10%, and electric mode in PHEVs is 80% of the annual range [11]

Taking into considerations the sales growth for the EV market, EU experienced in recent years a substantial increase in sales (around 40% annually [12]). For next decade, however, it is uncertain that the sales will be increasing in such pace. Sources like [57] project fluctuations between annual sales growth between 20% and 42% depending on the year, with an average annual rate around 35% till 2030, what means 7.5 million of EVs sold in 2030.

The graph below presents possible growth in energy demand yearly 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.

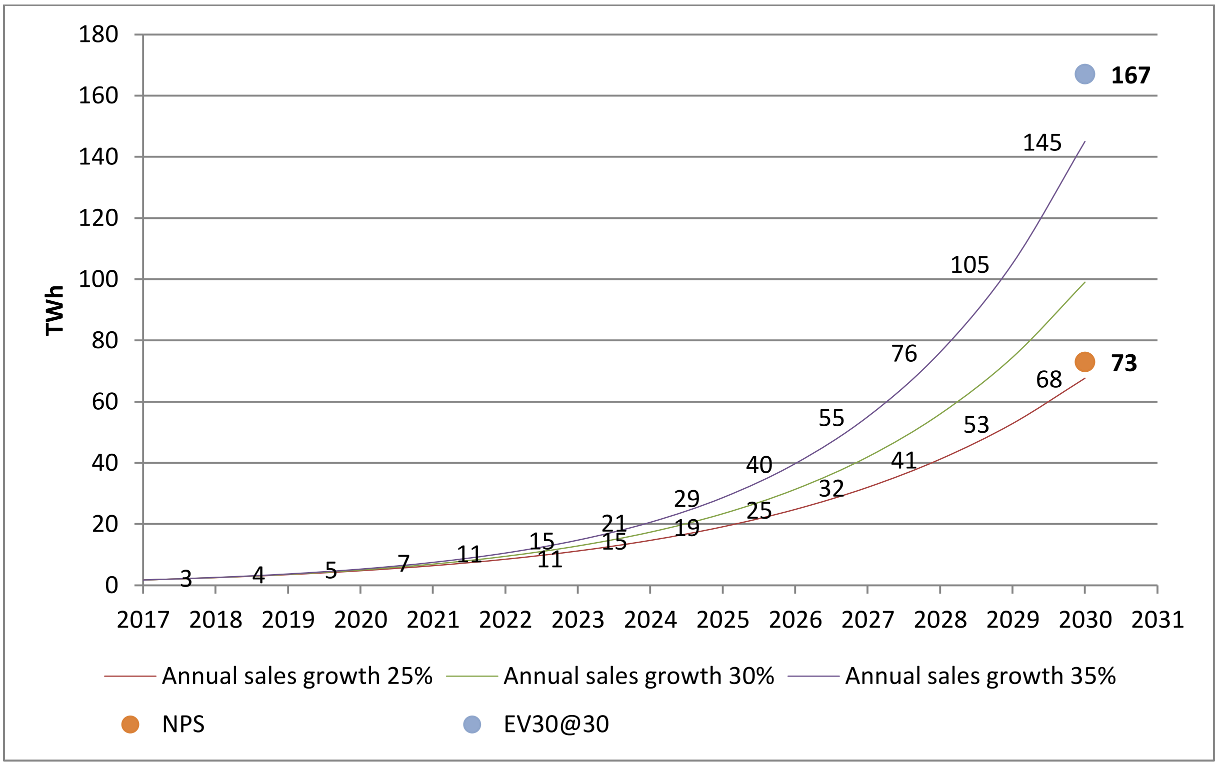


Figure 17 – Forecast of electricity demand attributed to EVs according to average sales growth till 2030. Electricity demand was calculated based on averages: yearly EVs mileage 15000 km and electricity usage 24kWh/100km. The ratio of electric drive for PHEVs was calculated incrementally for each year from 36% in 2017 to targeted 80% in 2030 [11]. The numerical data on the graph (electricity demand in TWh) is related to demand in corresponding years marked on the x-axis for sales growth 35% (purple line), 30% (green line) and 25% (red line) scenarios. NPS stands for New Policy Scenario while EV30@30 is EV30@30 scenario based on a target of having 30% of market share of EVs by 2030 [11], [12].

As it is expected, further introduction of electric mobility will generate the increase in electricity demand which is prone to high uncertainty depending on sales increase pace but also technical issues like electricity consumption or driving patterns of users. Generally, the projections like NPS and EV30@30 scenarios fit within the assumed averaged sales growth levels between 25% and 35% per year (specific values for electricity demand were highlighted on the graph).

In the long run, it is hard to forecast the accurate electricity demand even further, i.e. till 2050. Nevertheless, using the backcasting method, it is possible to give an idea of how the demand will shape for electric mobility. Backcasting is the technique which uses a precisely defined target or the outcome in future and predicts the way of achieving it backwards meeting present conditions [58].

According to European Alternative Fuels Observatory EAFO planned transition of the car fleet to 100% BEVs will contribute to drop in energy need from 9985 Peta Joules used in 2016 to 2197 Peta Joules in the year 2050. That means almost 610 TWh solely electric power used by the car fleet. The real amount, however, might be different because the estimations do not provide specific losses due to conversion, transport and production. Rapid innovation in charging technology and overall manufacturing in the automotive sector might also contribute to an energy value in this case, also driving patterns are playing a major role in establishing accurate values. Below two scenarios included in EAFO report was taken into account, both of them assume 100% of sales share of ZEV (Zero Emission Vehicle, a mix of BEVs, FCEVs and others) after 2035 to achieve 100% of ZEV in car fleet in 2050. Using the backcasting method, it is possible to estimate the car fleet and consequently electricity that has to be provided. The two scenarios are:

- *ZEV (Zero Emission Vehicle) Base Case*, which assumes a ZEVs (which consist mainly of BEVs) sales share of 35% in 2025, 70% in 2030, and 100% in 2035; with a final fleet of 170 million of BEVs cars in 2050.
- *PHEV bridging*, which assumes ZEVs sales share of 10% in 2025, 30% in 2030, and 100% in 2035 with high share of PHEV till 2035 (25% in 2025, 35% in 2035 and 0% in 2035); with final fleet of 200 million of BEVs cars in 2050 [59].

These two scenarios are the base for an approximation of electricity demand in period 2030-2050, estimations were presented in *Figure 18.* The values were collocated with *Bloomberg New Energy Finance* forecast up to 2040 and previously mentioned and described NPS and EV30@30 scenarios for 2030.

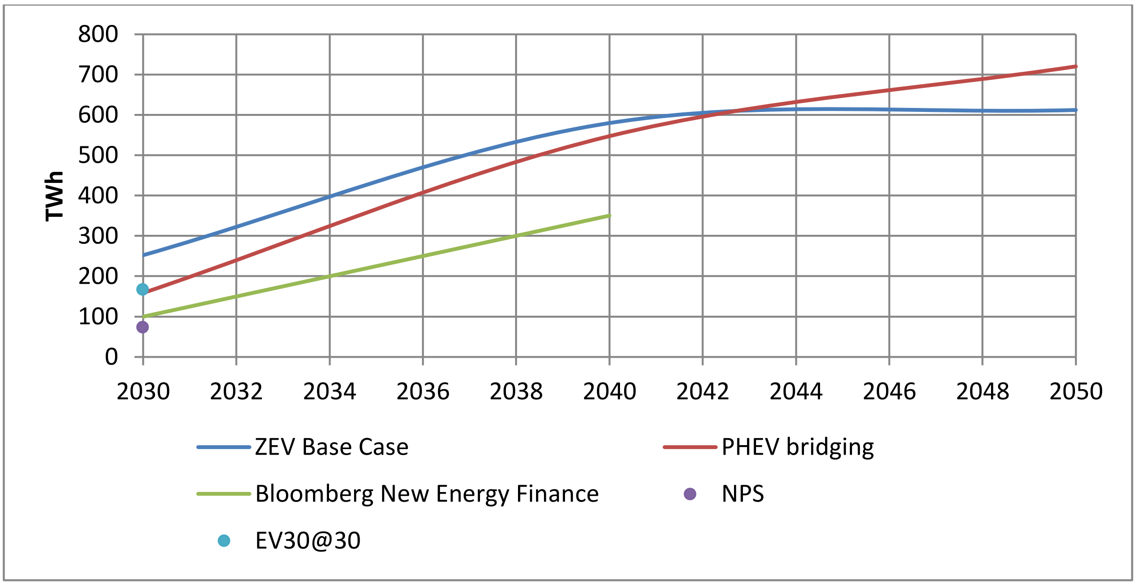
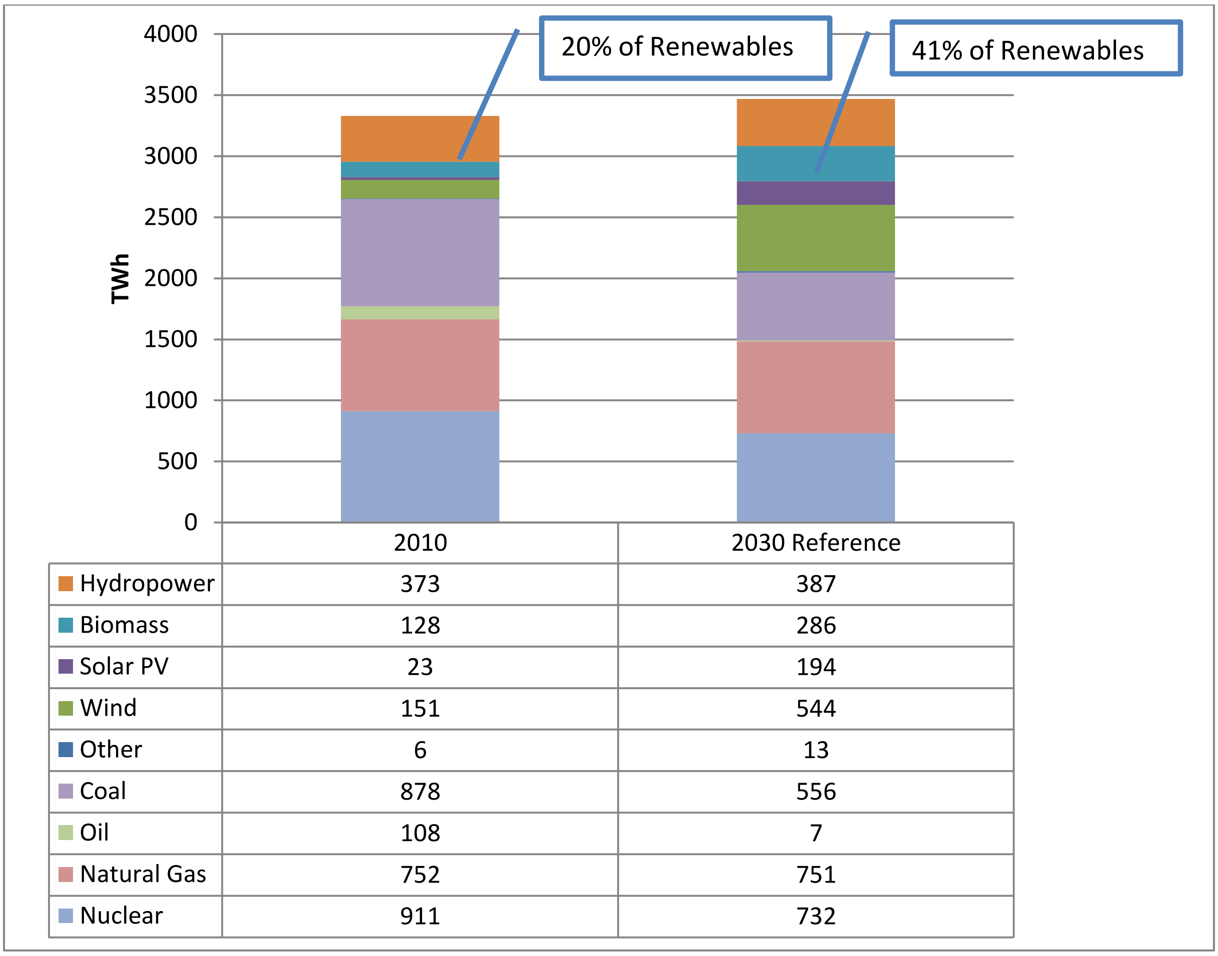


Figure 18 – Electricity demand considering assumptions of 100% electric vehicle fleet in 2050. For *ZEV Base Case* and *PHEV bridging* scenarios electricity demand was calculated based on averages: yearly EVs mileage 15000 km and electricity usage 24kWh/100km. The ratio of electric drive for PHEV is not less than 80% [59], [60].

Both scenarios estimate the electricity demand at the level of 600-700 TWh in 2050 what in relation with 2030 it is a 150-350% increase [59]. The *PHEV bridging* is perhaps closer in terms of electricity demand to earlier projections that used forecasting method with annual growth sale rate.

The current goal is to position this additional energy that has to be generated in the resources that can provide a low carbon impact. Taking into account the projections in *Figure 16*, current electricity generation profile in Europe and the profile for 2030 *"Reference Case"* (this projection implement the current national energy plans and goals to 2030 within EU states) it is possible to estimate the possible share of electricity demand attributed to electric mobility. *Figure 19* presents the previously mentioned profiles.



	2010	2030 Reference
■ Hydropower	373	387
■ Biomass	128	286
■ Solar PV	23	194
■ Wind	151	544
■ Other	6	13
■ Coal	878	556
■ Oil	108	7
■ Natural Gas	752	751
■ Nuclear	911	732

Figure 19 – Electricity generation by source/technology in EU in 2010 and according to 2030 *Reference Case* in TWh [32].

The key point is that the electricity generation projected for 2030 might achieve the value of 3470 TWh in which 1411 TWh would be produced by renewable energy sources (the given values are summed power generated by technology; moreover hydropower, biomass, solar PV, and wind were assumed as renewable sources of energy) [32]. Referring it to data from *Figure 16*, electricity demand attributed to electric mobility in this care will probably consume around 2.1% (for NPS Scenario) or 4.8% (for EV30@30 scenario) of projected electricity generated in Europe in 2030. In case of the most extreme, backcasting scenario of EAFO (*ZEV Base Case*) it will not exceed 7%. It can be covered in a high degree by renewables as the projection state 41% of renewables share in electricity generation.

There are many doubts if those percentage values put electric mobility as an obstacle or a challenge for electricity generation system or grid capacity [11], [3]. The impact of electric mobility in general, the worldwide case was investigated and according to IEA reports is manageable. For instance, the impact from growing EVs development was compared with impact from industry growth, increasing consumption within buildings as well as growth coming from transport and other sources. The results are shown in *Figure 20* – the simulation was done for projections for 2030 under 2DS (IEA Two Degree Scenario worldwide, mentioned in the introduction) [2]. The simulation in *Figure 20*, shows the increase in electricity demand in 2030 with reference to 2015 and split this demand among the responsible sectors. It is visible that electric mobility plays a minor role in demand increase – it will probably account for 6% of the general demand growth from 2015 to 2030, coming from the sectors mentioned above (industry, buildings, transport and other, EVs) [2].

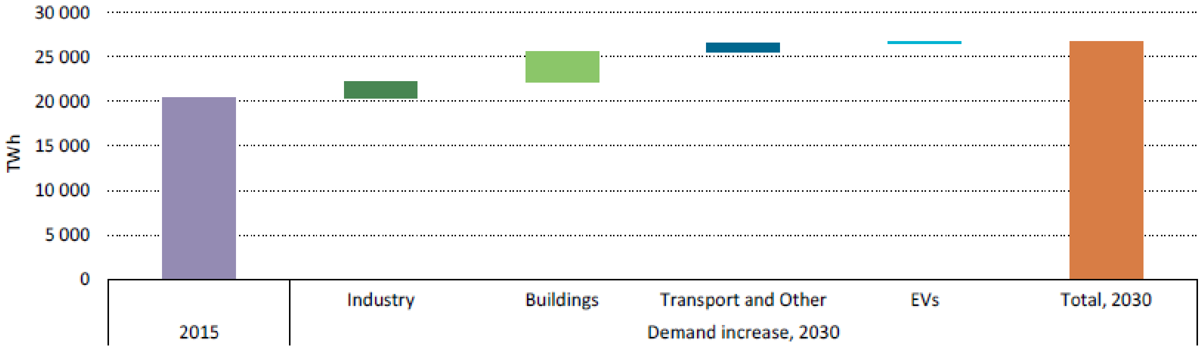


Figure 20 – Electricity demand growth (TWh) attributed to several sectors/sources in 2030 with reference to 2015 for 2DS Scenario [2].

Later on, as previously stated, if the projected electricity demand reaches the 600-700 TWh and expected electricity consumption in EU is not exceeding 5000 TWh as it is predicted by European Renewable Energy Council in 2050 (see: [61]), the electricity demand attributed to electric mobility will consume up to 12-14%. This is the comparable value with current reports, i.e. Bloomberg's *New Energy Outlook* which estimates electric mobility global demand share at the level of 9% in 2050 and indicates that in case of well-developed countries like Germany this value can reach even 24% of electricity demand by 2050 [62]. European Environment Agency states electricity consumption by electric cars in 2050 up to 9.5% of total demand in EU and underlines the significant spread between countries. The fluctuations between EU members can reach from 3% to 24% of the country's energy supply directly consumed by electric mobility. The difference between EAFO scenarios and European Environment Agency scenario is mainly caused by different electric vehicles sales share. European Environment Agency assumes 80% share of electric vehicles in the car fleet in 2050 [63]. In terms of demand increase, between 2030 and 2050 the electricity consumption is thought to increase by 1500 TWh. Considering the difference between demand attributed to electric mobility in 2050 and 2030 (see *Figure 18*), the share of the general demand growth till 2050 consumed by electric vehicles can reach more than 30%.

The assumption that the increase in demand for EVs is manageable comes from the premise that the development of EV market will happen along with the improvement of energy and grid efficiency and natural growth in installed capacity. It also counts the increase in renewables, i.e. in distributed generation and the improvement of the battery system and EV energy efficiency [5]. Although the conclusion is that general increase of demand attributed to EVs is manageable (at least in the next years, when e-mobility demand will consume up to 5%) and does not need to be mitigated, there were some concerns about the influence on electricity networks as EVs, especially BEVs, are not stationary loads. This is visible especially in the long run since the increase in demand past 2030 attributed to e-mobility is going to be the major issue.

Electricity networks are expected to give sufficient and quality service. Incorporation of the new loads to the grid must be done along with guaranteeing enough capacity available on demand. The vehicles are likely to impact low–voltage distribution grids as BEVs, for instance, are expected to be charged in homes and public charging facilities. This impact on the distribution grid is also highly dependent on charging patterns and charging technologies. BEVs charging patterns are described by the location, time and quantity of power transferred from charging infrastructure. Also, different BEVs and PHEVs charging patterns might result in different capacity required at certain times and locations [2]. Generally, road mobility is characterised by two peaks – they are concentrated in morning and evening hours. The power demand has its peak during evening hours while periods of low demand are during the night time. Electricity demand peak in the evening usually follows the traffic peak [11]. Uncontrolled charging might lead to simultaneous charging during evening hours, and that would result in demand accumulation and the rise of existing peak load further causing the stress upon existing infrastructure [11], [64], [65]. As an example on *Figure 21,* the electricity demand load for an average day in EU was presented with PV generation, averaged uncontrolled EVs charging scheme and combined net load with PV and charging together. Intermittent nature of PV generation would likely lead to mitigation of demand during the day whereas uncontrolled charging behaviours would result in increasing the demand load, later on, i.e. after sunset in this case [2].

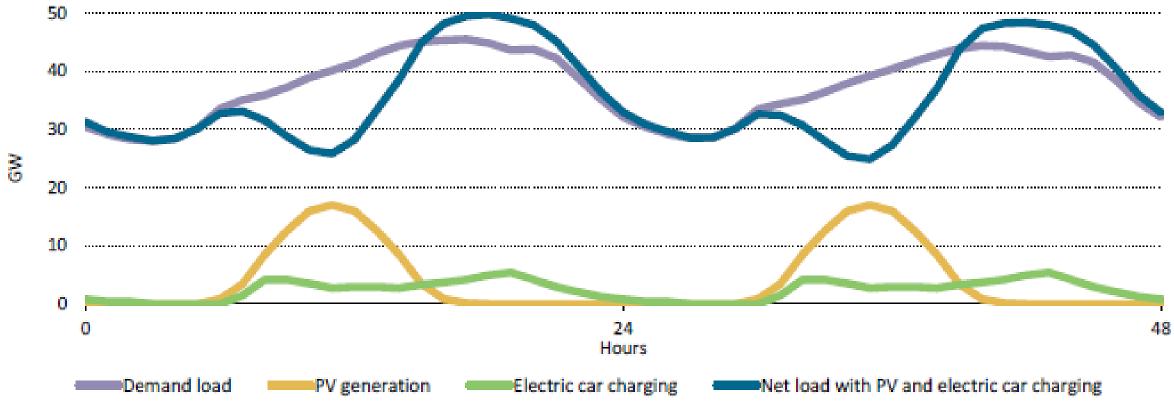


Figure 21 – Demand load profile with uncontrolled electric car charging and PV generation. Based on the EU data (average 2–day period, based on IEA's *Beyond Two Degree Scenario* for 2030) [2].

The consequences of excessive peak loads on energy system might be summed up to three subjects:

- Electricity price increase due to high demand and scarce capacity provided by generation service;
- The increase of stress on the system during peak hours, resulting in an intensification of frequency control and maintenance of reserve power capacity;
- Voltage drop resulting from overloading of power lines or other distribution;

Distribution grids are thought to be the first parts of the energy system to experience impacts of PHEVs and BEVs charging as they are thought to be the weakest part in the power grid system. Local network overloads might result in ageing of grid infrastructure through the rapid heating up the transformer's winding and damage of transformers insulators. It can cause service interruptions easily and impose need of investments for lines and transformers [2].

5.4. Managing the BEVs impact on power system

As stated in the previous chapter the share of electricity demand attributed strictly to BEVs is expected to grow from 1.5 TWh in 2017 to a possible value between 73 and 167 TWh in 2030. The management of the surplus of energy coming from this increase is a very complex process. The impact on power system should be based on three constraints:

- grid constraint – according to some sources (see [11], [32]) the key goal in the area of electric mobility development is to possibly mitigate the consequences of large-scale electric mobility adoption in terms of peak demand excess as BEVs are not stationary load easy to predict. This excess is caused by recharging process, and its impact is determined by variables: time, speed and location of EV charging.
- energy mix constraint – following the conclusions from chapter 5.2 *Impact of BEVs on the GHG emissions* the development of EV attributed installed capacity should involve the RES to the most significant extent. This seems to be feasible due to planned support and development of RES in energy supply system (see *Figure 19*). Unfortunately, the nature of

RES is intermittent and charging patterns of BEVs users seems to be unsynchronised with them;

- price constraint – BEVs as potential energy storage systems can help in levelling the prices of electricity.

From the point of view of grid constraint, a simple way to mitigate the impact is to shift the load. Location of charging put focus on building the infrastructure in the areas where the projected impact is low. This location shifting approach is already used in the Netherlands, where charging point are built in residential areas, and EVs drivers request a parking permit in advance to charge the vehicles there [2]. The load shifting might take place within the time of charging – shifting demand from high to low–demand periods. Although this can be done through coordination of EVs charging periods which requires huge interference but can easily minimise the impact and improve peak management of demand. Additionally, if the ability to control the time of charging would be possible, avoiding a rise in peak demand might be done by balancing the speed in which the cars are being charged [5]. This way fast charging station or semi-fast charging stations (based on AC, 3 phase or AC–DC parallel) could be limited by constraints of grid [66].

The potential for synchronising BEVs charging and RES production, i.e. solar energy is illustrated in *Figure 22*. With a reference to *Figure 21,* the load shifting could occur by synchronising the electric charging with the peak connected with PV generation during the day and with low demand during the night.

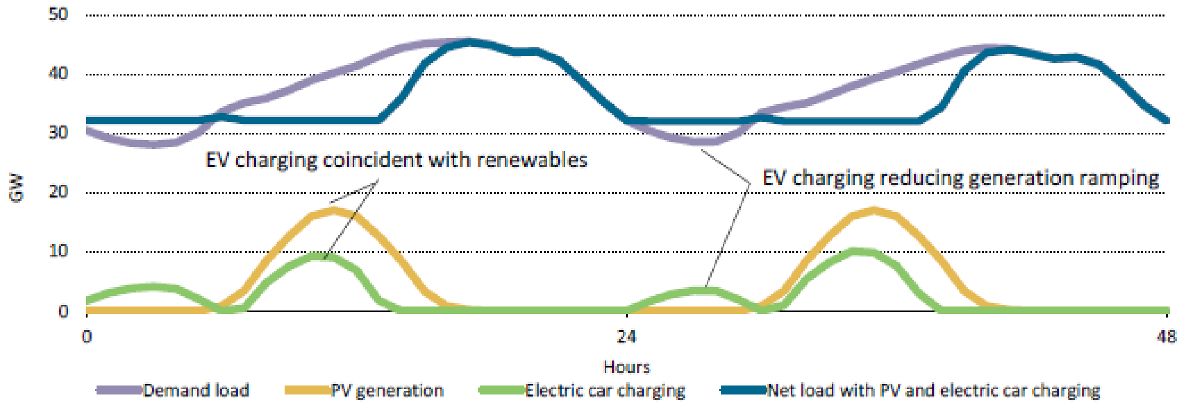


Figure 22 – Demand load profile with controlled electric car charging and PV generation. Based on the EU data (average 2–day period, based on *IEA Beyond Two Degree Scenario* for 2030) [2].

This kind of synchronised charging is based on the premise of fully successful communication between user and grid and user's voluntary choice to charge the cars at specific hours. Nevertheless, it is not expected to happen to a major extent [2]. Due to the fact that peak solar power production does not impose with the traffic peaks but impose the work schedule of the majority of users, it is important for an intelligent location of PV arrays. The majority of vehicles are parked for 95% of the time [67]. The proposed solution might be incentive the PV placement on commercial buildings, working spaces or even public parking spaces in the first place. The developing this additional RES would support local generation and decrease the transfers losses and support the load shifting idea. The example model of PV panel integration with battery pack is presented below (see*: Figure 23*)

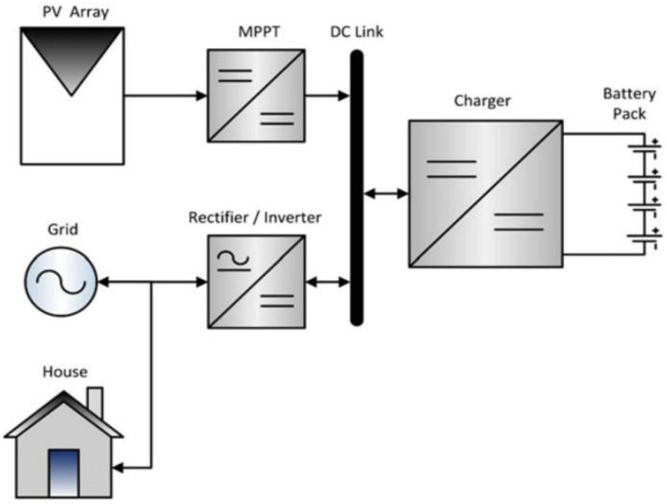


Figure 23 – Integration model between PV panel, building appliances grid and EVs battery pack. Description: MPPT – maximum power point tracking system, DC – direct current [64].

This configuration is a very flexible arrangement as it can deliver five different usage schemes:

- when power provided by PV panel is more than the necessary power for battery pack charging, remaining power can be injected into the grid;
- when power provided by PV panel is not enough to effectively charge the battery pack, the grid would be involved as additional supply for the power;
- when there is no power provided by PV panel, battery packs can be charged solely relying on the power from the grid;
- when there is power produced by PV, but there is no EV connected to this particular system, power can be injected into the grid;

BEVs can act as the energy storage systems, regardless of if they store excess power earlier produced from PV panels or power from the grid stored in the times of cheaper tariffs, battery packs can be discharged to the grid (*vehicle–to–grid)* or house (*vehicle–to–house)*. *Vehicle–to–grid* is the systems where plug–in BEVs communicate with the power grid and if possible sell electricity to demand response service by returning electricity to the grid or adjusting the charge rate [43]. *Vehicle–to–house* is a similar system that allows supplying the home or building with the energy previously stored in BEVs' batteries reducing the electricity drawn from the grid [11].

Another potential RES source is wind power. As seen in *Figure 24* the peak of wind power production occurs during the afternoon, evening and night hours. The peak in the afternoon and evening can be fully utilised because the demand is high. From 00:00 the supply might not meet the demand which appears to be much lower. This has already caused the negative prices of electricity several times within European countries like Germany, Belgium, United Kingdom, France, the Netherlands, and Switzerland (see [68], [69]).

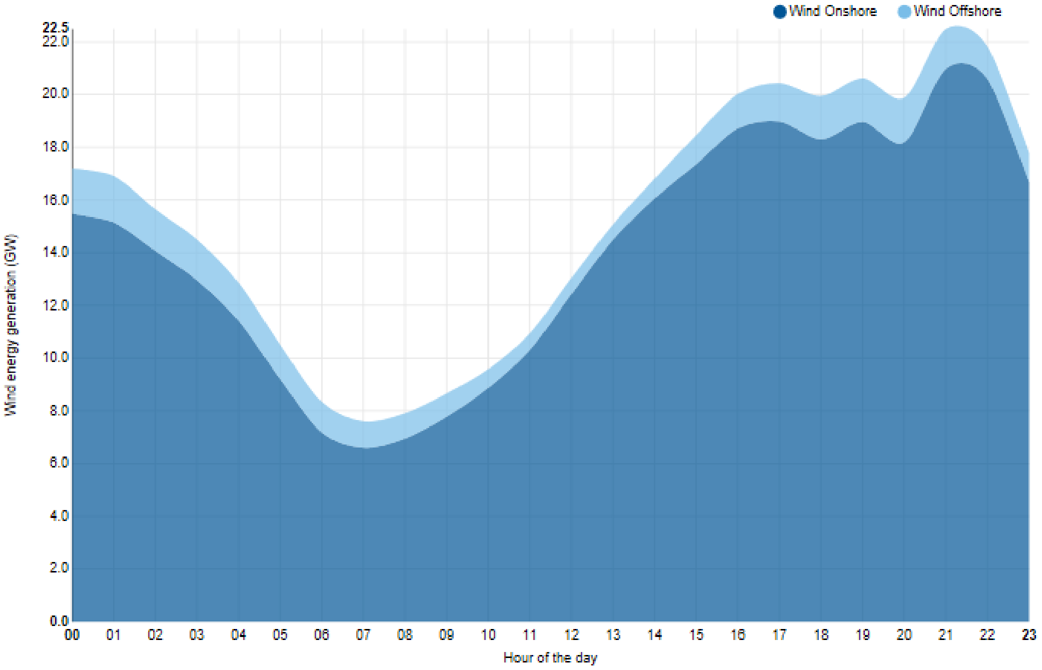


Figure 24 – Hourly wind energy generation (GW). Data for 15th of July 2018 for Europe [70].

Some researches (see [71], [72]) claims that a substantial part of the charging demand related to BEVs can be provided by unused wind power. The level of utilisation depends on the amount of conventional power that is required for grid stabilisation. As a specific example, the Netherlands is a country that wants to realise the goal of 10 GW installed wind power in 2020 and correspondingly achieve 1 million of EVs. The studies show that the plan might be feasible and the EVs demand could be covered by wind production to some degree. The condition is that there has to be some level of control over the charging patterns and involvement of load management utility. Charging regime would impose the charging slots exclusively during the night by slow charging mode. It would lead to the utilisation of unused wind power and avoid "*valleys*" in the load demand curve.

So far the ideas for mitigation of BEVs impact are based on the premise that charging patterns of users could be synchronised to wind or solar electricity generation predictions. For a solar generation, the location of charging points could be important, for wind generation the principle that user would start charging at the specific hour in the evening after peak load. Good management of electric mobility impact on power system has to take into consideration how to deal with uncontrolled, random BEVs charging schemes as well. To tackle this challenge, there is the need for demand-side management deployment, which can reduce the need for additional installed capacity and grid improvements. Demand–side management is a way of cooperation between transmission system operators, distribution system operators, utilities, and retailers to design the policy mechanism that will ensure not overloading the power grid. Demand–side management's goal is to optimise the charging time of BEVs and shift the load by electricity tariffs facilitation. The pricing schemes are called time–

of–use or real-time pricing. Time–of–use tariffs is a way to incentive the consumers to charge the vehicles during low loads or high share of RES involvement. This pricing scheme project low fares of electricity at those times. Implementing such tariffs imposes usage of smart charging or smart metering applications. These products are currently in testing, where they are tested to optimise the home charging scheme according to low electricity rate projections or, i.e. reduce consumption of appliances like heating and cooling and prioritising BEV charging. Intelligent metering would provide the basis for frequency regulation or voltage support and to further facilitate the bi-directional capabilities like the *vehicle–to–grid* or *vehicle–to–house* concepts [2].

Furthermore for uncontrolled charging behaviours and for future grid stabilisations EU targets predict a possibility of units energy storage systems (ESS) to store energy between intermittent RES generation for peak load related to, i.e. BEVs. This hybridisation of ESS and electric mobility with power electronics might lead to increasing the optimal power utilisation level. Generally, ESS technologies are divided into categories:

- electrochemical ESS generally referred to batteries;
- electromagnetic ESS, storing energy in either electric fields or magnetic fields (e.g. supercapacitors or superconductors);
- mechanical ESS, transforming mechanical potential (gravity, rotational) energy into electrical energy (e.g. pumped hydro);
- chemical ESS, e.g. hydrogen ESS or synthetic natural gas ESS. Surplus energy can decompose water (H_2O) into hydrogen (H_2) and oxygen (O_2). Stores hydrogen can feed fuel cells to produce energy back to the grid [73]. Additionally, it is possible to combine hydrogen from electrolysis with carbon dioxide coming from fossil fuel-based generation and convert these two gases to methane by a methanation reaction, i.e. Sabatier reaction or biological methanation. Resulting in extra energy conversion loss of around 8% the methane might be utilised as a power source or fed into the natural gas grid [74].
- thermal ESS, e.g. water tanks storing thermal energy for utilisation in peak hours, allowing for limited use of electricity for heat generation.

From the point of view of EVs deployment, the most important ESS that can be hybridised with them are electrochemical within residential buildings or chemical and mechanical within the large-scale (i.e. regional stations). Peak shaving and load levelling could be performed within fast response ESS [73].

The energy systems deploying electric mobility appears to be very complex. That is why further research should include the placement of BEVs within the idea of the so-called smart grid. The most fundamental idea of the smart grid is that power supply and demand must be entirely balanced over the time. The Smart grids are controlled automatically and multi-directionally by interactive IT systems. They shall consist of grid monitoring and management, advanced metering infrastructure, fast demand response and integrated maintenance. Positioning electric mobility within Smart Grids might develop their value proposition are contribute to further BEVs commercialisation [2], [75], [76].

6. Conclusions

This paper shortly reviews the current situation of BEVs market in the European Union and the state for its development. The European market is one the fastest growing market of electric mobility in the world, in 2017 the market share for BEVs achieved 0.64% while for BEVs and PHEVs combined 1.44%. Recent data for 2018 show the increase to correspondingly 0.75% and 1.65%. The issues that slow down the market development are the technical matters, what is typical for innovative technologies. In terms of BEVs, those are the limited driving range, long charging time or high purchase price in comparison to ICE vehicles. There are also minor socioeconomic factors like fuel price, consumer profile. Successful policy towards market development aims at reducing the importance of these issues and minimise the risk for customer buying BEVs. The policy might include incentives, research and development grants or investing in charging infrastructure. This paper included the basic assessment of the efficiency of these policies in developing the market share of BEVs. Statistical assessment underlined the importance of financial incentives and infrastructure development as primary policy measures what brings to the conclusion that the most important reason for a customer that makes him reluctant for buying BEV or PHEV is still a high price of vehicle and range risk related to a not convenient network of charging points. The key point for developing markets for BEVs is to adapt or built the policies around those issues reducing the risks related to ownership the BEV. The literature offers the analysis of the influence of incentives and other economic or sociologic factors on BEVs adoption on the market based on data before 2013 that provided the similar conclusions.

Further analysis of the market development of BEVs dealt with future perspectives and the impact on energy system in terms of environment and electricity demand. In the light of BEVs impact on the environment and Life Cycle Assessment, the demand increase attributed to electric mobility development should be highly covered by clean sources such as renewable energy: wind, photovoltaics or by deployment of clean fossil technologies cutting the carbon emissions. For further research, it is significant to provide the detailed LCA for BEVs and also ICE cars. For the better understanding the environmental impact of vehicles and tailoring the energy system to environmental constraints, there is a need for homogenous LCA assessment and specific calculations of the carbon footprint for different primary energy mixes. Although electric mobility might be less carbon-intensive given the EU average, discrepancies between countries or even driving patterns are so significant that proper BEVs related policy development or targeting should be based on more detailed data. LCA is currently the topic of growing debate since there is small amount any objective publications and often scientific sources are biased to a certain part of vehicle life cycle or misleading by using not one unit, i.e. the CO_2–equivalents.

As for the impact on the energy system – the value of the increase in demand is manageable and feasible in terms of capacity. It can be predicted to reach the values between 73 and 167 TWh, what corresponds to 2.1% and 4.8% of European electricity demand in 2030. In 2050 the demand attributed to e-mobility is expected to rise to 9-14% of total demand. It can be covered by the capacity that will be installed simultaneously to electric mobility stock increase. The problem that appears is the peak load increase strengthened by the recharging process. The feasible solutions could be based on the sustainable deployment of controlled charging (to feasible, possible extent) and the deployment of load management facilities and energy storage systems. These would help shift the load and avoid the grid network malfunctions. Deployment of RES generation has intermittent nature and not always could be integrated into the individual charging schemes of users that is why it is imperative to:

- develop the demand–side management and tailor tariffs for BEVs customers in a way they would incentive the customers following specific charging patterns, i.e. during low electricity load;
- establishing smart metering and charging system for charging control and for introducing *vehicle–to–grid* or *vehicle–to–home* concepts for grid stabilisation or storing intermittent renewable energy during low demand periods;
- establish a decision model or algorithm that predicting renewable energy productions and adapting EVs charging slots to fit the energy peaks generated by RES, i.e. positive projections of wind energy production during the night would encourage users to leave the BEV charging during the night;
- establishing ESS for peak load management coming from local uncontrolled charging;

From the perspective of BEVs users and stakeholders, smart grids allow utilising energy from integrated renewable sources or energy storage systems in BEVs. This idea seems to be feasible in theory, however, it needs to be tested and improved. Additionally, there is a major need for creating robust mobility business models that have to be developed by stakeholders: automotive industry, municipalities, energy systems and users. User-focused approach by defining their so-called pains and gains and tailoring the value proposition is a very useful tool in creating successful business models. In case of electric mobility, the cooperation of stakeholders aimed at, i.e. charging infrastructure development, combined with indisputable advantages of BEVs in cities, like low direct GHG emission or low noise pollution, can improve value proposition and transportation quality in cities. These observations are very important from the point of view of traffic density. Traffic and decreasing amount of parking space are considered an important issues and challenges for municipalities. Intelligent traffic management and *mobility-on-demand* could be vital elements in decreasing the traffic. Recently there has been a lot of discussion about the change of attitude towards an idea of car ownership. Customers obtained the possibility of using car sharing or *mobility–on–demand* schemes. This can lead to situation when one out of ten cars sold in 2030 will be a shared vehicle what could facilitate the development of market of electric vehicles, as this powertrain fits well this business model. This idea could be additionally supported by law incentives that can limit the mobility of ICE cars in favour of EVs, within the city centres or special “zero emissions” zones. Traffic and transportation management is a very interesting topic and commercialisation of EVs can contribute to new transportation and commuting schemes. These schemes and business models can be starting points for further analysis in terms of the energy system, environment and road traffic density.

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Annex 1

Table 7 – Data used in correlation test and ANOVA analysis [12], [77], [78].

Country	Number of relevant incentives in the country	Number of charging stations	Average fuel price	Net average monthly salary	Ratio of an electric vehicle price and average monthly income	Number of public charging points per 100 000 inhabitants	EV market share in 2017
Austria	6	3706	1.25 EUR	2 324 EUR	10.3	42.8	2.06%
Belgium	4	1765	1.48 EUR	1 920 EUR	12.5	15.7	2.68%
Bulgaria	0	94	1.29 EUR	457 EUR	52.5	1.3	0.56%
Croatia	1	436	1.33 EUR	834 EUR	28.8	10.2	0.05%
Cyprus	2	36	1.27 EUR	1 658 EUR	14.5	3.2	0.78%
Czech Republic	2	684	1.29 EUR	938 EUR	25.6	6.5	0.23%
Denmark	5	2582	1.43 EUR	3 270 EUR	7.3	45.5	0.57%
Estonia	0	384	1.33 EUR	957 EUR	25.1	29.3	0.20%
Finland	2	947	1.44 EUR	2 509 EUR	9.6	17.3	2.57%
France	5	16311	1.50 EUR	2 225 EUR	10.8	24.3	1.75%
Germany	5	25241	1.54 EUR	2 270 EUR	10.6	31.1	1.56%
Greece	3	38	1.52 EUR	917 EUR	26.2	0.3	0.22%
Hungary	4	272	1.21 EUR	635 EUR	37.8	2.8	0.98%
Ireland	6	1009	1.56 EUR	2 479 EUR	9.7	21.8	0.72%
Italy	3	2741	1.21 EUR	1 758 EUR	13.7	4.5	0.25%
Latvia	3	73	1.33 EUR	738 EUR	32.5	3.7	0.61%
Lithuania	2	102	1.33 EUR	690 EUR	34.8	3.5	0.28%
Luxemburg	3	337	1.32 EUR	3 159 EUR	7.6	59.1	1.88%
Malta	6	97	1.64 EUR	1 021 EUR	23.5	22.8	0.38%
Netherlands	3	32875	1.64 EUR	2 152 EUR	11.2	194.1	2.20%

Poland	0	552	1.16 EUR	832 EUR	28.8	1.4	0.21%
Portugal	5	1545	1.58 EUR	925 EUR	25.9	15.0	1.91%
Romania	4	114	1.14 EUR	565 EUR	42.5	0.6	0.36%
Slovakia	3	443	1.37 EUR	748 EUR	32.1	8.2	0.41%
Slovenia	3	495	1.30 EUR	1 077 EUR	22.3	24.0	0.74%
Spain	6	4974	1.36 EUR	1 749 EUR	13.7	10.7	0.61%
Sweden	3	4733	1.56 EUR	2 570 EUR	9.3	48.2	5.28%
United Kingdom	6	14256	1.41 EUR	1 990 EUR	12.1	21.9	1.90%