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ORIGINAL RESEARCH

E-mobility in Slovakia by 2030—End of oil dependency?

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Abstract

More European countries seriously depend on oil supplies from Russia primarily via one pipeline, which makes energy security weaker. This energy balance brings a massive problem for the import intensity; therefore, e-mobility might be a potential solution for the trade deficits of many European countries. Battery Electric Vehicles and Plug-In Hybrid Electric vehicles have been introduced within the priorities of the EC but also by car manufacturing companies worldwide. By 2050, massive growth of Electric vehicles (EVs) is expected, and significant changes in favour of electric cars have to be observed in new car sales till 2030. The article's main objective is to investigate whether and to what extent new sales of e-cars bring lower oil imports to Slovakia. The authors use three scenarios (based on regression models) differentiating market force intensity and regulation stringency till 2030. The significant findings of the models provide an estimated number of EVs on Slovak roads in 2030 and significant oil import cuts stemming from oil import substitution. The conclusion suggests that by 2030, Slovak oil imports will only slightly decrease due to e-mobility penetration, even in the most optimistic scenario.

KEYWORDS

e-mobility, energy security, foreign trade, oil dependency

1 | INTRODUCTION

The average import intensity of petroleum and petroleum products in European countries is more than 86%. The dependence of European countries on importing energy carriers from the third countries (primarily Central and Eastern European countries) is a crucial issue that the European Energy Union concept aims to solve. This strategic effort has been even intensified after high energy prices challenged the European industries in the pandemic era. Because of this problem and the environmental benefits of e-mobility, many experts, including the European Commission, expect a significant reduction in energy dependence from the Russian Federation and other third countries by 2030 via oil import decrease. It is expected to achieve this by using PHEVs (Plug-In Hybrid Electric vehicles (EVs)) and, in particular, Battery Electric Vehicles (BEVs) in European and Slovak transport systems. From a usability perspective, e-mobility has been made necessary in recent years due to more reasons—pollution reduction initiatives, government incentives, cost reduction, and fuel cost increase, among others [1]. In the coming years, EVs will have a critical role in smart cities, along with shared mobility, public transport etc. [2]. The high contribution of the road transport sector to climate change, oil dependency, and local air pollutants is proposed to be partially eliminated by actions concerning the electrification of road transport in Europe [3]. The total transport emissions can grow by 35% to 8.9 gigatonnes of carbon dioxide in 2030 (International energy agency—IEA). In its 2030 Climate and energy framework, European Union has laid down ambitious targets. In 2030, total greenhouse gas emissions will be at least 40% lower than in 1990 [4]. Fit for 55 package proposals have further intensified the ambitions by July 2021. The new EU's commitment is to cut emissions by at least 55% by 2030, and the transportation sector will play a crucial role in this regard via dramatic electrification of mobility.

Road transportation represents an extensive share of European and total global emissions. Comparing the levels for 1990, in most EU member countries, the volume of the emissions increased. In essence, there are three possible ways to reduce greenhouse gas emissions in road transportation. At first, to reduce the total volume of transportation (avoid), second, to shift travel and freight to more efficient transportation modes (shift) and third, to replace the energy technology of vehicles with more efficient and less carbon-intensive alternative vehicles (improve).

A study based on the data of the Ministry of Economy of the Slovak Republic (MESR) states that about 43% of emissions are generated by the sector of transportation [5]. However, Central and Eastern Europe (CEE) economies are vastly dependent on energy imports from third countries—war in Ukraine. Polish authors stress the advantages in the field of import substitution but also other vital benefits in the general transportation system in Poland [6]. Therefore, e-mobility is a vital way to lower energy dependence as well as a way to meet the environmental goals of the EU, particularly within the CEE countries. Nevertheless, Li-ion batteries seem to be a big question mark for the EU foreign trade, despite several studies stressing a perspective role of Li-S (Lithium–Sulphur) batteries [7]. The negative impact of batteries (their range and charging time) can also be solved through battery packs used in bigger cities [8]. This is valid even though some studies stress that the charging efficiency depends rather on 'charging strategy'[1] [9]. The electromobility market is very perspective in CEE countries [10], though the perspective and final effect among the countries differ considerably.

The article's objective is to analyse a perspective of e-mobility using a regression model based on current data and prediction of the spared crude oil and oil product import (import cuts) into the EU in a particular case of the Slovak Republic. Primary data in the model were sourced from Ref. [11] and [12], and other partial sources if specified. P. Harrison [13] stresses that for every €10 spent at the pump, €3.20 leaves the European economy to pay for petroleum imports. Replacing imported oil with domestically produced energy would keep €49 billion and avoid spending on oil imports in 2030. The study suggests achieving these oil import savings via a 33% share of PHEV and 15% BEV cars (of new sales) by 2030. European Investment Bank [14] focussed its analysis partially on raw materials. The transition to electromobility will unavoidably involve a shift to higher dependency on a small group of (partially flawed or outright non-democratic) countries and/or firms in the future, replacing (or at least for some time coming in addition to) Europe's reliance on oil and gas in the fossil energy past. Analysis assessing the oil displacement by e-mobility was carried out by the International Energy Agency [15]. IEA stress that the global EV fleet can reduce the oil consumption from 2.0 up to 3.4 mb/d according to various BEV/PHEV penetration scenarios. Within the most recent analyses by Ref. [16], the agency suggests 10 immediate actions where vast usage of EVs and more efficient vehicles are included. Adopting the 10 immediate actions, advanced economies can reduce oil demand before the peak demand season. The full implementation of the measures in advanced economies alone can cut oil demand by 2.7 million barrels daily [16] within 4 months.

Despite the mentioned studies, we seriously lack the particular study focussed on BEV and PHEV fleet prediction connected to oil import cuts since the topic has moved to the centre of the trade and energy policy of the EU. Authors consider the analysis in the field to be innovative and essential not only for the energy companies (oil refining companies, biofuels producers etc.) but primarily for the policymakers. Moreover, the topic is crucial for other EU countries heavily dependent on the oil imports from the Russian federation like Slovakia (e.g. Czechia, Bulgaria, Hungary, Poland, Romania, or Slovenia), where the conclusions can also be helpful. Therefore, the paper's authors want to shed light on e-mobility as a potential source of lower Slovak oil imports from the Russian federation. Events from February 2022 have emphasised a need to answer the question scientifically.

2 | LITERATURE REVIEW

Several studies investigate the potential of e-mobility in the EU, including a considerably lower amount of publications related directly to the Slovak market or smaller markets of the CEE region. Contrary to Slovak studies, foreign studies on the European or international level find e-mobility not an alternative or polemic but already a matter of fact in future transportation system development. The subject of research covers only the intensity of BEV and PHEV penetration.

E-mobility is a topic of growing interest between consumers and policymakers. Despite the related challenges, it is seen as a promising way of reducing the carbon intensity of transport systems [17]. Electric vehicles are seen as one practical tool for contributing to sustainable transport systems. [18]. According to Ref. [19], systemic change towards EVs will only be successful when the current dominance for systemic support of individual mobility and fossil fuels is broken. Most European Union countries have put EV policies into practice, and their short-term success appears to be quite feasible [20]. Key drivers favouring EVs include high crude oil prices, fast depleting fossil fuel resources, rising demand for low emission vehicles, and attractive incentives for EV manufacturers. Environmental regulation and its stringency will play a vital role concerning the EU e-mobility penetration rate. The intensity of challenges in promoting EVs is equally high, especially considering high investment cost, unaligned manufacturing lines, present low demand, and virtually non-existent charging infrastructure.

E-mobility will play a key role in reaching specified ambitious greenhouse gas reduction targets, for instance, in the

[1]Simulation results showed an improvement that ranges from 46.9% to 75.2% in terms of cost reduction of the charging process while maintaining similar battery levels ([56]). Also, according to Ref. [49], the EV will play a vital role in the future smart cities and have different charging strategies that can adapt to the users' needs will be of special relevance.

German transport sector of 42% between 1990 and 2030 [21]. A similar effect is expected in CEE countries [10]. According to IEA expectations [22], cumulative global sales of BEV and PHEV should reach 65 mil. pcs. Particularly in the EU, Ref. [23] has expected 7.48 mil. BEVs and PHEVs sold in the EU itself till 2030. Among other distinguished international relevant studies, European Commission has also based some regulatory frameworks for the potential of e-mobility on the finding of the EAFO [11]. This study brings three possible scenarios for future development of the European market with electric cars: the most conservative scenario forecasts 'only' 35% share of BEV on new car sales in 2030% and 15% share of hybrid plug-in cars into the electricity network. The optimistic (ecological) one expects up to 80% of the new car sales in BEV and a 15% market share as PHEV. As for other critical institutional studies, Boston Consulting Group [24] predicts a much more conservative 14% market share of new cars sold in 2030, PHEV with 6% sales share. Ref. [25] expects cumulative sales of e-cars to be 24% in 2030. According to Ref. [26], in the trend scenario, PHEV and BEV represent almost 94% of all new automobile registrations in 2025 and nearly 48% of the passenger car fleet. The BEVs alone stand for 46% of all new registrations and 24% of the fleet. An expert estimate made by Roland Berger Strategy Consultants is for Europe with up to 50% of EVs and 23% in Central and Eastern Europe in 2025. A study of driving patterns in two Italian provinces by Ref. [27] claims that EVs could replace approximately one-fourth of the urban fleet by 2030.

Significantly in favour of the development and refinement of electromobility, mainly on Chinese and European roads, speak the estimates and plans of the automakers themselves. Several automakers produce a number of BEVs or PHEVs that will make up a substantial proportion by 2030 and, in most cases, even the majority of the fleet sold (Toyota, Ford, GM, BAIC Motor, Changan etc.). In the case of Volkswagen, target sales by 2025 are at the level of 2-3 million pieces, or about a quarter of this year's sold product portfolio. In the case of Honda, it is even a 50% share of BEV in total corporate sales and a 15% share of BEV and fuel cell EV on sale by 2030.

Significant studies at the international level (generally, not particularly in Slovakia) accept that consumers' perceptions and individual characteristics play an important role in accepting EVs. The studies in Ref. [28] and [29] focussed primarily on the barriers of the faster penetration. Ref. [30] and [31] examined the influence of the charging infrastructure, and Sierzchula et al. (2014) studied the impact of specific policies and incentives. Other scientific studies combine several factors and rely on theoretical frameworks such as the theory of planned behaviour ([32] and [33]), while some studies focus on the impact of social influence ([34] and [35]) or sociodemographic factors ([36] and [37]). Relevant studies assessing potential fundamentals of e-mobility at the international level suggest that one has to focus on policies that affect the alignment between policymakers, societal actors, and technology [38].

E-mobility levels in Slovakia are far from essential goals even considering the state fleet compared to European or Chinese levels. Although the reasons vary, the most limiting factor, compared to Western Europe, is the population's standard of living—income and consumer preferences for car purchases, incentives from the government, weak infrastructure compared to the rest of the world, and others. Many studies on user acceptance of EVs that focus on consumers' needs have been published in the last years ([39] and [33]). Several studies examined basic factors and barriers fundamentally determining consumer adoption of EVs. Ref. [40] analysed fundamental factors influencing primary purchase potential for PHEV and found that respondents were more likely to buy PHEV when they reported reducing greenhouse gas emissions as an important target. However, in this study, potential fuel cost savings were scored by respondents as more important than cutting greenhouse gas emissions. The most sensitive consumers concerning EVs include the younger, well-educated, and environmentally aware people who mainly undertake urban trips and plug in their cars at home [41]. Ref. [42] used a logistic regression method to predict how consumers with engineering and technology backgrounds differ in EV acceptance compared with the general population. Among other factors, their results suggest that the perceptions of EV regarding environment-friendliness and speed are significant for the consumers' interest in purchasing an EV. Ref. [33] analysed 16 empirical studies focussing on consumer adoption of EVs and the metastudy split their results into four groups: (1) technical factors—speed, performance, safety, recharging time, environmental attributes etc., (2) contextual factors—visible charging stations in public, tax incentives, charging infrastructure etc., (3) cost factors—running cost, purchase cost, long payback time etc., and (4) individual and social factors—age, gender, education, lifestyle, hands-on experience with EVs etc. They identified the range limitation and charging behaviour as influencing factors against the adoption of EVs. Ref. [43] realised a survey on the user behaviour of 3111 EV owners in Germany. The majority of the respondents (84%) attach great importance to the environmental aspects of using EVs. Consumers considered technical affine are more likely to be early adopters of EVs if EVs surpass conventional vehicles in terms of performance [3].

Concerning the share of electromobility (BEV and PHEV) in the Slovak Republic, four basic conceptual documents have been developed stating the fleet restructuring of these vehicles in the future as clear objectives: (1) Action Plan for the Development of Electromobility in the Slovak Republic (2019), (2) Strategy for the Development of Electromobility in the Slovak Republic and its Impact on the National Economy of the Slovak Republic (2015) and transposition documents, (3) National Policy for Deploying Infrastructure for Alternative Fuels in the Slovak Republic (2016), and (4) National policy framework for the development of the alternative fuel market (2016).

The first primary document in the Slovak Republic is the conceptual material of MESR from 2014, which the EC required. This strategic material works with two baseline scenarios—in the standard scenario, the 10,000 BEVs and PHEVs sold on the Slovak market in 2020 and the technology scenario of 25,000 of these vehicles. Subsequently, in 2016, the vision of the development of electromobility in Slovakia was supplemented by the 'National Political Framework for the Development of the Alternative Fuels Market' (MESR), where the BEV and PHEV number in the Slovak Republic is quantified at 35,000 sold cars in 2030, representing approximately 35% of currently sold vehicles. The third baseline document is the 'Action Plan for the Development of Electromobility' (MESR), which significantly strengthens the objectives of the intensity of electromobility progress in the SR (Slovak Republic) and a variety of specific tools for their use. At the same time, however, the document itself states that efforts will be concentrated on enhancing the environmentally friendly transport of people. Generally, there is a lack of studies related directly to e-mobility penetration in Slovakia. Among relatively rare studies related directly to this market, they mainly state electric car market in Slovakia is in the early stages of development, as evidenced by the small share of such vehicles in the automotive market and the lack of a sufficiently developed network of public charging points [44].

In general, the causality between more massive sales of BEV and PHEV and lower imports of crude oil and petroleum products is part of several reputable models but also of the EC policy itself. This trend is very evident in the Fit for 55 package of July 2021 and the war in Ukraine, and significant changes in political and foreign trade relations between the EU and the Russian Federation will significantly strengthen efforts to eliminate the enormous dependence on oil and gas imports from the Russian Federation as much as possible.[2]

The passenger vehicle sector represents only about one-quarter of the oil demand, but the sector receives significant attention from some governments and academic research. This is mainly due to the belief that a rapid transition from conventional oil-powered cars to EVs is possible and necessary to reduce greenhouse gas emissions and improve urban air quality [45]. Not only for Slovakia but also at the international level, the most recent studies reveal electric cars can cut oil consumption substantially in the coming decades, and oil products oil as the primary fuel for transportation could have a much shorter life span left than commonly assumed [46]. The forecasts of global oil demand in passenger transport differ. According to some metastudies in the field, global oil demand forecasts in passenger transport differ. Nevertheless, it is expected that even after 2020, the oil consumption in the sector will slightly increase [45]. The stringent regulation to support e-mobility in the EU since 2021 proposals suggest vast oil demand replacements.

Among the most important studies examining the causality of the growing sales of BEV and PHEV (and their share in the passenger car fleet) and consumption, respectively, are the studies mentioned within the introduction part. Direct imports of petroleum products include the studies mentioned in the Introduction section. However, it can be deduced from these studies that they deal more with the global impact of electromobility on the volume of oil imports, respectively, with the impact at a regional level. However, several CEE economies have fundamental specificities (high dependence on the Russian Federation, lack of alternative suppliers and alternative oil transport routes, absence of ports, and network interconnections). Because of this, it can be believed that especially after soaring energy prices since the end of 2021 and a sharp change in political and trade relations with the Russian Federation, the issue of electromobility is a possible way out of many CEE countries' dependence on the Russian Federation is a legitimate and necessary issue of the research. Therefore, intense e-mobility penetration would be crucial for net oil importers such as Slovakia.

3 | METHODOLOGY

Given the stated objective of the contribution, the methodology is based on the regression of the model of the prediction of the number of newly registered BEV in the Slovak Republic through a linear regression model based on the panel data of the new BEV at the European level of the European Union countries. Source data is the primary data from Ref. [11, 47] and [48]. An analysis of the individual fundamentals of a group of countries in the EU suggests a prediction model, which, in the case of three scenarios, also anticipates the number of new BEV and PHEV registrations in the Slovak Republic in 2030. Subsequently, the statistically estimated volume of fuels representing a saving reduces the import demand for oil and petroleum products, assuming an increase in electric mobility at a certain level. The fundamentals determining the speed of electromobility advancement in Slovakia were set as follows:

1. The living standard in the SR is measured through constant GDP p. c. [48].
2. Technological factors (the assumption of equal BEV and ICEV—internal combustion engine vehicles purchase price since 2025 due to falling battery prices, increasing battery density, and economy of scale)
3. Infrastructure (increase in the number of public classical and fast-charging units in the Slovak Republic by 10%)
4. Incentives in the area of electromobility on a scale from 0% to 100%

The phenomenon of electromobility is relatively new, which affects the availability of data and prevents the application of time series analysis. For this reason, we have created our own methodology for creating scenarios for the development of new EV registration in the future, based on data in which the cross-sectional component predominates. Apart from the Slovak Republic, these scenarios can be applied to any other country for which there is information on the number of chargers for normal and high (fast) power and on the amount

[2]This problem, which has escalated by the war in Ukraine, is extremely noticeable in the Slovak Republic, as according to official data from the Office of the Government of the Slovak Republic, up to 100% of oil imported into the Slovak Republic comes from the Russian Federation. In addition, substituting the Russian Federation for another oil supplier will not be easy, as the technologies of the monopoly refining company in the Slovak Republic are set to heavy Russian oil. E-mobility, therefore, appears to be a rational starting point for the decline in oil imports from the Russian Federation.

of gross domestic product per capita. It is also possible to add other determinants to the regression model and scenarios, such as population information or to express all variables per capita. This is where the advantage of interpreting regression models as elasticities can be applied because from our point of view it is not a problem to use the results of the regression model in absolute terms and per capita for the purpose of prediction. Our scenarios are also significantly affected by the type of regression equation estimator. First, it is necessary to obtain a relevant estimate of the parameter of the logarithmic variable so that the results can be interpreted in percentage changes. We used a pooled Ordinary Least Square (OLS) estimator because in our case according to the Hausman test it was not possible to use a random-effect estimator and when estimating with fixed-effects some parameters were estimated insignificantly.

Regression analysis as a basis for the predictive model was elaborated in the gretl program and was interpreted via specialised literature ([49] and [34]), and following a predictive model of new BEV registrations and a simple calculation of fuel savings based on an average annual consumption of gas, diesel oil, ETBE (ethyl tert-butyl), bioethanol, and RME (rapeseed methyl ester) was elaborated. The software used is an open source platform as well as the databases used are publicly available. The results and predictions can be updated annually after new data are published in the databases. Any automation or application of artificial intelligence software should be used for manually demanding data collection from EAFO websites. In addition to GRETL, Microsoft Excel was also used to specify the model and create the scenarios, which opens up the possibility of a possible application of the methodology to other countries and other authors.

In order to increase the predictive and statistical ability of the regression equation, we also have used logarithms of dependent and independent variables; such type of regression equation is interpreted as elasticity. The regression equation predicting the elasticity of new BEV registrations is as follows:

$$\begin{aligned} \text{l\_new\_BEV} = \beta_0 + \beta_1 * \text{l\_Fast\_ch\_points} + \beta_2 \\ * \text{l\_Normal\_ch\_points} + \beta_3 \\ * \text{l\_GDP\_pc\_const} \ + \text{u} \end{aligned}$$

Estimated coefficients based on the past state in the European Union allowed us to predict an increase in the number of new BEV and PHEV registrations in the Slovak Republic built on the current state. The model below assumes that PHEV demand and supply will be significantly reduced to BEV in the future due to the price equalisation of BEV and ICEV around 2025 (calculated by different rates according to the scenario). The current dataset with the dependent variable new registration of BEVs is seen in Figure 1.

Prediction of newly registered EVs in the Slovak Republic was based on regression coefficients, especially on current Slovak indicators from 2020, which were part of the input data of regression analysis. The regression coefficients are interpreted as a percentage change of the dependent variable when the independent variable changes by 1%. For this reason, we predicted the percentage changes of individual independent variables. We have always made adjustments to the baseline (the year 2020), so we have worked with cumulative percentage changes.[3] In the case of the quantification of the new BEVs, we used chain indices.[4]

Based on the observation of scatterplots, we can conclude that there is a functional relationship between both types of infrastructure and dependent variables. Between GDP p. c. and an independent variable heterogeneity is detected that may weaken our analysis. Ref. [49] points out that the predictions of elasticity (logarithmic transformation of both sides of the equation) can be interpreted up to 10%. However, we have exceeded this limit in our scenarios, which can be considered a limitation of our methodology. On the other hand, we needed to predict by 2030 based on a short time series. The data provided by the EAFO have provided data since 2008, and very few countries have shown positive values during this period. We did not apply stationarity diagnostics for short time series (minimum 1 and maximum 10). However, Ref. [50] points to an indicator of possible spurious regression if the coefficient of determination (R-squared) is higher than the Durbin–Watson statistic. For this reason, the direction of the correlation, that is, the mathematical signs of the estimated parameters of the regression equation, is also confirmed by Spearman's correlation coefficients. Ref. [51] recommends using this type of correlation analysis if the variables do not have a normal distribution. This applies especially to the mentioned GDP p. c. We accepted the estimated parameter of this variable, and we used it in our scenarios also due to logical theoretical assumptions.

For this reason, we relied on the regression coefficients of the regression analysis despite the mentioned limitation. However, we point out that this limitation may weaken the predictive power of our scenarios. The approach of Pooled OLS panel data estimation was used for the model. We excluded the use of the Random Effects model due to the low value of Hausman statistics, and we did not consider the Fixed Effects model to be reliable, and not all variables were estimated with statistical probability. Finally, our analysis is determined by the low value of the Durbin–Watson statistic; therefore, we decided to apply

[3]The model is based on a linear year-on-year increase in the variables against the base period 2020, meaning that they will not be in exponential relation to the reference period (annual percentage change such as the compound interest calculation, instead of that we used methodology like simply interest calculation). Our correction is to see in Table 2, row 'Expected increase in % (exponential; against basis 2020)' compared to the row 'Expected increase in % (linear; the sum of % change and previous year)'. For example, in infrastructure normal, we calculated the effect of this variable on new BEV registrations in 2030 at a level of 100% increase compared to 2020 and not 159%, thus achieving the moderation and more realistic prediction of the impact of the examined factors on new registrations. In our case, we predicted the number of new registrations in 2030 caused by the increase in infrastructure normal using the following relationship: (new_BEV in 2020 x (1 + ['Expected increase in% (linear; sum of% change and previous year) in 2030' x estimated parameter of Normal_charging_points] from regression analysis]/100))—new_BEV in 2020.

[4]The effect of the various modelling factors followed the previous years. The regression model should always be based on the reference period rather than the previous years. On the other hand, in this way, we can include other factors in our model that were not elsewhere or subjectively corrected. If demand for BEV is triggered, it can be expected to stimulate further demand in the next period. In this way, we included time continuity in the predictive model, and we achieved acceleration later.

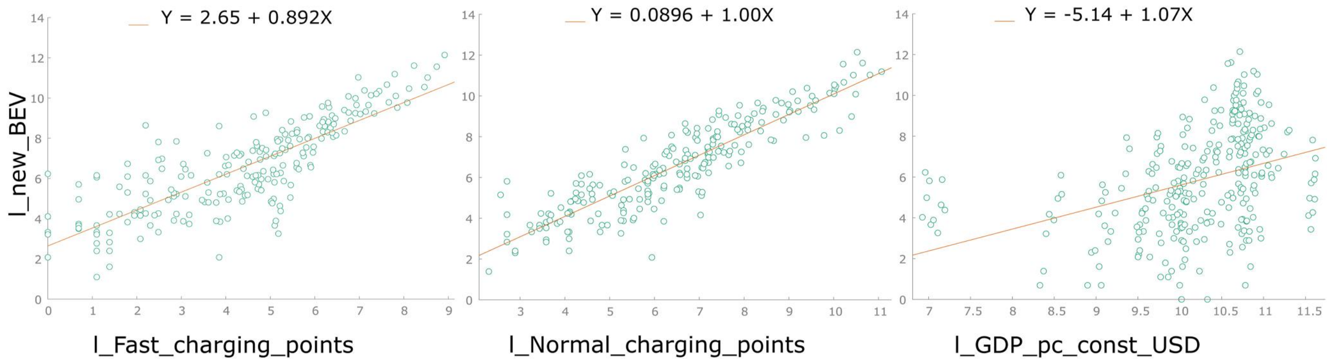

FIGURE 1 Scatter plots of variables. *Source*: Own calculation, based on Ref. [11, 47], and [48]

HAC (heteroskedasticity autocorrelation corrected) robust standard errors for the model. However, for our needs, even in combination with graphical analysis, we considered the estimated coefficients reliable and used Pooled OLS.

In addition to creating a reference, ecological and fossil scenario, we combined new EV (BEV) predictions in the case of the reference scenario based on two specifications of regression analyses and their confidence intervals. The maximum and minimum values for 2025 and 2030 represent the range of prediction of new electric cars.

Figure 2 shows the development of Slovak input data from 2008 to 2020. 2020 represents the initial situation for our reference, ecological and fossil prediction scenario. Interestingly, registrations of new BEVs accelerated in 2020, as did infrastructure growth in the form of standard chargers, despite the recession caused by the COVID-19 pandemic in 2020, which can be seen in the development of the GDP per capita in the 2010 constant price curve. We recorded a 456% increase in new registrations and an 87% increase in the penetration of standard charging points in a 5% economic recession.

4 | RESULTS AND DISCUSSION

In environmental benefits, electromobility is an alternative to transport development, which has its undeniable advantages in terms of air cleanliness in larger cities, CO2 emissions, and other parts. However, this assumption is not a general rule in the EU. For example, in the event of a comprehensive fleet transformation to BEV and PHEV, Poland would be likely to have higher emissions of harmful exhales due to a fossil fuel-based energy mix in electricity generation (a share of coal in electricity production approximately of 80%). However, in the case of the Slovak Republic, this energy mix is ideal since sources with a flat production volume (nuclear energy) and renewable energy sources (about 14%) are represented. Even though the government supports e-mobility in Slovakia, the current state of the EV penetration is one of the lowest in the EU28 not only in terms of the BEV and PHEV share of the fleet but also in the number of newly sold vehicles in 201 and 2018 (only 209 new BEV and 185 PHEV in 2017), and the trend remained till 2020 [44]. Nevertheless, it should be noted that after the change in the structure of the supporting electromobility tools in the Slovak Republic (in favour of charging stations), the number of BEV and PHEV increased year-on-year by tens of %. The prospect of a steep progression of electromobility in the Slovak Republic is unlikely regarding slowly converging living standards to income in Western Europe and conservative consumer preferences not considering the environmental aspects of buying a new passenger car enough.

4.1 | Model and scenarios

Considering the specifications mentioned above, we present the following results of the prediction model of electromobility development in Slovakia as compared to the target set by the state administration bodies in the SR. The results of regression analysis of input data are shown in the table:

Naturally, our results must be seen as statistical estimates dependent on the input historical data and on the chosen estimator. Confidence intervals (95%) of the estimate of our parameters are wider for GDP p. c. (p-value only 0.053):

1. l_Fast_charging_points: 0.26,222–0.56,162;
2. l_ Normal_charging_points: 0.41,301–0.83,209;
3. l_GDP_pc_const: −0.00,453 – 0.57,121.

With a 1% increase in charging devices with average power, we expect an increase in new BEVs by 0.62%, with higher performance chargers up to 0.41%. With GDP p. c. growth of 1%, we expect an increase of new BEV by 0.28%. The estimate of this variable has a statistical significance of only 90%, which is due to the significant heterogeneity. We accept it only based on a logical assumption about the relationship between the economic level and new EV registrations and the correlation analysis below.

However, there is a strong assumption that the electromobility market will be, in the future, fundamentally affected by state interference and the technological and economic efficiency of batteries. In the Slovak Republic, 302 BEVs were registered in the year 2018, but in the year 2019 only 156 BEVs, in the year 2020 867 new BEVs registrations, with 656

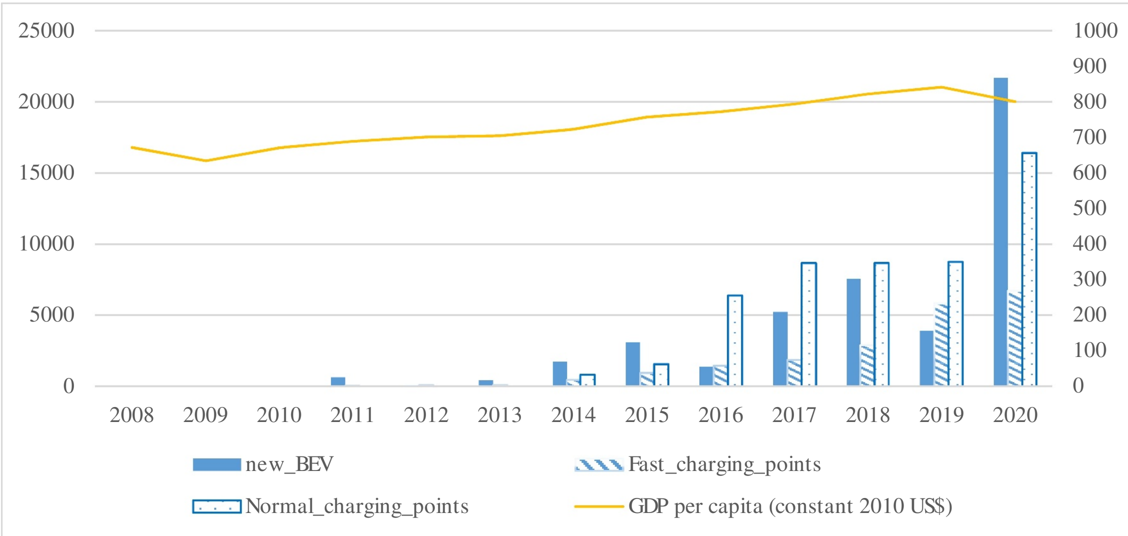

FIGURE 2 Development of input values in Slovakia from 2008 to 2020. *Source*: Own calculation, based on Ref. [11, 47], and [48]

placing charging stations with normal charging mode and 268 higher power stations on its territory in 2019 [15, 16]). In 2018, the Slovak Republic achieved GDP p. c. at USD 20,537. In the year 2019, it was USD 21,024, and we observed a decline in 2020, that is, USD 20,008 ([57]).

The Spearman's correlation coefficient between the variable l_new_BEV and l_Fast_charging_points has a value of 0.81 between the independent variable and l_Normal_charging_points 0.90 l_GDPpercapitaconstant2010 0.44. All coefficients have expected positive values. To further strengthen our assumption about the direction of correlation, we also created Spearman correlation coefficients based on cross-sectional data from 2020. In this case, we obtained the following correlation coefficients based on 28 observations: l_Fast_charging_points (0.91), l_Normal_charging_points (0, 96) and GDP p. c. (0.59). For this reason, we can accept estimations in order to develop scenarios (Table 1).

However, more robust estimates were provided by the variables transformed per capita in Table 2 and their confidence intervals. We used this in the robustness check of our reference scenario, in which we used the results of the estimation of analysis parameters 1 and 2 and their confidence intervals. Thus, we obtained the minimum and maximum values of the prediction of 2030 in the reference scenario. Analysis 2, unlike analysis 1, has all estimates except the constant estimated with a 99% probability (we reject the null hypothesis that the estimate is insignificant at the 99% significance level) (Table 3).

For an alternative specification with per capita variables, the confidence intervals (95%) were as follows:

1. l_Fast_charging_points: 0.28,268–0.56,167;
2. l_ Normal_charging_points: 0.26,906–0.62,637;
3. l_GDP_pc_const: −0.24,509 – 0.65,260.S

To prepare a forecast taking into account different starting points—from maintaining a significant position of fossil fuels to an optimistic (ecological) variant, three different models were proposed: reference, fossil, and ecological, taking into account different intensity of key variables—number of fast chargers, number of regular chargers, GDP p. c. and stringency of environmental regulation in the field of electromobility in the Slovak Republic.

Based on the reference scenario, we assume that ca. 5258 pieces of new BEVs will be registered in Slovakia in 2025 and almost 24,280 new BEVs in 2030. The baseline situation strongly influences our prediction. To the authors' surprise, in 2019 a significant drop was documented in new registrations of electric cars in Slovakia and followed by a sharp increase in new registrations. We indeed consider a conservative estimation of our prediction to be more realistic in light of the uncertain developments caused by the global coronavirus pandemic. The year 2019 can be considered economically positive in terms of the business cycle and further dramatically negative impact of COVID-19, and nevertheless, a decrease in new registrations of electric cars was reported. The 15-year time horizon does not represent a long enough time series for us to expect rapid saturation of electromobility in Slovakia.

In Table 4, we can see combinations of expected new BEV registrations in 2025 and 2030 based on different estimates of variable parameters. In 2025, the reference scenario predicts an increase in new BEVs ranging from 3498 to 6505 and in 2030, from 13,057 to 32,231 (Table 5–7).

We can predict a fossil or environmental scenario by modifying the reference scenario. The fossil scenario operates with low incentives and only 1.5% year-on-year GDP growth p. c. In this way, we estimate in Slovakia about 15,006 new BEVs in 2030. In the case of an environmental scenario, we expect acceleration in the number of charging equipment and subsequent market saturation from 2020 to 2025, with a fall to 10% year-on-year growth, with a 3% year-on-year GDP p. c. growth and with higher incentives. In the methodology part, we have described two problematic points of our predictive model. Nevertheless, we proved that factors such as infrastructure and economic

TABLE 1 Regression analysis 1 of new Battery Electric Vehicle (BEV) registrations—panel data

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
Const	−2.17337	1.20294	−1.807	0.0824	*
l_Fast_charging_points	0.411919	0.0728263	5.656	<0.0001	***
l_Normal_charging_points	0.622547	0.101940	6.107	<0.0001	***
l_GDP_pc_const	0.283339	0.140046	2.023	0.0534	*
Mean dependent var	6.772397		S.D. dependent var	2.132947	
Sum squared resid	148.4434		S.E. of regression	0.861520	
R-squared	0.839267		Adjusted R-squared	0.836856	
F (3. 26)	271.1524		*p*-value(F)	9.95e-20	
Log-likelihood	−257.0360		Akaike criterion	522.0720	
Schwarz criterion	535.3445		Hannan-Quinn	527.4409	
Rho	0.606786		Durbin-Watson	0.616216	

Notes: Model: Pooled OLS, using 204 observations (HAC robust standard errors), Dep. var.: l_new_BEV. Included 27 cross-sectional units (EU), Time-series length: minimum 1, maximum 10 (2008–2020). Collinearity analysis—Variance Inflation Factor (VIF < 10): l_Fast_charging_points 2.564; l_Normal_charging_points 3.615; l_GDP_pc_const 1.739.
Source: Own calculation, based on Ref. [11, 47], and [48]. Due to lower value of DW (Durbin-Watson test), robust standard errors were applied.

TABLE 2 Regression analysis 2 of new Battery Electric Vehicle (BEV) registrations p. c.—panel data

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
const	−4.84944	1.17045	−4.143	0.0003***
l_Fast_charging_points_pc	0.422170	0.0678634	6.221	<0.0001***
l_Normal_charging_points_pc	0.447716	0.0869137	5.151	<0.0001***
l_GDP_pc_const	0.448843	0.0991257	4.528	0.0001***
Mean dependent var	−9.389061		S.D. dependent var	1.727154
Sum squared resid	143.1331		S.E. of regression	0.845970
R-squared	0.763636		Adjusted R-squared	0.760090
F (3. 26)	199.0637		*p*-value(F)	4.76e-18
Log-likelihood	−253.3202		Akaike criterion	514.6405
Schwarz criterion	527.9130		Hannan–Quinn	520.0094
Rho	0.617831		Durbin–Watson	0.603231

Notes: Model: Pooled OLS, using 204 observations (HAC robust standard errors), Dep. var.: l_new_BEV_pc. Included 27 cross-sectional units (EU), Time-series length: minimum 1, maximum 10 (2008–2020). Collinearity analysis—Variance Inflation Factor (VIF <10): l_Fast_charging_points_pc 2.434; l_Normal_charging_points_pc 3.277; l_GDP_pc_const_pc 1.763.
Source: Own calculation, based on Ref. [11, 47], [48], and [58]. Due to the lower value of DW, robust standard errors were applied.

levels do not generate sufficient new registrations in the future, as predicted based on available predictions and expectations of political support for electromobility. In all three scenarios, the most crucial impact has incentives represented by significant stimuli in the form of political interventions, and technological and economic determinants.

4.2 | Discussion

Without a doubt, EVs constitute a valuable alternative to traditional combustion-based vehicles since they offer many advantages, especially in terms of energy cost, pollutant emissions, maintenance, and efficiency [1]. Concerning the advantages, authors realised a research study focussed on the penetration rate of the BEV and PHEV sales in Slovakia as a typical representant of the CEE countries with a below-average standard of living and high oil import dependence on the Russian Federation. Second, a pilot study assessing the impact of e-mobility penetration on oil import cuts was realised.

The estimate of the share of newly registered cars in the Slovak Republic according to individual scenarios is not entirely indicative, as the average age of the vehicle in the Slovak Republic is 14,0 years [52] and [53], which results in a relatively slow increase in the share of EVs in Slovakia also in 2030. According to the above scenarios, the cumulative number of newly registered EVs (BEV + PHEV) is projected at 31,456 (26.65% of the new cars) units for the fossil

TABLE 3 Prediction model—reference scenario based on analysis 1

	2020	2025	2030
Expected increase infr. normal in % (year-on-year)		10	10
Infr. normal in pieces	656	1056	1701
Expected increase in % (exponential; against basis 2020)		61	159
Expected increase in % (linear; sum of % change and previous year)		50	100
New reg. BEV induced by infr. normal in %		31.13	62.25
New reg. BEV induced by infr. normal (based on 2020)		1137	1407
Effect on new BEV caused by infr. normal (based on 2020)		270	540
Expected increase infr. high in % (year-on-year)		10	10
Infr. high in pieces	268	432	695
Expected increase in % (exponential; against basis 2020)		61	159
Expected increase in % (linear; sum of % change and previous year)		50	100
New reg. BEV induced by infr. high in %		20.60	41.19
New reg. BEV induced by infr. high (based on 2020)		1046	1224
Effect on new BEV caused by infr. high (based on 2020)		179	357
Expected increase GDP p. c. in % (year-on-year)		2	2
Real GDP p. c. in USD[a]	20,008	22,090	24,390
Expected increase in % (exponential; against basis 2020)		10	22
Expected increase in % (linear; sum of % change and previous year)		10	20
New reg. BEV induced by GDP p. c. in %		2.83	5.67
New reg. BEV induced by GDP p. c. in comparison 2020		892	916
Effect on new BEV caused by GDP p. c. (based on 2020)		25	49
Effect of model factors (based on 2020)		473	946
New reg. BEV—model factors included previous demand conditions	867	2286	6070
Incentive effect and battery prices in % (Year-on-Year)	10.0	30.0	40.0
Expected increase in % (linear; sum of % change and previous year)	10.0	130.0	300.0
Expected new BEV registrations	867	5258	24,280

[a]subjective forecasted.

Source: Own calculation.

TABLE 4 Prediction range based on different parameter estimates

Variant (reference scenario)	Expected new BEV registrations in 2025	Expected new BEV registrations in 2030
Analysis 1	5258	24,280
Min. conf. interval analysis 1	4011	16,330
Max. conf. interval analysis 1	6505	32,231
Analysis 2	4865	21,772
Min. conf. interval analysis 2	3498	13,057
Max. conf. interval analysis 2	6132	29,852
Min.	3498	13,057
Max.	6505	32,231

Source: Own calculation.

TABLE 5 Prediction model—ecological scenario based on analysis 1

	2020	2025	2030
Expected increase infr. normal in % (year-on-year)		30	20
Infr. normal in pieces	656	1486	6815
Expected increase in % (exponential; against basis 2020)		127	939
Expected increase in % (linear; sum of % change and previous year)		90	270
New reg. BEV induced by infr. normal in %		56.03	168.09
New reg. BEV induced by infr. normal (based on 2020)		1353	2324
Effect on new BEV caused by infr. normal (based on 2020)		486	1457
Expected increase infr. high in % (year-on-year)		30	20
Infr. high in pieces	268	607	2784
Expected increase in % (exponential; against basis 2020)		127	939
Expected increase in % (linear; sum of % change and previous year)		90	270
New reg. BEV induced by infr. high in %		37.07	111.22
New reg. BEV induced by infr. high (based on 2020)		1188	1831
Effect on new BEV caused by infr. high (based on 2020)		321	964
Expected increase GDP p. c. in % (year-on-year)		3	3
Real GDP p. c. in USD [a]	20,008	23,195	26,889
Expected increase in % (exponential; against basis 2020)		16	34
Expected increase in % (linear; sum of % change and previous year)		15	30
New reg. BEV induced by GDP p. c. in %		4.25	8.50
New reg. BEV induced by GDP p. c. in comparison 2020		904	941
Effect on new BEV caused by GDP p. c. (based on 2020)		37	74
Effect of model factors (based on 2020)		844	2495
New reg. BEV—model factors included previous demand conditions	867	2951	12,663
Incentive effect and battery prices in % (Year-on-Year)	10.0	30.0	60.0
Expected increase in % (linear; sum of % change and previous year)	10.0	130.0	360.0
Expected new BEV registrations	867	6787	58,249

[a]subjective forecast.
Source: Own calculation.

TABLE 6 E-mobility impact on oil products consumption/import savings by scenarios (for 2030)

Scenario		Market share (BEV and PHEV on new passenger cars sold in 2030)	Market share (BEV and PHEV on total passenger cars fleet in 2030)	Market share (BEV and PHEV on total passenger cars fleet in 2030)	Saving of total ICE oil products consumption	Fuel savings (diesel and gasoline in 2030)
Fossil	BEV	12.71%	7.00%	3.06%	100%	5.03%
	PHEV	13.94%		3.95%	50%	
Reference	BEV	20.57%	10.82%	4.66%	100%	7.74%
	PHEV	21.14%		6.15%	50%	
Ecological	BEV	49.35%	17.57%	11.16%	100%	14.37%
	PHEV	24.95%		6.41%	50%	

Source: Own calculation.

scenario, 49,230 (41.71%) for the reference scenario, and approximately 87,699 (74.30%) for the ecological scenario in 2030. However, the total number of vehicles in the Slovak Republic is 3.268 mil. (of which 2393 million passenger cars) for the year 2019, and the number of newly registered passenger cars 2019 was 243,659 units [54]. It follows that if the

TABLE 7 Prediction model—Fossil Scenario based on analysis 1

	2020	2025	2030
Expected increase infr. normal in % (year-on-year)		10	10
Infr. normal in pieces	656	1056	1701
Expected increase in % (exponential; against basis 2020)		61	159
Expected increase in % (linear; sum of % change and previous year)		50	100
New reg. BEV induced by infr. normal in %		31.13	62.25
New reg. BEV induced by infr. normal (based on 2020)		1137	1407
Effect on new BEV caused by infr. normal (based on 2020)		270	540
Expected increase infr. high in % (year-on-year)		10	10
Infr. high in pieces	268	432	695
Expected increase in % (exponential; against basis 2020)		61	159
Expected increase in % (linear; sum of % change and previous year)		50	100
New reg. BEV induced by infr. high in %		20.60	41.19
New reg. BEV induced by infr. high (based on 2020)		1046	1224
Effect on new BEV caused by infr. high (based on 2020)		179	357
Expected increase GDP p. c. in % (year-on-year)		1.5	1.5
Real GDP p. c. in USD *	20,008	21,554	23,220
Expected increase in % (exponential; against basis 2020)		8	16
Expected increase in % (linear; sum of % change and previous year)		7.5	15
New reg. BEV induced by GDP p. c. in %		2.13	4.25
New reg. BEV induced by GDP p. c. in comparison 2020		885	904
Effect on new BEV caused by GDP p. c. (based on 2020)		18	37
Effect of model factors (based on 2020)		467	934
New reg. BEV—model factors included previous demand conditions	867	2268	6003
Incentive effect and battery prices in % (Year-on-Year)	10.0	15.0	20.0
Expected increase in % (linear; sum of % change and previous year)	10.0	65.0	150.0
Expected new BEV registrations	867	3742	15,006

fleet were to remain structurally at the same level until 2030, EVs (BEV + PHEV) would contribute to the total number of passenger cars at a maximum share of 7.00% for the fossil scenario, 10.82% reference scenario, and 17.57% for the environmental scenario. The rest of the fleet would remain as standard ICE passenger cars.

The results are comparable to the assumptions even in more developed market economies with a higher standard of living. In this context, it is necessary to emphasise that due to the negative economic impacts of the COVID-19 pandemic, it can be assumed that with a decline in the standard of living in 2020, slower sales of new electric cars on roads in the Slovak Republic and the EU can be expected compared to the forecasted economic growth.

In 2017, 209 BEVs and 185 PHEVs were registered in the Slovak Republic, which means 571 BEVs and 447 PHEVs in 2018. In 2020, it was 867 BEV and 852 PHEV as new e-cars registered. The reasons for the low penetration of electromobility in the Slovak Republic are international aspects of electromobility (total cost ownership (TCO), battery prices, mileage etc.). The critical factors regarding EVs that will determine the vehicle's autonomy comprise batteries [1] and available infrastructure (347 public slow chargers and 96 fast chargers in 2018). Another reason is the intent to purchase electric cars, which were evaluated as less intensive than several European countries, even countries at a comparable level of economic development. Without a significant increase in the MESR budget for this initiative and a more comprehensive legislative advantage for EV owners, no significant changes in market share can be expected.

Based on our model, it is possible to identify the fundamental aspect of the tendency to prefer the purchase of BEV/PHEV in comparison with a standard ICE vehicle to Slovak consumers. This parameter is GDP p. c.—a standard of living predisposes one to purchase a classic ICE vehicle, which will probably be more affordable for several years to come, especially concerning battery prices and a significantly lower standard of living for the Slovak consumer than the European average. In the case of the Slovak consumer, however, in addition to the lower disposable income, it is also possible to identify specific preferences when purchasing an electric car. Slovak respondents are more focussed on standard decision-making factors (price, performance, and maintenance costs) when buying a car, and the environment does not play such an important determinant of consumer preferences for them. To some extent, this can be explained by disposable income, but it is not the only factor in this approach. Unless electric cars become a matter of prestige and image, it is unlikely that factors such as environmental protection or environmental responsibility will prevail among Slovak consumers. According to Ref. [55] and [56], this is also proved by the high ratings of the masculinity of Slovak culture (Index MAS 100), which prioritises career and success over values such as family, leisure, or the environment, unlike the highly feminine Scandinavian culture, which is strongly oriented towards social values and the environment. At the same time, Scandinavia's femininity explains why electric cars are relatively popular in these countries and are the preferred choice for consumers. In the case of the Slovak consumer, electric cars would have to become a product that represents a particular exceptional image and gives its owner a specific status that sets it apart from others. The factor of environmental protection in the current value setting of Slovak culture will not play a significant role in purchasing decisions for a very long time.

Other specifics of the Slovak customer preferences may explain the gap in new BEV and PHEV registrations compared to western EU countries. They are connected either to infrastructure or regulation in the field. In particular, the structure of highways in the country—the more developed western part of Slovakia has a much better highway network and charging infrastructure. Moreover, e-car drivers heading to eastern Slovakia and larger cities such as Košice or Prešov are challenged by the BEV and PHEV range from Bratislava. The distances among the biggest cities in Slovakia are usually around 200 km, with return mileage within the same day more than 400 km. Insufficient charging points and slower chargers in the eastern part of the country can negatively determine the customers using highways and travelling for longer distances. New opportunities could be brought by Fit for 55 package implementation in Slovakia, where new financing of the fast chargers together with voluntary charging points in the highways were introduced (every 60 km of the highway).

The character of many Slovak cities—fewer family homes and many blocks of flats living style can be a problem for the charging infrastructure regarding access to the charger and additional costs for the electricity infrastructure robustness and the electricity peak costs. The possible effect of the TCO advantage in favour of BEV or PHEV in Slovakia is also positively limited by electricity prices. Unlike prices for industrial producers, electricity prices for household customers are one of the lowest in the EU. Only three EU countries have cheaper electricity for households than Slovakia, and this price is about 15% lower in 2021 than the EU average [12]. Nevertheless, the first charging electricity tariffs have been applied in Slovakia from 2020, which could boost the preferences of the customers to charge their cars at home in the upcoming years. Nevertheless, the prices (charging tariffs) are not subsidised by the government enough. Due to these reasons, families still prefer to buy a new BEV/PHEV only as a second car in the family, primarily used for urban transportation and rather shorter distances with slow charging at home (garages). For the positive effects of electromobility, the decisive benefit results from comparing the carbon footprint and emissions of internal combustion engines versus engines using domestic electricity. This argument highlights the result of the SAO's (Supreme Audit Office of the Slovak Republic) inspection in the Slovak Republic, where it was found that the Slovak Republic's obligations in air quality protection were not met. Exclusively from the point of view of the energy mix in electricity production, the Slovak Republic is an exceptionally suitable candidate for the establishment of electromobility through the prism of ecology. Electricity in the Slovak Republic is only about 18% generated from fossil sources (oil, gas, and coal); the rest is RES (renewable energy sources) and nuclear energy. In this context, it is also necessary to emphasise the intensive effects of electromobility on the electricity network, requiring massive investment by households and businesses. As proposed by Ref. [9], higher infrastructure capital expenditures and operating expenses will be required in order to satisfy the peaks of high energy demand, especially in the near future, when the market penetration of EVs are higher. The government should build charging stations and robust and stable networks to maintain system stability. The commercial perspective of electromobility in the Slovak Republic was assessed through three scenarios depending on the environmental ambitions of future Slovak governments. The initial factors were statistically significant at the international level—the structure and number of charging stations, technological progress in the production of BEV, state support and legislation, and the growth of living standards in the Slovak Republic.

In the case of the fossil scenario, the share of BEV on the Slovak market in 2030 is estimated at 4.1% of the share in newly registered cars; in the case of PHEV, it is only 2.29%. In the case of the reference scenario, the share of net EVs is estimated at 8.4% and the share of new hybrids at 4.6%, mainly due to more intensive support, charger density, and incentive legislation. Considering the international development of electromobility and very favourable conditions for supporting the purchase of BEV, a sharp drop in battery prices, a rapid development of the network of charging stations, and electromobility supporting regulation is the case of the most optimistic variant—the ecological scenario. Under these assumptions, BEV's expected share of the Slovak car market in 2030 would be approximately 19.6%, and BEV's share only 7.3%.

The impact of electromobility on individual areas of the national economy would be massive even in the reference scenario. When setting the mentioned conditions of support, legislation, and regulation, it would be possible to expect a more significant impact on the fuel market, but in the case of the reference scenario, this decrease would reach a maximum of 1.6% of the volume of fuels sold in the Slovak Republic compared to 2017. In the case of the ecological scenario, we estimate the impact of the decrease in fuel consumption at the level of 6.0% of fuel sold in 2017. In parallel, an increase in the number of vehicles can be expected due to higher living standards, especially the still dominant share of non-passenger vehicles in fuel consumption. For this reason, we do not consider the significant progress of electromobility in the Slovak Republic until 2030 to be significantly threatening economic interests and sales potential of companies operating in the field of fuel sales, respectively, biofuel production.

The final part of the research study—a comparison of the impacts of electromobility on oil imports— was made based on the assumptions of 100% fuel savings in the case of BEV and 50% fuel savings in the case of PHEV usage.[5] According to the particular scenario, a replacement of the ICE passenger vehicle by BEV or PHEV was expected.

According to the last known data, about 473.5 tonnes of gasoline and 1720.7 tonnes of diesel were consumed in Slovakia. Besides this amount, about 32.2 tonnes of ETBE were mixed into consumed oil products. Therefore, e-mobility replaces oil fuels and biofuels, mostly of first generation, decreases the potential and benefits of import substitution.

This analysis shows that the volume of spent fuel (passenger car segment) in the Slovak Republic will be relatively low. In the case of the fossil scenario, electromobility would save only 5.03% of the fuel consumed in the passenger car segment, with the most optimistic scenario being 14.37%. Based on these data, it should be stressed that such a saving (not to mention the impact of battery production and necessary commodities import etc.) is significantly under the effect of other measures, such as the implementation of biofuels in passenger transport. Between 2019 and 2020, the oil price volatility caused a significant Slovak import value to decrease by −23.76%, from the results of the modelled future development of electromobility results only in the relatively small contribution of EVs and hybrids for reducing the import intensity in the field of oil and petroleum products' imported volume and value. An additional amount of electricity will have to be produced to replace the consumed amount of the oil products within the ICE passenger car segment (based on the conclusion of Ref. [57]). At the same time, the model results point out that much more efficient and more targeted instruments with instant effects to support the purchase of EVs and hybrids will have to be implemented for the faster electrification of the passenger car segment. Road transport represents about 48% of the oil consumption in Slovakia. Within other segments (e. g. truck transportation and other oil products consuming sectors), the savings will probably be even lower due to the much more difficult switch to EVs.

5 | CONCLUSION

According to the commitments stemming from the COP26 agreements, a trend of e-mobility is a must for most countries. Nevertheless, implementing such an idea seems not so beneficial under any circumstances and in the concise run. First, the electricity generation energy mix has to be changed more in favour of renewable energy sources and nuclear power electricity since some countries could cause even a negative carbon footprint in case of any enforceable change. Slovakia is a unique example of possibly high benefits for the emission in case of switch onto electric cars.

Many European countries have achieved quite encouraging results in e-mobility as the share of BEV and PHEV on new car sales. However, real numbers are meagre due to relatively lower standard of living, insufficient incentives, consumer preferences, charging infrastructure, and still relatively low regulation (e.g. carbon taxing). On the other hand, mainly CEE countries have been facing slower electrification of passenger transportation since the standard of living is a significant fundament. Particularly in Slovakia, only 1.10 of the new car sales are covered by BEV and 1.10% by PHEV for 2020, and the 'electrification' of the car passenger segment is relatively slow. In the past, strategic goals for e-mobility in Slovakia were set considerably higher.

Based on our regression model, the Slovak market is predicted to have a relatively small share of BEV and PHEV on the horizon by 2030. Consumers' preferences seem to play a vital role since customers tend to prefer environmentally friendly BEV and PHEV cars, but the reality of the car distributors seems to be different. Three scenarios reveal a low potential for e-mobility penetration in the Slovak market. In 2030, the fossil scenario predicts a 12.71% share of BEV in the new car market and 13.94% of PHEV, and the share of the total fleet will be around 7.00%. This low share will occur primarily thanks to the higher average age of the car on the Slovak roads. As for the reference scenario, 20.57% market share for the new BEV passenger car sales and 21.14% of PHEV is forecasted in 2030, which creates a 10.82% market share for all passenger vehicles. The most optimistic ecological scenario predicts a 74.30% share of the passenger cars (49.35% of BEV and 24.95% of PHEV) to be electrified, with 17.57% of total passenger cars in 2030.

Several institutions point to the undeniable benefits of expanding electromobility for investment, employment, and the environment. Fewer analyses point to savings in imported oil. This topic has become crucial, especially after the outbreak of war in Ukraine and the fundamental changes of the USA and especially the EU towards the Russian Federation, as the EU states import energy worth 500 billion a year. €. The contribution of these impacts on a small open economy in the CEE region, such as Slovakia, is significant. In addition to the abovementioned fundamental analysis using a model predicting new BEV and PHEV registrations according to individual scenarios, the authors also mapped the effects of electromobility penetration on reducing imported oil for fuel needs. This aspect was missing in the analyses of key institutions, and it is necessary to process such an analysis, as the approach of the CEE countries towards the Russian Federation is also different, with potentially different effects on changes in the oil balance.

Besides the forecasted global levels, the real potential for diesel and gasoline savings in Slovakia seems to be very low.

[5] Saving rates differ among many authors, for example, Ref. [50] identified only 20 % cost savings per km in the case of hybrid vehicles.

Considering the market mentioned above share, only about 5.03% of oil products as a fuel in the passenger car segment will be spared in the most pessimistic scenario. The reference scenario expects to save 7.74% of the oil products, and the most optimistic 'eco-friendly' scenario brings around 14.37% fuel savings in 2030. Concerning permanently increasing consumption of oil products in the Slovak transportation, steady benefits of e-mobility till 2030 are somewhat doubtful, and import substitution will be very low and not bring oil independence. Besides weak oil import cuts, new imports from the third countries are expected, e. g. importation of lithium, cobalt, manganese, nickel, and other commodities or semi-finished products is needed for battery production and recycling. In this regard, e-mobility will not be the most effective tool for enhancing energy security and self-sufficiency of the EU members, particularly the EU members from the CEE region.

If we consider that oil prices more than doubled between the first quarter of 2022 and 2021, the effect of electromobility will have only a minor effect on the volume and value of imported oil to the Slovak Republic by 2030. However, it should be emphasised that concerning consumer preferences and a very high masculinity factor in Slovakia, incentives and regulatory measures by the government to support electromobility will be crucial. Several instruments, including direct financial support, which has caused a significant increase in the purchase of these vehicles in Western Europe, have not yet been exhausted in the Slovak Republic. In the case of a more massive shift away from oil imports and intensive diversification of sources and roads, we consider intensive support for electromobility, an effective tool for 'decarbonisation' in the Slovak Republic in the medium and long term.

Authors are fully aware of some limitations of their research, primarily in the field of normal distribution of the data, mainly due to the new trend—electromobility dominating the European market since 2015 and the Slovak market primarily since the end of 2016 when the first financial incentives for BEV and PHEV purchases were implemented. Only a few scientific sources were also found regarding qualified oil product savings rate (fuel consumption savings) in the case of BEV and PHEV, which needs a more comprehensive analysis of the authors in technological fields.

Further research is essential due to the short time series within international databases published so far, and deeper analysis using quarterly or monthly data is irrelevant. According to our results, the effects of financial incentives for new BEV and PHEV purchases must be researched at the commercial and policy-making levels. The second most crucial factor stemming from the Fit for 55 package proposals is the importance and stringency of regulation in e-mobility, particularly in the CEE countries.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in 'The EAFO' at www.eafo.eu, reference numbers [13, 14] and in 'The WBG' at databank.worldbank.org, reference number [45, 46].

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