The influence of electric vehicles' development on wholesale electricity price - The case of Lithuania

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Abstract

Driven by environmental policymaking, electro-mobility is gaining popularity as a crucial tool to mitigate the transport induced CO2 emissions and is being subsidized by Governments, creating more incentives for end users to adapt. This article addresses the extensive e-mobility transition's influence on the electricity wholesale market in Lithuania. The global market for Electric Vehicles (EVs) is expanding at an increasing pace, having more Original Equipment Manufacturers announced their intentions to switch their powertrains to electrified ones in the upcoming decade. These global trends are affecting the Lithuanian market as well, which, however, is currently insignificant, accounting for 900 registered vehicles by the end of August 2018. To capture the possible effect on the wholesale market, the analysis is set up to picture the market in 2025, when the number of vehicles is expected to reach around 21000 with an annual growth rate of 57%. The Lithuanian electricity market is participating in the cross-border Nord Pool trading market, where the main bottleneck is the interconnection NordBalt, connecting the Lithuanian price region with Sweden. NordBalt serves as the main access point to the cheaper hydro- and nuclear-based electricity. For the purpose of this analysis, three different days were selected, representing separate characteristic seasons consumption-wise, and a least-squares methodology was applied to estimate price changes. With the predicted market's behavior having an additional load from EVs charging, a neglected wholesale price effect was identified and quantified. These findings anticipate a discussion regarding societal fairness, as the subsidized industry is ultimately affecting the retail price of electricity.

Keywords: Electric Vehicles, Wholesale, OLS, Electricity, Price effect, Lithuania

1. Introduction

The ever-changing world is on the verge of transition towards more efficient and cleaner transport. The majority of economic activities are being supported by the transport means, which unlocks possibilities to expand the markets, breaking the barriers of distance. In the environmental context, the prevailing internal combustion based transportation is accelerating the global warming process, which ultimately will change the climate with severe distortions in weather patterns. The need for more sustainable solutions, especially in a carbon-intensive industry as transport, has given rise to electrified transportation. The Electric Vehicles (EVs) market is growing at an increasing pace, recording a 57% annual growth rate in 2017, accumulating over 3 million vehicles globally[1]. The electrified transport is a direct substitute for internal combustion vehicles. However, it comes with some emerging technical issues down the supply chain.

The main purpose of this article is to evaluate the EVs influence on the Lithuanian electricity wholesale market. An Ordinary Least-Squares (OLS) methodology is used to analyze consumption and price dependencies in the Nord Pool open market. The key hypothesis raised is that the increased electricity consumption will have an impact on wholesale price.

2. Background

Global development

The scarcity of crude oil, environmental severe pollution problems, growing carbon dioxide emissions and other factors, initiated a transition towards a more efficient and ”greener” economy. Announced in December 2015 and enforced in November 2016, the Paris Agreement set the objective of limiting the increase in the global average temperature to well below 2C above preindustrial levels and pursuing efforts to curb the temperature increase to 1.5C above pre-industrial levels[2]. The temperature rise is caused by the Green-House Gasses(GHG), mainly CO2 emissions. Aiming to achieve the decarbonisation of the energy system, a significant role in electrification is played by transport, where increasing transport electrification goes together with decarbonising the energy sector.

In recent years a dynamic market uptake of electric vehicles has occurred. Cost reductions in EV-related technologies further strengthen their competitiveness compared with Internal Combustion Vehicles(ICEVs). The global stock of electric passenger cars reached 3.1 million in 2017 - an increase of 57% from the previous year, and is similar to the 60% growth rate in 2015 and 2016[3][4].

Moreover, to make the transition quicker in pace, a number of countries have announced their intentions to forbid the purchase of ICEVs or entirely ban ones on the road. By 2030, sales of ICEVs will be banned in Ireland, Netherlands, Norway and Slovenia[5][6][7][8]. Some of the major Original Equipment Manufacturers (OEMs) - *Volvo*, *Toyota* and *Fiat Chrysler*, have shown their commitment to phase out their diesel powertrains by the end of 2022[9][10][11]. On-going support and commitments for increased deployment of EVs from policymakers and the automotive industry suggest that this trend is not going to slow down in the coming decade.

Problematics

By the end of 2017, the estimated global electricity demand accumulated from electrical transport was 54 terawatt-hours (TWh) - a comparable amount to an average sized European country[12]. The rising demand for electricity due to the electrification of transport is an issue, but it is manageable if the supply capacity is concerned. The amount of GWh required to supply the charging of EVs is easily coped with an existing generation infrastructure as there is a lot of reserve capacity left for security purpose. On the other hand, the supply remaining in the reserve has high electricity production costs, leading to higher electricity prices if the capacity expansion is needed. However, the main problems occur when the charging behavior is analyzed in depth. Firstly, the majority of EVs charging is done in the residential area, where the low-voltage grid is present. The system's infrastructure is designed to supply the aggregated households' consumption in the area, which usually consists of around 200 separate houses with an average inlet power of 10kW. If the maximum capacity is reached in the particular neighborhood, the additional load would need to be reinforced with an expansion of the infrastructure itself.

Additionally, the occurrence of the charging load is closely matching with the peak consumption of the household itself, creating an exaggerated peak in the evening. With an increasing number of EVs, the demand for electricity for the same particular residential area is expected to rise, causing additional constraints on the local grid. It is a technological constraint which will have to be addressed in the near future.

From the electricity wholesale price point of view, the increasing consumption of electricity will result in the distortion of prices. The fact that the peak charging load profile is matching with the ordinary electricity consumption peak in the evening, imposes that the price sensitivity will be higher. On a daily basis, the differences in the price range depend on the particular situation in the market. This is influenced by many factors: available generation capacity, its Marginal Cost (MC) structure, transmission lines status and any maintenance of the whole supply chain. Thus, in practice, the additional amount of electricity that will be required to be delivered will increase the price. The rising wholesale electricity prices due to transport electrification will be translated to the whole society, including ones who do not employ any of the electrified transport means. This raises a discussion of fairness, which will be addressed throughout the dissertation.

Transport in Lithuania

The Lithuanian passengers' transport sector accumulatively has almost 1.3 million registered vehicles, accounting for 456 cars per 1000 inhabitants (the European Union (EU) average is 505 vehicles per 1000 inhabitants)[13]. The sector has few statistical issues, which are affecting the further transition to the electrified transport. Firstly, Lithuania has an exclusive market for pre-owned vehicles, which serves as a center of attraction for buyers from Belarus, Poland, Latvia, Russia, and other countries. This ever growing secondhand fleet vehicle market has created a highly unbalanced system between new and secondhand vehicles sales. Secondly, according to the Eurostat database, Lithuania has the oldest cars fleet in the EU, accounting for almost 81% of all vehicles to be over ten years old. It imposes a peculiar consumption habit, suggesting that the market for new cars is small (2.3% of vehicles are less than two years old)[13]. Since pre-owned EVs market is insignificant and purchases of new vehicles are unlikely, the adoption of transport electrification will not happen on quick pace without the external incentives in the near future.

Currently, there are around 900 registered EVs on Lithuanian roads, accounting for less than a 1% of total newly registered vehicles annually. As the statistics indicate, the ratio between brand new and used EVs on average is 1:2 respectively, suggesting that the consumers are following the analog pattern, having a preference for a pre-owned vehicle. The general annual growth of electrified private passengers' transport since 2012 was 55% on average, showing no significant fluctuations in the growth rate[14].

The main incentive for e-mobility that the Government is offering is the free charging infrastructure until 2023. Currently, a nation-wide infrastructure project is under development, which by the end of 2019 will be providing a public fast-charging station on every major state highway not more than 50 km apart. This will allow a long distance coverage with EVs without fuel costs. Besides the charging infrastructure, there are few minor tax exemptions, such as registration and emission fee, which are applied for EVs owners, as well as free parking in city centers in major municipalities. Given the lack of direct investment incentives and assuming the purchase habits of the society, the growth rate of 55% is a reasonable assumption to evaluate the dynamics of EVs until 2025.

Electricity market in Lithuania

Lithuania was a nuclear country, having a double reactor power plant (Unit 1 and Unit 2) which played a key role in the Lithuanian energy sector producing up to 70-80% of the electricity. During the process of accession into the EU, one of the country's obligations was a decision on the early closure of Ignalina Nuclear Power Plant (NPP). It was agreed that Unit 1 of this power plant would be closed before 2005 and Unit 2 in 2009. Thus, currently, more than half of the required electricity is imported from neighboring countries. At the moment, Lithuania is trading the electricity in the open Nord Pool market, which serves as a main pool for Nordic countries. The main access to the Swedish hydro- and nuclear-based electricity market is through the cross-border NordBalt interconnection which was commissioned in 2016, unlocking a total of 700 MW interconnection capacity[15].

The Nord Pool is the physical wholesale marketplace which, using a market coupling methodology, establishes a system price for any given hour in all of the price regions. The price differences emerge as a function of insufficient transfer capacity between the bidding areas. From Lithuania's point of view, the main bottleneck is the NordBalt interconnection, which imposes a market-split between Sweden and Lithuania having the saturation of the cable. For further analysis, to investigate a peculiar behavior of the domestic market of Lithuania, days during which the NordBalt is utilized at full capacity will be taken as reference data-sets.

3. Methodology

The ultimate goal of this article is to test the predictability of electricity wholesale price with relation to increased national consumption due to the presence of the EVs charging load. The hypothesis is that the price will rise with increased consumption. The data inputs of these two variables are continuous and ordered, giving values on an hourly resolution continuously annually. The nature of this data alignment suggests that the Ordinary Least-Squares (OLS) methodology can be applied to determine the relation factor between the consumption and the price. In practice, this methodology is frequently employed determining various markets behavior[16].

To understand the key factors which influence the electricity price on the market, it is necessary to draw the system's boundaries. For example, due to extraordinary events on the grid, the price can be influenced by the maintenance of the infrastructure. To avoid the unnatural price deviation, the choice of the reference days was restricted to obey the predetermined conditions. It allows identifying the causalities of price dynamics and at the same time keep the simulation consistent. For this particular case, to bring the simulations closer to the real conditions, three main scenarios are analyzed depending on the time frame: ***Winter period, Summer period and Spring/Autumn period***. These periods are representing three different demand curves, resulting in the different price dependency on the grid load. To make these scenarios comparable on the technical point of view, exact dates were chosen during which the connections are maintenance-free, the NordBalt connection is working on highest capacity and the main electricity generators are not in the maintenance. Having the NordBalt connection working on the full capacity, an additional increase of a local consumption would have to be supplied within the local regions, resulting in a market split price-wise.

Having in mind these constraints, the reference days for each of the characteristic periods are:

- *28th of February, 2018,* representing **Winter** period;
- *10th of April, 2018,* representing **Spring/Autumn** period;
- *12th of June, 2018,* representing **Summer** period.

Data analysis

Having a predicted number of private EVs in 2025, a charging behavior must be established. The approach of Hao Q. *et al.* was used, which focused on EVs charging behavior and its impac on China's electricity grid [17]. Assuming that the charging participation would be 70% and the number of EVs in Lithuania by 2025 would account fo 21268 vehicles, the charging pattern is obtained as shown in Figure 1.

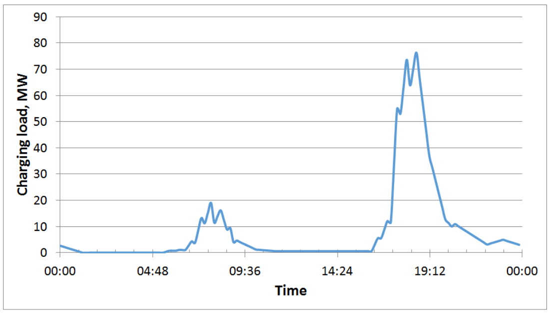

Figure 1: An aggregated EVs charging load in Lithuania in 2025

Every reference day was divided into separate periods. This division differentiates the peak, off-peak and transition periods, allowing to capture the characteristic consumption impact on the price behavior. For each particular period an OLS regression function was estimated, having consumption as explanatory variable and price as the response variable. The division and regression functions for each of the reference days are shown in Figures 2, 3 and 4.

The red lines in dash represent the regressed price curves. High consumption in the Winter period is explained with the additional heating demand, required to be supplied from the grid. Considering that the charging profile peaks in the evening, the dynamics of peak No. 2 has more importance for the analysis. For Winter's period it reaches maximum at around 18:00. The reference day of Spring/Autumn periods is considered to be a transition period, when there is no cooling or heating demand present. The division is similar to winter's season, however peak No.2 is postponed, reaching its maximum at 20:00. During the summer time, when the temperature rises above the comfort level, cooling demand starts to be visible in the consumption curve. The characteristic profile of summer's day has no peak No. 2.

To evaluate the regression functions, P-value and determination coefficients R^2 are calculated. The obtained P-values and R^2 are outlined in Table 1.

The equation used for R^2 is shown in Equation 1[18].

$$R^2 = \frac{RSS_{diff}}{RSS_{\bar{y}}}; \qquad (1)$$

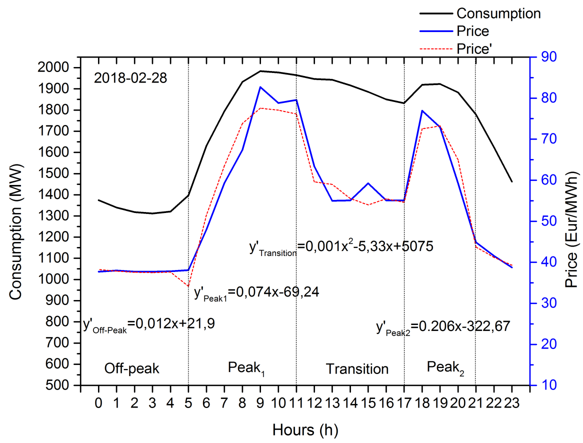

Figure 2: Consumption and price variations on February 28th of 2018.

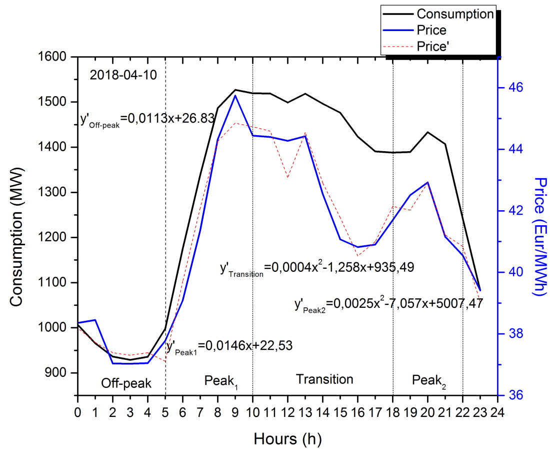

Figure 3: Consumption and price variations with regression curves on April 10th of 2018.

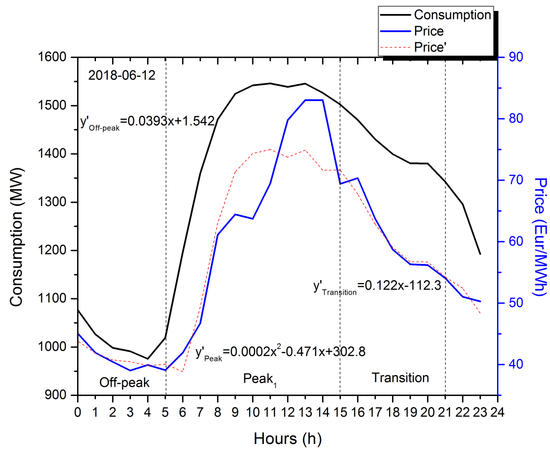

Figure 4: Consumption and price variations with regression curves on June 12th of 2018.

where RSS_{diff} stands for residual sum of squares compared to regression function and $RSS_{\bar{y}}$ for residual sum of squares between the mean value of explanatory variable.

The separate periods' regression parameters are not identifying overall model's fit condition. Therefore, the overall adjusted R^2_{adj} for each of the seasons was calculated using Equation 2.

Table 1: Significance and determination coefficients for multiple regression curves applied in Winter, Spring/Autumn and Summer periods.

		Off-peak	Peak No.1	Transition	Peak No.2
Winter	P-value	4.845 x 10^{-4}	4.87 x 10^{-4}	5.7 x 10^{-2}	9.67 x 10^{-4}
	R^2	0.93	0.928	0.43	0.92
Spring/Autumn	P-value	1.08 x 10^{-4}	7.0 x 10^{-4}	1.502 x 10^{-4}	4.83 x 10^{-4}
	R^2	0.901	0.957	0.877	0.867
Summer	P-value	1,9 x 10^{-5}	2,7 x 10^{-4}	1,6 x 10^{-4}	-
	R^2	0.961	0.816	0.935	-

Table 2: Normalized and adjusted overall determination coefficients for each of the seasons.

	Winter	Spring/Autumn	Summer
R^2_{adj}	0.912	0.928	0.843

$$R^2_{adj} = \frac{\sum_{i=1}^{n} \frac{RSS_{diff,i}}{n_i}}{\sum_{i=1}^{n} \frac{RSS_{\bar{y},i}}{n_i}}; \quad (2)$$

where RSS_{diff} and $RSS_{\bar{y}}$ are the corresponding residual sum of squares and *n* number of observations for regression function *i*. The adjusted R^2_{adj} values are outlined in Table 2.

To investigate the possible price effect of the EVs charging load present on the grid, a simulation was done adding the estimated profile shown in Figure 1 to national consumption. At this point, the comparison is done between the regressed price curve in dash and regressed price curve with EVs charging load in solid. The illustrations for each of the seasons are shown in Figures 5, 6 and 7.

The price effect is more severe having the charging load profile matching with the existing national consumption peak (see Figure 5). In Winter the regressed price curve suggests that the price without EVs' charging profile should be $72.52 Eur/MWh$ and with increased load price it should peak around $86.5 Eur/MWh$. For this particular day, a 3.5% of consumption increase caused by additional charging load resulted in 19.3% of increase a wholesale electricity price.

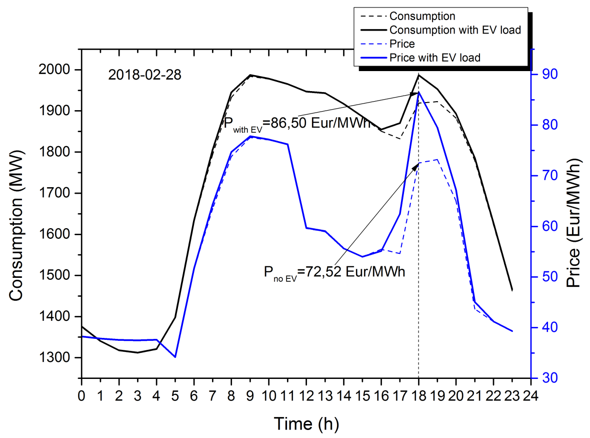

Figure 5: Multiple regression model applied for 28th of February with EVs charging load.

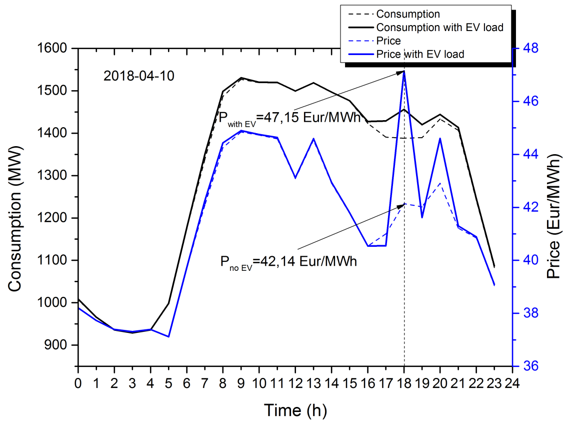

Figure 6: Multiple regression model applied for 10th of April with EVs charging load.

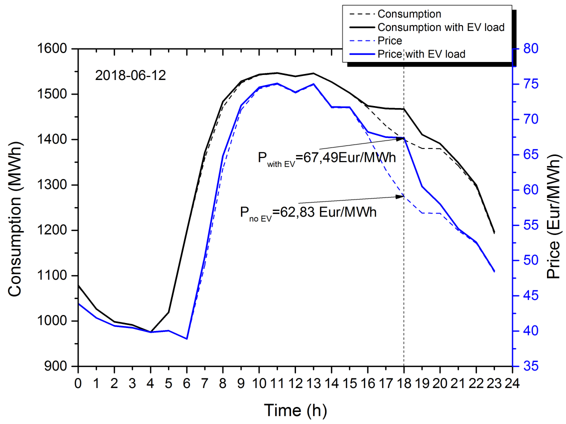

Figure 7: Multiple regression model applied for 12th of June with EVs charging load.

Looking into the Spring/Autumn reference day (see Figure 6), given the fact that the national consumption peak No.2 is a bit postponed compared to the winter season, EVs charging load falls into the transition period. That will affect the price dependency, as the market's price elasticity in lower consumption levels is higher - there are more available production options than in peak hours. On peak charging time (18:00), the regressed price for April 10th without the EVs load is $42.14 Eur/MWh$, whereas price with increased consumption is $47.15 Eur/MWh$. So, an increase in consumption by 4.9% will ultimately increase wholesale electricity price for Lithuanian region by 11.9% during the Spring/Autumn period.

In the Summer period (see Figure 7) the consumption levels are similar to the Spring/Autumn period - the heating demand is being compensated with decreasing national consumption due to typical vacation period in Lithuania. There are higher deviations of the wholesale electricity price compared to off-peak and peak hours. In this reference day the regressed electricity price for regular national consumption should be 62.83 Eur/MWh, whereas with added charging load it should be 67.49 Eur/MWh. Hence, during this characteristic period an increase of 4.85% of consumption would result in an increase in wholesale electricity price by 7.42%.[1]

4. Results & discussion

To summarize, there is a clear indication that the increased consumption due to electrification of transport will affect the wholesale price. The price deviations with peaking charging load are very dependent on the characteristic electricity consumption pattern, creating a more noticeable effect if the charging is matching with the natural national consumption peak (as it was seen during the Winter's season analysis). The increase of the wholesale price by 19,3% on a particular hour of the day seems to be significant. However, the versatile wholesale market is having even more exaggerated price differences on hourly bases. In a few cases, the price may increase by 200% for a single hour, but this price effect is usually explained with extraordinary system's failures or unexpected breakdowns of some crucial supply chain component. For example, an emergency stop of the NordBalt interconnection, which occurred on March 21st, 2016, has immediately caused a price increase by 40.6% in the Lithuanian price region[19]. It does not precisely mean that the system is vulnerable to minor fluctuations, though the NordBalt interconnection is playing an essential role in order to minimize the wholesale price.

This paper has shown the existence of price effect deriving from increased transport electrification. The resulting wholesale electricity price is affecting the whole society, also increasing the retail price. Transportation transition will eventually substitute ICEVs, resulting in a distortion in the national budget collection by an excise tax on fossil fuels.

The fact that supposedly having a relatively low number of EVs in Lithuania by 2025 (around 21000) will translate into an additional retail price increase for a country of 2.8 million people raises doubts about the fairness of the society benefit. The idea of transport electrification is driven by the environmental policies, tackling the reduction of CO2 emissions in this sector. For this purpose, governments are choosing to invest public capital in raising an incentive for society to switch into zero emission vehicles. At this moment, without any subsidies for the investment, the cost of ownership of new EVs is barely equalizing with conventional ICEVs. The existing difference is caused by few factors: the inbuilt battery system is still expensive, even though the production costs are being reduced annually; and the economies of scale achieved by ICEVs are not yet matchable by EVs. For the Lithuanian market case, there are no massive direct investment incentives, which would cover part of the fixed costs related to the ownership of EVs. They are allocated in the utilization part, subsidizing charging costs, parking tickets and allowing to use particular traffic lines in major cities. In other words, the incentive system is focusing on subsidizing the variable costs that end users are witnessing. Additionally, these incentives are arguably applying to the whole society, as the average price of EVs is affordable for just a top fraction of society with higher income levels. Incentives, which refer to the rich part of the community, leading to a higher retail price of electricity will eventually cause negative externalities - the societal marginal cost of transport electrification will be higher than the private marginal cost.

Another effect that this paper identified is the possible distortion of the taxation system in Lithuania. Currently, 14.6% of the national budget is gathered from the excise duty tax, including the excise of petrol and diesel products, which are heavily used in transportation[20]. Practically, 21000 EVs will not cause a significant difference of diesel/petrol consumption compared to 1.6 million conventional vehicles on the road. However, in theory, aiming for a complete electrification of the transport sector will minimize the collected excise duty tax, creating a budget gap, which will definitely be filled with additional taxes in other industries. This suggests that significant tax reforms will be needed in the future to rearrange the budget constraints caused by transport electrification.

The critical issues stated above are not meant to criticize or object the electrification of transport. Induced global warming due to excess usage of fossil fuel indicates that the electrification is a favorable solution. However, the major transition in the transport sector will disrupt the existing situation. These effects are practically occurring on a small scale already, thus with the increasing pace of electrification adoption governments will be forced

[1] For the purpose of the analysis the polynomial regression function was investigated as well. The reference day was not divided into characteristic periods, but taken as whole and a single polynomial regression applied. However, the results were less satisfactory compared to the multiple regression methodology. Therefore, results of the polynomial regression approach are not discussed.

to adjust and enforce some radical changes in the future.

Proposed solutions

The main issue that can be drawn from the empirical results obtained is that price is more sensitive when the charging peaks are matching with national consumption peaks. There could be two mechanisms identified tackling peaking EVs charging load profile - smoothing out the load by scattering the charging load into separate hours or postpone the peak charging into a less price sensitive time of the day. A behavioral or technical solution can be applied.

Behavioral adjustment. In general, electricity price for end users in Lithuania is not high, reaching 12-20 Euro cents per kWh on average, depending on the tariff. Currently, the electricity price is divided into night and day tariffs, differentiating the price fluctuations on the wholesale market in these two periods. However, the retail price is not deviating on an hourly basis in either of the price zones. The fact that there is no difference in price wherever it is consumed during the peak or off-peak hours throughout the day is not raising any awareness of personal consumption. Recently, to increase the predictability and adjustments from a demand point of view, the Demand Side Management (DSM) methodology has been introduced. The DSM is an important instrument that can significantly reduce the need for grid upgrades and additional generation capacity due to electrification of road transport[1]. Regulators, utilities, transmission system operators, distribution system operators and retailers are already taking methodology measures and designing policy mechanisms to ensure that the EVs uptake will not overload the power grid. For EVs, DSM mainly consists of the optimization of the charging time of the vehicles, shifting loads to ensure a good match between the power supply and demand with the aim to move the aggregated load of charging related power demand from the peak hours to the off-peak period. A dynamic tariff system would indicate the market's price fluctuations in real or close to real time. A Time-of-use (TOU) or real-time pricing (RTP) mechanisms can be proposed[1]. The latter RTP solution would naturally indicate EVs owners what the current price of electricity is and would be obliged to pay extra for peak hours - when the electricity is more expensive. The TOU solution incentivises the end users to charge during the hours when the system is less saturated, and discourage using the grid when it is overloaded. The differentiation of price would directly impose a behavioral change from the demand-side point of view, reducing a need of investment into infrastructure to support an increasing number of EVs on the road.

Technical adjustment. While behavioral adjustment is impactful, the precise estimation of how will the demand side behave is rather difficult. It is easier to predict a full load at the peak hours, however the investment into infrastructure would impose unbearable costs, which would ultimately settle among the society. From a technical point of view, there is a solution, which controllably tracks the charging of the vehicle and automatically postpones, or even reverses, it to achieve load shifting. The advantage of this smart charging protocol is that it does not require any personal effort from the end user. Smart charging is automatically tracking the on-going price fluctuations in the market, which are indicating the consumption loads, and directly through charging cable communicates with the vehicle itself. This methodology minimizes the plug and charge effect when uncontrollably EVs have began to charge at the moment of insertion. The plug and charge effect is inducing the characteristic peak of EVs charging on the grid. Analyzing further, this methodology unlocks the Vehicle-to-Grid (V2G) possibility, when EVs are utilized as an external electricity source to power up residential households, as well as provide ancillary services for the grid itself. Employing both, smart charging and V2G, a national consumption peak shaving effect can be achieved[1].

Concluding, both of these adjustments would positively contribute to the future of transport electrification and beyond, as they provide three key benefits:

- Reduction of the need for additional generation capacity by shifting charging loads to periods with lower demand. Moreover, charging in off-peak hours would induce a lower electricity price.
- Optimization and further utilization of existing grid equipment during the day, increasing their efficiency factor and increasing their profitability, therefore reducing their cost per kWh.
- Reducing curtailment of renewable generation by aligning EVs charging with periods of high output from renewables, such as nighttime charging when production from wind generators is often highest, or mid-day when Photovoltaic (PV) generation peaks[1].

5. Conclusions

The analysis done on the Lithuanian electricity market has identified an effect on prices, caused by the upcoming EVs charging load in the national consumption curve. The paper was not intended to deliver a precise electricity market analysis tool with high prediction accuracy, but rather to highlight a possible impact on society. As it has been shown, in a versatile market as Nord Pool, where the region's price fluctuations are dependent on several variables, a relatively low EVs penetration in the area could significantly influence the wholesale price. Such an effect will cause the retail price to rise accordingly.

These results raise a discussion regarding the societal fairness issue. The transport sector's transition towards electrification will cause just a part of the society to use the benefits of the subsidized industry, while the rest of society will be witnessing increased retail electricity prices. Such a system will ultimately be exploited by the rich part of the society, as the EVs are considered to be a luxury good. However, the overall influence is severe due to the characteristic charging load, which has a marked peak in the evening. The charging profile is closely related to natural consumers' habits. Therefore, behavioral and technological solutions were presented. Both types of proposed solutions are aiming to create an incentive to postpone the charging, either it is automated or manual. Creating an economic incentive to switch charging habits will help to smooth the profile peak and scatter the load throughout the day, especially in less loaded hours (night time).

The transition towards electrified transportation means is inevitable and desired from an environmental point of view. However, this paper has shown that the particular adoption of EVs must be analyzed from different perspectives, especially when public spending is concerned.

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