ECONOMICS AND CULTURE 20(1), 2023

DOI: 10.2478/jec-2023-0009

ELECTRIC VEHICLES FROM AN ECONOMIC POINT OF VIEW

Mária Urbánová[1], Dominika Čeryová[2], Viktória Benďáková[3], Patrícia Husárová[4]

[1] *Institute of Economics and Management, Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic, maria.urbanova1@uniag.sk, orcid.org/0000-0003-4281-7329*

[2] *Institute of Economics and Management, Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic, dominika.ceryova@uniag.sk, orcid.org/0000-0003-2924-2284*

[3] *Institute of Economics and Management, Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic, xbendakova@uniag.sk, orcid.org/0000-0002-1079-6458*

[4] *Institute of Economics and Management, Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic, xhusarovap@uniag.sk, orcid.org/0000-0003-1135-3429*

Received 4 April 2023; accepted 29 May 2023

Abstract

Research purpose. In recent years, the importance of moving from a linear economy to a circular economy in every area and sector of the economy has been discussed more than ever before. This includes discussions on a net zero energy system as the basis for a fully decarbonised electricity sector. The increase in demand for electricity and the push for net zero emissions are leading to a focus on using electric vehicles to meet the EU's sustainability targets. The European transport sector is responsible for a significant part of the European Union's total greenhouse gas emissions. The main aim is to evaluate the impacts of the automotive industry from an economic point of view because the increase in sales of electric cars can lead, among other things, to the mitigation of environmental problems.

Design / Methodology / Approach. Electric cars and biofuel cars are the two most discussed solutions in the transport sector. As EVs are sustainable to the extent that their energy sources are sustainable, the main aim of this research paper is to investigate the impacts of the chosen electric vehicle types from an economic point of view, especially the sales of electric vehicles in the time period of 2010-2021. Battery electric vehicles and plug-in hybrid vehicles' sales situation will be analysed in Europe and globally. The assumptions and hypotheses were set and verified through regression and correlation analysis.

Findings. The research results have confirmed our assumptions that the number of vehicles sold in Europe and worldwide is increasing with time. During the time period under consideration, electric car sales increased worldwide. 6,600,000 battery electric vehicles and plug-in hybrid vehicles were supplied in total in 2021, representing a 45% increase from the previous year. The most significant growth in car sales in Slovakia was in 2021, but only one-tenth of one per cent were electric vehicles.

Originality / Value / Practical implications. A gradual shift of the main interest from automakers to electric vehicles is seen. At the same time, there are other questions connected to electric vehicles that need to be addressed and analysed, such as their high price, charging options and infrastructure and, nowadays, the electricity price.

Keywords: Electric vehicles; Circular economy; Sustainable economics

JEL codes: Q42; Q50; L94

Introduction

The present economic model is the linear economy, in which natural resources are taken, processed, used and disposed of (Johannsen et al., 2022). This model is, however, totally unsustainable (Tan et al., 2022); therefore world came up with the idea of a circular economy that is durable, green and sustainable (Sulich & Soloducho-Pelc, 2022). Environmental regulation and environmental awareness drive the

© 2023 Authors. This is an open-access article licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0)

circular economy (Neves & Marques, 2022), which is a challenging model getting a lot of critiques from one side (Corvellec et al., 2022), offering many opportunities on the other side (Marsh et al., 2022). The idea of transitioning from a linear approach is not new. Society started to make efforts to prevent environmental problems stemming from a linear model of the economy by the 1960s and 1970s by discussing the necessity of recycling, the protection of wilderness, and issues connected with air and water pollution (Mulvaney et al., 2021). The circular economy model is considered an excellent tool for reaching sustainable development goals, according to Rodriguez-Anton et al. (2022). The aim of the Paris Agreement from 2015 to keep global warming to no more than 1.5°C requires greenhouse gas emissions to reach net zero by 2050 (Bataille et al., 2018). The circular economy concept looks for new ways of providing everything society needs. It revolves around deploying rather than consuming materials, using them more than once, and redesigning them to make them as efficient as possible – both economically and environmentally (Ashby, 2016). This transition is also dependent on the use of more efficient products, enabling smart homes and hybrid plug-in electric vehicle technologies, according to Abdallah and El-Shennawy (2013). Climate changes significantly affect the electric sector, electricity demand, supply, and infrastructure (Jaglom et al., 2014). As a result of global warming, the annual cost of electricity production will increase by 14% by 2050 (Gerlak et al., 2018). The fact that society depends highly on fossil fuels is one of the greatest problems nowadays, since this leads to significant environmental issues, there is a need to find an alternative to fossil fuel that will be environmentally friendly, sustainable as well as efficient. Fuel cell technologies represent one of the most promising alternatives to fight these problems (Wilberforce et al., 2016).

The main objective is, therefore, to evaluate the impact of the automotive industry from an economic point of view since an increase in the sale of electric cars (battery electric vehicles and plug-in hybrid vehicles), which are considered to be a more environmentally friendly alternative compared to petrol and diesel cars, could lead, among other things, to the solution of some environmental problems. Plananska (2020) agrees and adds that many governments also introduced measures to promote electric vehicle sales (mainly regulation, financial incentives, and information-based interventions) designed to motivate electric vehicle purchases by raising awareness about electric vehicles and their environmental benefits.

Literature review

Li et al. (2019) divides all electric vehicles into three classes depending on the purpose. The first class is the Urban electric vehicles with a maximum speed of up to 100 km/h, the second is highway electric vehicles with maximum speed over 100 km/h, and the third is sports electric cars with a maximum speed of over 200 km/h. According to Wilberforce et al. (2017), electric cars cost around 2 cents per mile which is a great difference compared to conventional petrol-powered cars that cost 12 cents per mile. Also, electric cars are able to operate within 4–8 miles per kWh of energy with zero emission of greenhouse gases. Fuel cells produce zero-emissions power by using hydrogen as a fuel to generate electrical energy through a chemical reaction (Baroutaji et al., 2015). Kundu and Dutta (2016) name some advantages of hydrogen fuel cells over battery systems: instant recharging via replacement or a refilled fuel cartridge, independence from electricity, longer cell lifetime, or higher energy conversion (chemical to electrical) efficiency. Even more than a decade ago, fuel cells were considered as appropriate as portable power systems due to their durability and low cost (Cacciola et al., 2001). From a fuel cell, through a chemical reaction with oxygen, hydrogen as the energy carrier can be converted into electricity (Khan & Iqbal, 2009). Plug-in electric vehicles have been seen since the beginning of their development as part of the solution to reduce road transport emissions of CO_2 (Meinshausen et al., 2009). The result of the study from 2010 showed that in the situation in which the entire 2009 passenger car fleet would be replaced by an equal share of three battery electric vehicles available in that year, and then CO2 emissions would be reduced by 51 – 91% in European countries (Inderwildi et al., 2010). Graham-Rowe et al. (2012) named three broad types of plug-in electric vehicles: (i) battery-electric vehicles, (ii) plug-in hybrid electric vehicles that developed from hybrid electric vehicles, and (iii) range-extended electric vehicles. The complete list of hybrid and electric vehicles also includes hybrid electric vehicles and vehicles powered by hydrogen fuel cell technologies. The study from 2019 shows that even though electric and plug-in hybrid car prices have decreased since 2010, it is crucial to give attention to

non-cost market barriers for these vehicles, such as recharging infrastructure (Weiss et al., 2019). Electric and plug-in hybrid cars are becoming financially more attractive to consumers and economically more efficient in mitigating the negative impacts of road transport, according to Degraeuwe et al. (2016).

Also, the share of respondents considering purchasing a hybrid or electric vehicle in the near future across the European Union in the study from 2019 increased from 32% in 2014 to almost 38% in 2018 (Christidis & Focas, 2019). Although the rapid progress of the world economy and technology has advanced human civilisation, it has also caused tremendous damage to the global ecological environment (Tu, 2002). Electric power as a currently viable energy solution can solve the country's dependence on petroleum resources to some extent (Liu, 2008). One of the important causes of environmental pollution is the large increase in car ownership and use (Hao et al. 2016). According to International Energy Agency (IEA) statistics, there are currently approximately 1 billion vehicles in the world, consuming about 60 million barrels of oil per day (about 70% of total oil production); private vehicles consume an average of about 36 million barrels of oil per day, emitting 14 million tons of carbon dioxide (Sang & Bekhet, 2015). Therefore, one of the solutions to environmental problems is to replace traditional vehicles with new energy vehicles (IEA, 2017). From an energy perspective, having more energy sources for vehicles will improve the reliability and balance of energy consumption. In conjunction with the smart development of electric vehicles, transport conditions and road use will be significantly improved (Eltayeb et al., 2010). Ellingsen et al., however, have clearly stated that considering the whole life cycle of vehicles (production, use and scrappage), pure electric vehicles can reduce GHG emissions by around 30% compared to combustion engine vehicles in the current European electricity generation mix. Given the pressures of resource reduction and environmental change, electric vehicles will become a significant trend in the development of the future automotive industry. Therefore, developing low-carbon, energy-efficient, intelligent electric vehicles is imperative to reduce environmental impact (Tu, 2002).

Research Methodology

The main aim is to evaluate the impacts of the automotive industry from an economic point of view. The objects of research are two types of electric vehicles, namely:

- battery electric vehicles in Europe and the world (BEV),
- plug-in hybrid vehicles in Europe and the world (PHEV).

The primary data were collected from publicly available databases (International Energy Agency) and subsequently processed and evaluated in Microsoft Excel.

In the context of the research part of this paper, we have set research assumptions, which we have verified through regression and correlation analysis:

1. The number of battery electric vehicles sold in Europe increases with increasing time;
2. The number of plug-in hybrid vehicles sold in Europe increases with increasing time;
3. The number of battery electric vehicles sold in the world increases with increasing time;
4. The number of plug-in hybrid vehicles sold worldwide increases with increasing time.

We have chosen the hypotheses based on previous assumptions that as the time period increases, the number of electric cars sold increases because people in the world and Europe are more and more interested in buying electric cars, on the basis of which we believe that people are more and more concerned about the environment, as electric cars are generally considered to be more environmentally friendly. It is obvious that additional variables, such as average income or vehicle pricing, should have been considered to assess the overall economic condition and the readiness for the widespread use of electric automobiles. However, here we focus mainly on the development of the number of electric vehicles and the prediction for the future. Later research and the project, of which this paper is also a part, will address other economic points and consumer needs to boost electric vehicle sales.

We considered the time period of 2010-2021 as the independent variable and the sales of battery electric vehicles and plug-in hybrid vehicles in Europe and worldwide as the dependent variable. The null and alternative hypotheses were set as follows:

- H0: the time period does not affect the number of battery electric vehicles sold in Europe
- H1: time period affects the number of battery electric vehicles sold in Europe

- H0: the time period does not affect the number of plug-in hybrid vehicles sold in Europe
- H1: time period affects the number of plug-in hybrid vehicles sold in Europe

- H0: time period does not affect the number of battery electric vehicles sold worldwide
- H1: time period affects the number of battery electric vehicles sold worldwide

- H0: time period does not affect the number of plug-in hybrid vehicles sold in the world
- H1: time period affects the number of plug-in hybrid vehicles sold in the world

After applying all the regression models, the polynomial function proved to be the most appropriate in terms of the coefficient of determination for describing the relationship between the observed variables.

$$y_j^{'} = b_0 + b_1 * x_j + b_2 * x_j^2 \quad (1)$$

Where:

- b_0 – intercept,
- b_1 – regression coefficient,
- $y_j^{'}$ – j-th value of the dependent variable,
- x_j – j-th value of the independent variable.

The Durbin-Watson statistic is a test statistic to detect autocorrelation in the residuals from a regression analysis.

$$d = \sum_{t=2}^{T}(e_t - e_{t-1})^2 / \sum_{t=1}^{T} e_t^2$$

Where:

- T – The total number of observations
- e_t: – The tth residual from the regression model

This test uses the following hypotheses:

- $H0_{DW}$: there is no correlation among the residuals.
- $H1_{DW}$: the residuals are autocorrelated.

The Durban-Watson statistic will always assume a value between 0 and 4. A value of DW = 2 indicates that there is no autocorrelation. When the value is below 2, it indicates a positive autocorrelation and a value higher than 2 indicates a negative serial correlation. To test for positive autocorrelation at significance level α (alpha), the test statistic DW is compared to lower and upper critical values:

- If DW < Lower critical value: There is statistical evidence that the data is positively autocorrelated
- If DW > Upper critical value: There is no statistical evidence that the data is positively correlated.
- If DW is in between the lower and upper critical values: The test is inconclusive.

Research results

World and European vehicles sales situation

The following figure (Fig. 1.) shows the number of sales of selected vehicle types worldwide and in Europe during the period under review (2010-2021).

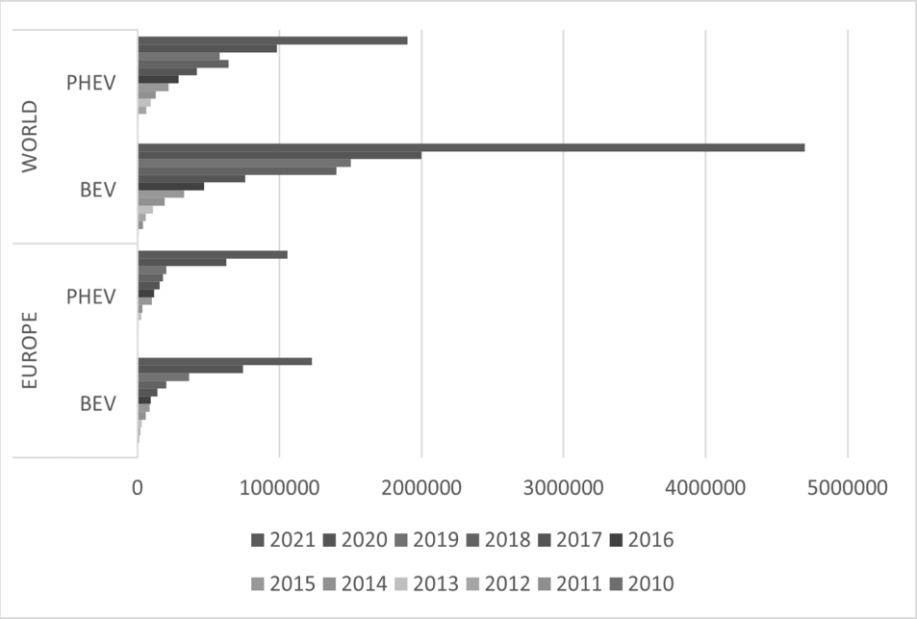


Fig. 1. Number of sales of selected vehicles types in the world and in Europe (Source: own processing)

The global battery electric vehicles and plug-in hybrid vehicles market developed at an increasing pace during the period under review, with battery electric vehicles and plug-in hybrid vehicles sales in Europe following this trend. The growing consumer interest in battery electric vehicles and plug-in hybrid vehicles is due, among other reasons, to the increase in average CO2 emissions and the rise in fuel prices.

Share of global sales of electric and hybrid vehicles

The following table (Table 1) provides an overview of the percentage of global sales of battery electric vehicles, plug-in hybrid vehicles, and both in Europe.

Table 1. Share of global sales of electric and hybrid vehicles (Source: own processing)

SHARE (%)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average
BEV	28.78	27.43	31.94	29.78	31.29	26.43	19.68	18.29	14.43	24.17	37.07	26.14	**26.29**
PHEV	11.05	4.88	15.34	28.23	26.35	45.44	40.27	37.15	28.11	35.24	63.68	55.66	**32.62**
BEV + PHEV	27.92	23.25	23.50	29.07	29.28	34.04	27.54	25.00	18.72	27.26	45.82	34.64	**28.84**

Based on our calculated data for the period under review (2010-2021), we found that European sales account for an average of 26.29% of global Electric vehicles (battery electric vehicles) sales, and thus, more than a quarter of global battery electric vehicles sales are in Europe. If we look more closely at plug-in hybrid vehicles (plug-in hybrid vehicles), we can see from the table above that sale of these vehicles have a larger share (32.62%) of total sales, so we can conclude that customers prefer to buy plug-in hybrid vehicles over battery electric vehicles. In the last reporting year, 2021, the highest sales value was recorded in Germany for both battery electric vehicles and plug-in hybrid vehicles (360,000 - battery electric vehicles; 330,000 - plug-in hybrid vehicles). In contrast, Greece accounted for the smallest share of battery electric vehicles and plug-in hybrid vehicles sales within Europe (2,200 -

battery electric vehicles; 4,800- plug-in hybrid vehicles). Despite a significant increase in EV sales in recent years, battery and hybrid electric cars account for only 1.5% of all vehicles in Europe.

Table 2. Share of powertrain types of vehicles in Slovakia in 2021 (Source: own processing)

	Battery electric vehicles	Plug-in hybrid vehicles
Slovakia	0.1	0.1
EU (average)	0.8	0.7

According to the available data in 2021, petrol vehicles dominate in terms of the powertrain used, with a percentage share of 50%, followed by diesel vehicles with a percentage share of 40%. The share of electric vehicles (battery electric vehicles) is 0.1%, plug-in hybrid vehicles (plug-in hybrid vehicles) 0.1%, and the remaining 3.3% is accounted for by hybrid and gas vehicles in Slovakia. Slovakia is below the EU average for battery electric vehicles and plug-in hybrid vehicles sales.

Regression-correlation analysis

In the following pictures (see Figure 2-5), values are situated around the trending line. The convex shape shows that the years 2010-2021 increase are also increasing sales of battery electric vehicles and plug-in hybrid vehicles in Europe and the world. According to mentioned figures, we could state that there is significant dependence between variables that a polynomial function can describe. Even though the analysis focuses solely on determining the dependence between time period and the number of battery electric vehicles and plug-in hybrid vehicles sold in Europe and the world, the number of sold vehicles can be affected by the number of additional determinants that are not included in our analysis (for example customer preference, prices of vehicle, etc.). After applying all regression models, the polynomial function appears from the point of view of the coefficient of determination as the most fitting for a description of dependence between observed variables.

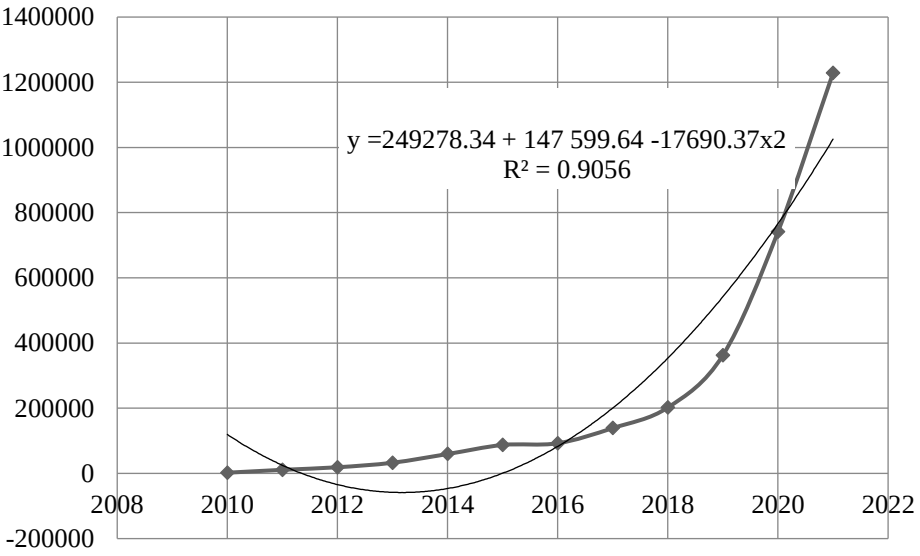


Fig. 2. Europe – Battery electric vehicles - sales (Source: own processing)

The quality of the chosen polynomial model is tested using regression and correlation analysis results that consist of three parts, each having a different role. The first part is made of correlation analysis by which we can test the strength of dependency between variables. Multiple R, multiple correlation coefficient has a value of 0,977868818 that shows the strong dependency between time period and the number of sold battery electric vehicles, since the closer the number is to 1, the stronger the dependency. R Square, coefficient of determination informs us that chosen regression function (polynomial) describes and explains around 96% variability of battery electric vehicles sold. The remaining part

means unexplained variability, the influence of random or other factors. A higher percentage means a better description of the dependence by the regression model. The polynomial model we chose shows the highest percentage of explained variability among all regression models. Adjusted R square is the adjusted coefficient of determination, taking the number of estimated parameters and measurements into account, and its value is close to the coefficient of determination value. The value of Standard Error should be as small as possible. The last evidence that correlation analysis offers is Observations, so the number of measurements. Analysis of dependence between the time period and sales of battery electric vehicles was realised during a time period of 12 years. The task of the second part of the testing is to verify the fitness of the chosen model using the null hypothesis, according to which the chosen model is not suitable. The alternative hypothesis states otherwise. For the evaluation of hypotheses F test, the comparison of the value of Significance F with the level of significance alpha is used. We test with a significance level of 0.05, and if the value of Significance F is lower than alpha, we reject the null hypothesis. In our case is Significance F (4.03E-08) < alpha (0.05), according to which we can reject the null hypothesis and accept the alternative hypothesis, which means the suitability of the regression model. The last part of the output is regression analysis which observes the relationship between variables. Based on that, we are able to formulate a regression function: y=249278.34 + 147 599.64 - 17690.37x squared. In this part, we test hypotheses too. Hypotheses are related not only to the whole model but also to locating constant and regression coefficients. The null hypothesis states that the coefficient is statistically insignificant, and the alternative hypothesis states the opposite. To choose the hypothesis, we use P-value and compare it with the level of significance alpha 0.05, as before. We can see that the P-value of the Intercept is greater than the alpha, which means that locating the constant is statistically insignificant. The P-value for the regression coefficient time period (x) is lower than the level of significance alpha that shows us the significance of this coefficient. Its value of 147 599,64 means that if the time period rises by one unit, which means one year, we can expect an increase in the sale of battery electric vehicles by 147 599,64 pieces on average.

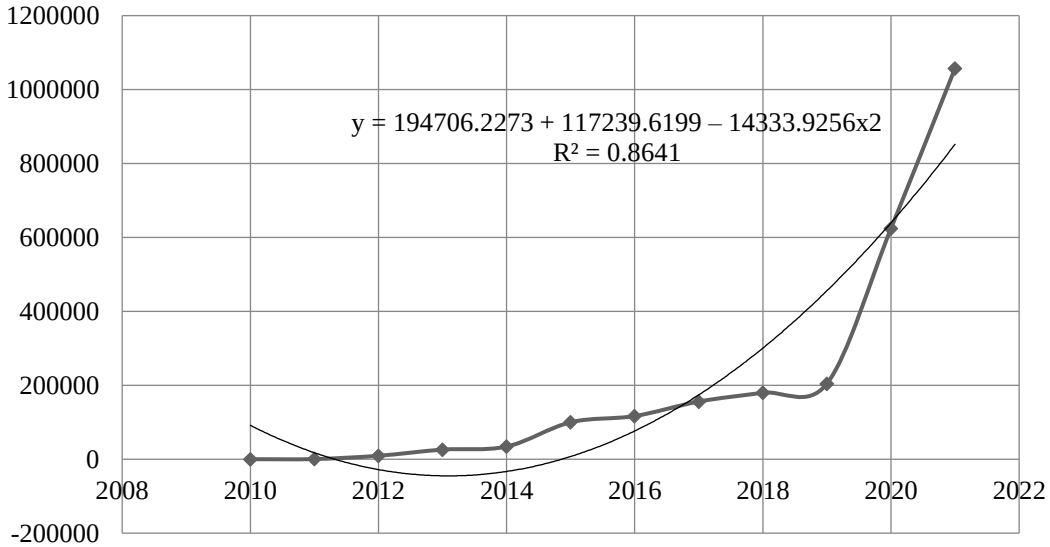


Fig. 3. Europe – Plug-in hybrid vehicles – sales (Source: own processing)

Multiple R, so the correlation coefficient in our correlation analysis has a value of 0.9296; according to that, we can state there is high dependence between variables. Next is the coefficient of determination, which stands for 86%, while the remaining 14% stands for undescribed variability. Based on the regression analysis, we can formulate a regression function which takes the following form: y = 194706.2273 + 117239.6199 - 14333.9256x^2. To verify the assumption "The number of plug-in hybrid vehicles sold in Europe increases with increasing time", we use the P-value and compare it with a significance level of alpha = 0.05. In this case, the intercept constant is statistically insignificant because its P-value is more significant than alpha. Its value of 194706.2273 indicates that with an increase in the

time period by one unit (year), the sales of plug-in hybrid vehicles in Europe will increase by 194704.2273 vehicles.

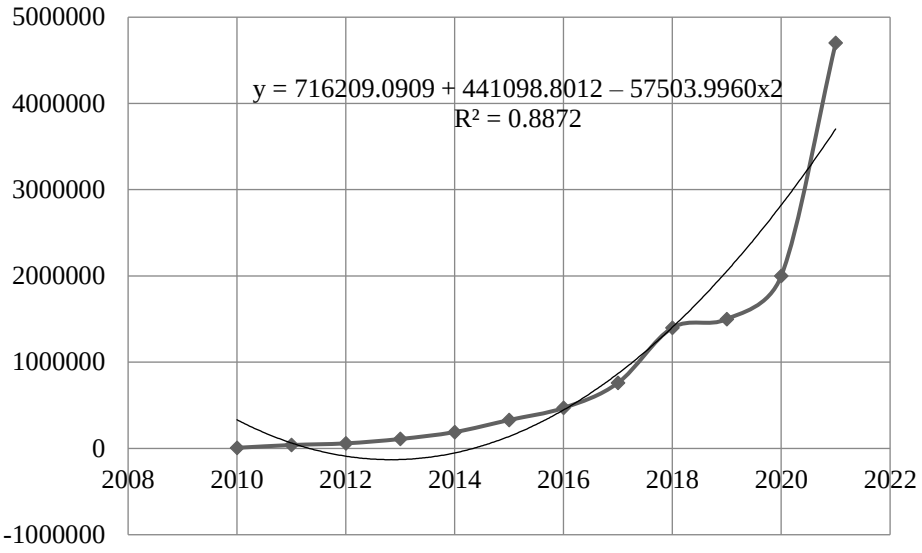


Fig. 4. World – Battery electric vehicles – sales (Source: own processing)

We have analysed the battery electric vehicles and plug-in hybrid vehicles sales situation not only within Europe but also globally, based on available data, and have come to the following conclusions. The results are very similar, as European sales of battery electric vehicles contribute to a large share of total global battery electric vehicle sales. Also, in this section, we have followed all the mentioned outputs of the regression and correlation analysis and thus:

- the polynomial regression function explains 89% of the variability of battery electric vehicles sold in the world,
- the multiple correlation coefficient takes the value of 0.9419, which also indicates a very high dependence between the variables studied,
- based on Significance F, which is lower than alpha, we reject the null hypothesis, i.e. that the number of battery electric vehicles sold in the world increases as the time period increases,
- the regression function is of the form $y = 716209.0909 + 441098.8012 - 57503.9960x^2$,
- the p-value at the locus constant is greater than alpha, and hence the locus constant is statistically insignificant.

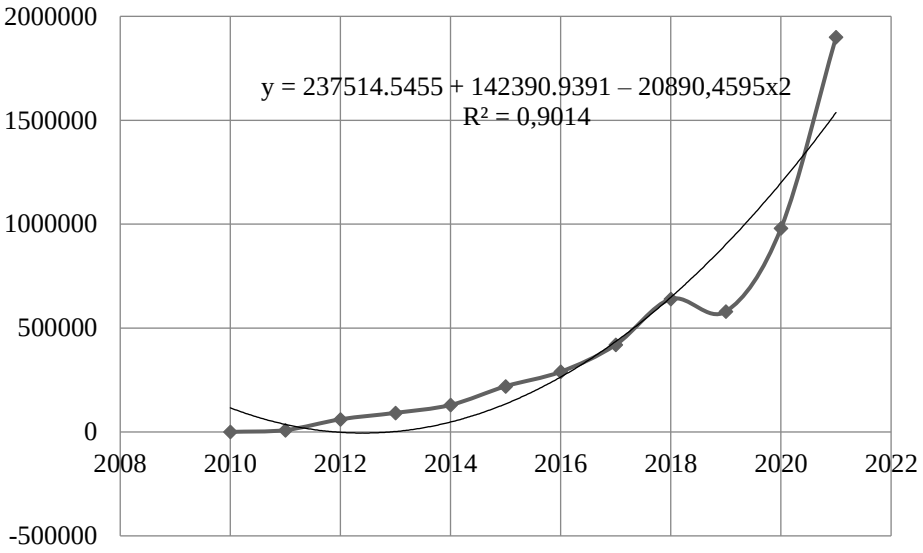


Fig. 4. World – Plug-in hybrid vehicles - sales (Source: own processing)

The last regression analysis was performed on global plug-in hybrid vehicle sales, where the assumption we examined that the number of plug-in hybrid vehicles sold worldwide increases with time was again confirmed. Based on the regression analysis output, we constructed a polynomial regression function: $y = 237514.5455 + 142390.9391 - 20890.4595x^2$.

Regression-correlation analysis – Durbin – Watson test

Based on the results of the Durbin-Watson test, we can conclude that it indicates positive autocorrelation in all of our chosen statistical models. Subsequently, comparing the lowest and highest critical values, we found that the tests are non-transitive because the Durbin- Watson test value is between the lowest and highest critical value in all four cases (WORLD BEV 1.70; WORLD PHEV 1.44; EUROPE BEV 0.78; EUROPE PHEV 0.99). Since our test statistics do not lay outside of this range, we do not have sufficient evidence to reject the null hypothesis of the Durbin-Watson test - there is no correlation among the residuals.

Conclusion and Discussion

Global sales of electric vehicles were up during the period under review. In 2021, a total of 6,600,000 battery electric vehicles + plug-in hybrid vehicles were delivered, representing an increase of +45% compared to 2020. Consumer attitudes, perceptions, and political actions directly impact the acceptance of new and/or evolving technology. In order to understand the hurdles to entrance and consumer mass adoption of electric vehicles, numerous studies have been done and examined the effects of political and economic support decisions (Emanovic et al., 2022; Ling et al., 2021). The European market contributed 26.29% of global sales for battery electric vehicles and 32.62% for plug-in hybrid vehicles. According to the electric vehicle market, which is one of the leading global advocates for the use and adoption of electric vehicles, the market is constantly growing at the level of the European Union (through the standard policies adopted), with an increase in the number of newly registered electric vehicles over the past five years. Figures, however, are comparatively small when compared to the total number of vehicles registered in the European Union, necessitating more substantial and more direct action in order to identify (and put into effect) the necessary steps to increase the share of electric vehicles in the market for vehicles while also getting rid of the old and polluting ones (Mariasiu et al., 2023). Slovakia saw the most significant increase in cars sold in 2021. It is clear that Slovakia steadily holds the rapid growth of its infrastructural country's electromobility coefficient, which is far above the V4 average (Skrabulakova et al., 2021), but electric cars still account only for one-tenth of one per cent. In 2021, Slovakia sold more electric vehicles than rechargeable (plug-in) hybrids.

Regarding the spread of electric cars, we are still well below the average in Europe. Skrabulakova et al. (2021) also agree and discovered that Slovakia is well behind the European Union leaders in terms of electromobility preparation. However, it is still at a fairly good stage, and the electromobility infrastructure in the Slovak Republic had grown rapidly during the previous five years, with a 334 times increase in the country's electromobility coefficient. The article's main aim was to examine the situation with electric vehicles from an economic point of view and to confirm or refute the assumption that there is a dependence between the time period and the number of cars sold. This could, among other things, result in the resolution of some environmental issues. By examining the relationship between the time period and the number of cars sold in Europe and worldwide, we rejected the null hypotheses and confirmed the stated assumptions that as the time period increases, the number of electric cars sold increases using regression-correlation analysis which supports our belief that people are becoming more and more concerned about the environment. Zhang and Fujimori (2020) point out also that switching to clean energy sources for electricity production is necessary for vehicle electrification to help mitigate climate change. They also state that electric vehicles can lower mitigation costs, suggesting that transportation policies favour the economy. Based on the findings, Ling et al. (2021) recommend that authorities continue or increase providing direct monetary incentives to purchase electric vehicles.

Acknowledgements

Paper was prepared within the project "Výskum nákupného správania a preferencie spotrebiteľov elektromobilov na Slovensku." no. 02/2022/GA FEM SPU supported by Grant Agency – Faculty of Economics and Management – Slovak University of Agriculture in Nitra.

References

Abdallah, L., & El-Shennawy, T. (2013). Reducing carbon dioxide emissions from electricity sector using smart electric grid applications. *Journal of Engineering*, 845051 https://doi.org/10.1155/2013/845051

Ashby, M. F. (2016). Chapter 14 - The vision: A circular materials economy. In M. G. Ashby (Ed.), *Materials and Sustainable Development* (pp. 211-239). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-08-100176-9.00014-1

Baroutaji, A., Carton, J. G., Sajjia, M., & Olabi, A. G. (2015). Materials in PEM fuel. *Reference Module in Materials Science and Materials Engineering.* https://doi.org/10.1016/B978-0-12-803581-8.04006-6

Bataille, C., Ahman, M., Neuhoff, K., Nilsson, L. J., Fischedick, M., Lechtenbohmer, S., Solano-Rodriquez, B., Denis-Ryan, A., Stiebert, S., Waisman, H., Sartor, O., & Rahbar, S. (2018). A review of technology and policy deep decarbonisation pathway options for making energy-intensive industry production consistent with the Paris Agreement. *Journal of Cleaner Production*, *187*, 960-973. https://doi.org/10.1016/j.jclepro.2018.03.107

Cacciola, G., Antonucci, V., & Freni, S. (2001). Technology up date and new strategies on fuel cells. *Journal of Power Sources*, *100(1/2)*, 67-79. https://doi.org/10.1016/S0378-7753(01)00884-9

Christidis, P., & Focas, C. (2019). Factors affecting the uptake of hybrid and electric vehicles in the European Union. *Energies*, *12(18)*, 3414. https://doi.org/10.3390/en12183414

Corvellec, H., Stowell, A. F., & Johansson, N. (2022). Critiques of the circular economy. *Journal of Industrial Ecology*, *26(2)*, 421-432. https://doi.org/10.1111/jiec.13187

Degraeuwe, B., Thunis, P., Clappier, A., Weiss, M., Lefebvre, W., Janssen, S., & Vranckx, S. (2016). Impact of passenger car NOx emissions and NO2 fractions on urban NO2 pollution - scenario analysis for the city of Antwerp, Belgium. *Atmospheric Environment*, *126*, 218-224. https://doi.org/10.1016/j.atmosenv.2015.11.042

Eltayeb, T. K., Zailani, S., & Jayaraman, K. (2010). The examination on the drivers for green purchasing adoption among EMS 14001 certified companies in Malaysia. *Journal of Manufacturing Technology Management, 21(2),* 206–225. https://doi.org/10.1108/17410381011014378

Emanovic, M., Jakara, M., & Baric, D. (2022). Challenges and opportunities for future BEVs adoption in Croatia. *Sustainability, 14(13),* 8080. https://doi.org/10.3390/su14138080

Skrabulakova, E. F., Ivanova, M., Rosova, A., Gresova, E., Sofranko, M., & Ferencz, V. (2021). On electromobility development and the calculation of the infrastructural country electromobility coefficient. *Processes, 9(2),* 222. https://doi.org/10.3390/pr9020222

Gerlak, A. K., Weston, J., McMahan, B., Murray, R. L., & Mills-Novoa, M. (2018). Climate risk management and the electricity sector. *Climate risk management*, *19*, 12-22. https://doi.org/10.1016/j.crm.2017.12.003

Graham-Rowe, E., Gardner, B., Abraham, C., Skippon, S., Dittmar, H., Hutchins, R., & Stannard, J. (2012). Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: A qualitative analysis of responses and evaluations. *Transportation Research Part A: Policy and Practice*, *46(1)*, 140-153. https://doi.org/10.1016/j.tra.2011.09.008

Hao, Y., Dong, X. Y., Deng, Y. X., Li, L. X., & Ma, Y. (2016). What influences personal purchases of new energy vehicles in China? An empirical study based on a survey of Chinese citizens. *Journal of Renewable and Sustainable Energy*, *8*, 065904. https://doi.org/10.1063/1.4966908

IEA (2017). *Global EV outlook: Two million and counting*. International Energy Agency.

Jaglom, W. S., McFarland, J. R., Colley, M. F., Mack, C. B., Venkatesh, B., Miller, R. L., Haydel, J., Schultz, P.A., Perkins, B., Casola, J. H., Martinich, J. A., Cross, P., Kolian, M. J. & Kayin, S. (2014). Assessment of projected temperature impacts from climate change on the US electric power sector using the Integrated Planning Model®. *Energy Policy*, *73*, 524-539. https://doi.org/10.1016/j.enpol.2014.04.032

Johansen, M. R., Christensen, T. B., Ramos, T. M., & Syberg, K. (2022). A review of the plastic value chain from a circular economy perspective. *Journal of Environmental Management*, *302(PartA)*, 113975. https://doi.org/10.1016/j.jenvman.2021.113975

Khan, M. J., & Iqbal, M. T. (2009). Analysis of a small wind-hydrogen stand-alone hybrid energy system. *Applied Energy*, *86*(11), 2429-2442.

Inderwildi, O., Carey, C., Santos, G., Yan, X., Behrendt, H., Holdway, A., Maconi, L., Owen, N., Shirvani, T., & Tevtelboym, A. (2010). *Future of mobility roadmaps: Ways to reduce emissions while keeping mobile*. University of Oxford & Smith School of Enterprise and the Environment.

Kundu, P. P., & Dutta, K. (2016). Hydrogen fuel cells for portable applications. *Compendium of Hydrogen , 4*, 111-131. https://doi.org/10.1016/B978-1-78242-364-5.00006-3

Li, Z., Khajepour, A., & Song, J. (2019). A comprehensive review of the key technologies for pure electric vehicles. *Energy*, *182*, 824-839. https://doi.org/10.1016/j.energy.2019.06.077

Ling, Z., Cherry, C. R., & Wen, Y. (2021). Determining the factors that influence electric vehicle adoption: A stated preference survey study in Beijing, China. *Sustainability*, *13(21)*, 11719. https://doi.org/10.3390/su132111719

Liu, Y. L. (2008). Research and discussion on the development trend of new energy vehicles. *Coast. Enterp. Sci. Technol*, *5*.

Mariasiu, F., Chereches, I. A., & Raboca, H. (2023). Statistical analysis of the interdependence between the technical and functional parameters of electric vehicles in the European market. *Energies*, *16(7)*, 2974. https://doi.org/10.3390/en16072974

Marsh, A. T., Velenturf, A. P., & Bernal, S. A. (2022). Circular economy strategies for concrete: Implementation and integration. *Journal of Cleaner Production*, *362*, 132486. https://doi.org/10.1016/j.jclepro.2022.132486

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C., Frieler, K., Knutti, R., Frame, D. J., & Allen, M. R. (2009). Greenhouse-gas emission targets for limiting global warming to 2 C. *Nature*, *458*, 1158-1162. https://doi.org/10.1038/nature08017

Mulvaney, D., Richards, R. M., Bazilian, M. D., Hensley, E., Clough, G., & Sridhar, S. (2021). Progress towards a circular economy in materials to decarbonise electricity and mobility. *Renewable and Sustainable Energy Reviews*, *137*, 110604. https://doi.org/10.1016/j.rser.2020.110604

Neves, S. A., & Marques, A. C. (2022). Drivers and barriers in the transition from a linear economy to a circular economy. *Journal of Cleaner Production*, *341*, 130865. https://doi.org/10.1016/j.jclepro.2022.130865

Plananska, J. (2020). Touchpoints for electric mobility: Investigating the purchase process for promoting sales of electric vehicles in Switzerland. *Energy Research & Social Science*, *69*. https://doi.org/https://doi.org/10.1016/j.erss.2020.101745

Rodriguez-Anton, J. M., Rubio-Andrada, L., Celemín-Pedroche, M. S., & Ruiz-Penalver, S. M. (2022). From the circular economy to the sustainable development goals in the European Union: An empirical comparison. *International Environmental Agreements: Politics, Law and Economics*, *22(1)*, 67-95. https://doi.org/10.1007/s10784-021-09553-4

Sang, Y. N., & Bekhet, H. A. (2015). Modelling electric vehicle usage intentions: An empirical study in Malaysia. *Journal of Cleaner Production, 92*, 75–83. https://doi.org/10.1016/j.jclepro.2014.12.045

Sulich, A., & Sołoducho-Pelc, L. (2022). The circular economy and the green jobs creation. *Environmental Science and Pollution Research, 29,* 14231–14247. https://doi.org/10.1007/s11356-021-16562-y

Tan, J., Tan, F. J., & Ramakrishna, S. (2022). Transitioning to a circular economy: A systematic review of its drivers and barriers. *Sustainability, 14(3),* 1757. https://doi.org/10.3390/su14031757

Tu, J. C. (2002). *Product sustainable design - green design in theory and practice.* Asia Pacific Press.

Weiss, M., Zerfass, A., & Helmers, E. (2019). Fully electric and plug-in hybrid cars - an analysis of learning rates, user costs, and costs for mitigating CO2 and air pollutant emissions. *Journal of Cleaner Production, 212,* 1478-1489. https://doi.org/10.1016/j.jclepro.2018.12.019

Wilberforce, T., Alaswad, A., Palumbo, A., Dassisti, M., & Olabi, A. G. (2016). Advances in stationary and portable fuel cell applications. *International Journal of Hydrogen Energy, 41(37),* 16509-16522. https://doi.org/10.1016/j.ijhydene.2016.02.057

Wilberforce, T., El-Hassan, Z., Khatib, F. N., Al Makky, A., Baroutaji, A., Carton, J. G., & Olabi, A. G. (2017). Developments of electric cars and fuel cell hydrogen electric cars. *International Journal of Hydrogen Energy, 42(40),* 25695-25734. https://doi.org/10.1016/j.ijhydene.2017.07.054

Zhang, R., & Fujimori, S. (2020). The role of transport electrification in global climate change mitigation scenarios. *Environmental Research Letters, 15(3),* 034019. https://doi.org/10.1088/1748-9326/ab6658