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The Future Trend of E-Mobility in Terms of Battery Electric Vehicles and Their Impact on Climate Change: A Case Study Applied in Hungary

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Abstract

The transportation sector is responsible for 25% of the total Carbon dioxide (CO_2) emissions, whereas 60.6% of this sector represents small and medium passenger cars. However, as noted by the European Union Long-term strategy, there are two ways to reduce the amount of CO_2 emissions in the transportation sector. The first way is characterized by creating more efficient vehicles. In contrast, the second way is characterized by changing the fuel used. The current study addressed the second way, changing the fuel type. The study examined the potential of battery electric vehicles (BEVs) as an alternative fuel type to reduce CO_2 emissions in Hungary's transportation sector. The study used secondary data retrieved from Statista and stata.com to analyze the future trends of BEVs in Hungary. The results showed that the percentage of BEVs in Hungary in 2022 was 0.4% compared to the total number of registered passenger cars, which is 3.8 million. The simple exponential smoothing (SES) time series forecast revealed that the number of BEVs is expected to reach 84,192 in 2030, indicating a percentage increase of 2.21% in the next eight years. The study suggests that increasing the number of BEVs is necessary to address the negative impact of CO_2 emissions on society. The Hungarian Ministry of Innovation and Technology's strategy to reduce the cost of BEVs may increase the percentage of BEVs by 10%, resulting in a potential average reduction of 76,957,600 g/km of CO_2 compared to gasoline, diesel, hybrid electric vehicles (HEVs), and plug-in hybrid vehicles (PHEVs).

Keywords

Battery Electric Vehicles (BEVS), Gasoline, Diesel, Hybrid Electric Vehicles (HEVs), Plug-In Hybrid Vehicles (PHEVs), Climate Change, Carbon Dioxide

(CO_2) Emissions

1. Introduction

Climate change is widely recognized as a critical global concern due to the continued emission of greenhouse gases into the atmosphere, posing a significant and long-term risk to both the natural environment and society. The massive increase in Carbon dioxide (CO_2) emissions from petroleum vehicles over the last decade has strongly encouraged major automobile manufacturers to shift to environmentally friendly technologies in an effort to significantly reduce the high amount of CO_2 emissions caused by petroleum vehicles (Pažun et al., 2019). According to the EEA (2021), "the automotive sector is the largest factor contributing to the European Union's emissions of CO_2". However, additional expansion of the EU's Battery electric vehicles (BEVs) might support the EU in achieving emission depletion goals and making steady progress toward their long-term goal of becoming GHGs-free by the next 20 years. BEVs are considered a crucial goal of Europe's mobility system, helping mitigate the consequences of climate change and air pollution (Pažun et al., 2019). Globally, it has been agreed that BEVs are a potentially crucial part of the climate change solution plan (Lomborg, 2013).

In 2017, BEVs accounted for approximately 0.6% of the new cars enrolled in the European Union (EEA, 2018). Based on future EU-WFA CO_2 prescribed limits for small and medium automobiles, BEVs might contribute 4% to 13.1% of new vehicles enrolled by 2030 (EC, 2017). While in 2022, in the European Union's 28 countries, BEVs accounted for approximately 9.9% of all new car enrollments (ACEA, 2022). In comparison, there is an apparent disparity between the European Union members. The considerable disparity between the European Union members can be clearly seen. In comparison, in 2022, the number of BEVs in Germany reached 32,234 (Kane, 2022). While in 2022, the number of BEVs in Hungary reached 18,800 (Medve, 2022). However, the number of BEVs in Hungary has increased considerably in the last seven years. The BEVs saw the light officially in Hungary in 2016 with about 405 BEVs, which is considered the start of the BEVs in Hungary (Medve, 2022). After 2016, the number of BEVs in Hungary increased significantly, with 1153 new BEVs recorded in 2017, 2460 in 2018, 3696 in 2019, 6101 in 2020, 10,626 in 2021, and 18,800 in 2022 (Medve, 2022). The modern transportation system and climate change are firmly bound in various manners (Fuinhas et al., 2021).

A large number of empirical research have examined the link between BEVs and CO_2 emissions in response to climate change. Based on **Table 1**, Doucette and McCulloch (2011) examined the relationship between BEVs and CO_2 emissions. As a result, they found that BEVs can reduce up to 68.88% of CO_2 emissions compared to fuel vehicles. Furthermore, Casals et al. (2016) discovered that BEVs could help decrease harmful emissions, particularly in densely crowded regions. Hofmann et al. (2016) investigated the impact of BEVs on Carbon dioxide emissions. The investigation findings indicated that BEVs could assist in lowering carbon dioxide emissions by 25% of the total CO_2 emissions. Mishina and Muromachi (2017) determined by estimating the possible future Carbon dioxide emissions reductions from BEVs in Japan. Plötz et al. (2018) studied the impact of daily and annual driving on fuel economy and CO_2 emissions of plug-in hybrid electric vehicles in the United States. The study examined Plug-in Hybrid Electric Vehicles (PHEVs), revealing deviations from standardized values ranging from 2% to 120%, particularly in short-ranged models. It shows daily and annual driving distances significantly impact fuel consumption showing a decrease of 2% to 3% in CO_2 emissions per additional km of electric range. Fritz et al. (2019) explored and examined the impact of fuel economy regulations on CO_2 emissions reduction, highlighting the importance of plug-in electric vehicles (PEVs) to achieve targets below 75 gCO_2/km. Analyzing European regulations, which aim for 59.4 gCO_2/km by 2030, it projected PEV sales and CO_2 emissions based on data from 2010 to 2016, showing a need for PEVs to represent 27% to 41% of sales by 2030. However, the study suggested that current regulations might not meet car manufacturers' targets by 2025.

Table 1. List of empirical research studying the relationship between EVs and CO_2 emissions.

Scholars	Perspective	Topic	Samples
Doucette & McCulloch (2011)	Relationship between EVs and CO_2 emissions	Modelling the prospects of plug-in hybrid electric vehicles to reduce CO_2 emissions	China
Casals et al. (2016)	Relationship between EVs and CO_2 emissions	Sustainability analysis of the electric vehicle use in Europe for CO_2 emissions reduction	Europe
Hofmann et al. (2016)	Relationship between EVs and CO_2 emissions	Assessment of electric vehicles as a successful driver for reducing CO_2 emissions in China	China
Mishina & Muromachi (2017)	Relationship between EVs and CO_2 emissions	Are potential reductions in CO_2 emissions via hybrid electric vehicles actualized in real traffic?	Japan
Plötz et al. (2018)	Relationship between EVs and CO_2 emissions	The impact of daily and annual driving on fuel economy and CO_2 emissions of plug-in hybrid electric vehicles.	United States of America
Fritz et al. (2019)	Relationship between EVs and CO_2 emissions	The impact of ambitious fuel economy standards on the market uptake of electric vehicles and specific CO_2 emissions.	European Union-28 countries
Küfeoğlu & Hong (2020)	Relationship between EVs and CO_2 emissions	Emissions performance of electric vehicles: A case study from the United Kingdom.	United Kingdom

Source: Own elaborations based on Doucette & McCulloch (2011), Casals et al. (2016), Hofmann et al. (2016), Mishina & Muromachi (2017), Plötz et al. (2018), Fritz et al. (2019), and Küfeoğlu & Hong (2020).

2. E-Mobility in Terms of BEVs and CO_2 Emission Reduction

In the last ten years, reducing CO_2 emissions has become one of the entire world's interests in serious endeavors to mitigate the consequences of climate change on the entire planet. However, these endeavors were translated into the so-called European Union's long-term strategy, which seeks to cut CO_2 emissions by more than half over the next 30 years (Kawase et al., 2006). In the EU-28 countries, car emissions of CO_2 represent approximately a quarter (25%) of carbon output. Solely transportation sector has seen a rise in CO_2 emissions over the last three decades, 33.5%, compared to the residential and commercial sector, Energy supply sector, industry sector, and agricultural sector (EP, 2022), as shown in **Figure 1**.

Road transportation accounted for 71.7% of the 25% of total CO_2 emissions emitted by the transportation sector between 1990 and 2019 (European Environment Agency, 2022). The CO_2 emissions differ between the modes of transportation, exceptionally hanging on the mode of transportation, which is distributed as follows: 60.6% standard passenger cars, 27.1% Heavy duty trucks, and 11.0% light duty trucks (EP, 2022), as shown in **Figure 2**.

According to the European Union's long-term strategy, the best way to reduce CO_2 emissions is to change the fuel used for various reasons, including climate change and scarcity of resources. BEVs when compared to fuel vehicles, it is widely assumed that BEVs emit less CO_2 and have high energy efficiency (Dong, 2020; Magazzino et al., 2021). Electric vehicles (EVs) utilize electrical power to supplant the current energy sources in the field of transportation to assist in minimizing CO_2 emissions and reducing air pollution (Xu et al., 2021).

2.1. Previous Methods for Determining the Connection between EVs and Atmospheric CO_2 Emission Levels

Around 90% of the research examining the relationship between EVs and

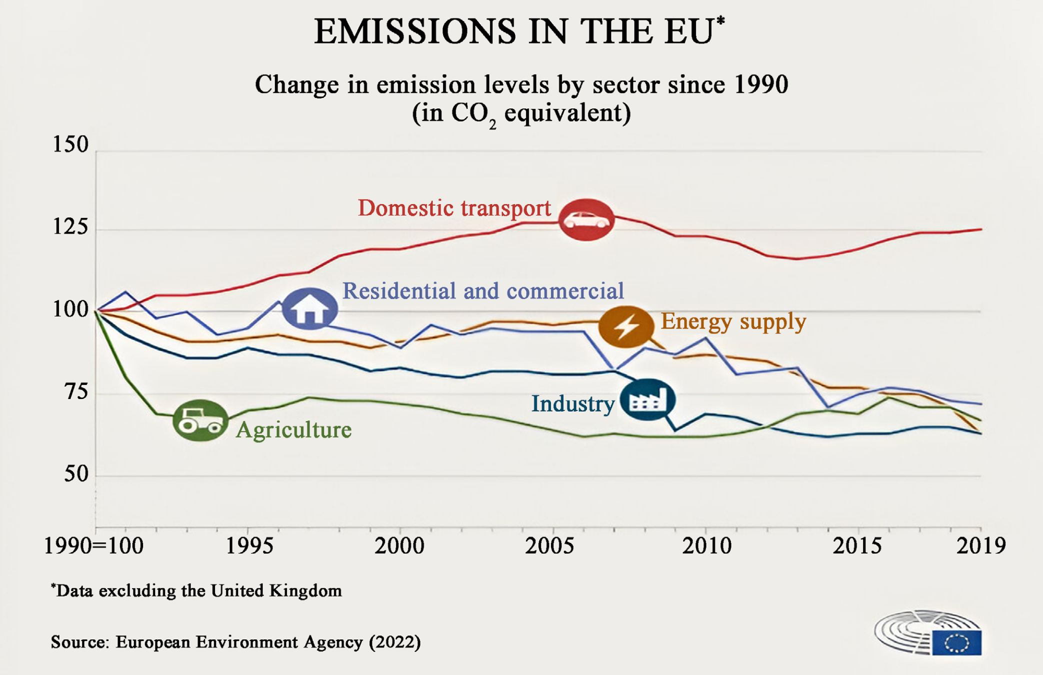

Figure 1. CO_2 emission levels by sector since 1990 in the EU [Source: European Environment Agency (2022)].

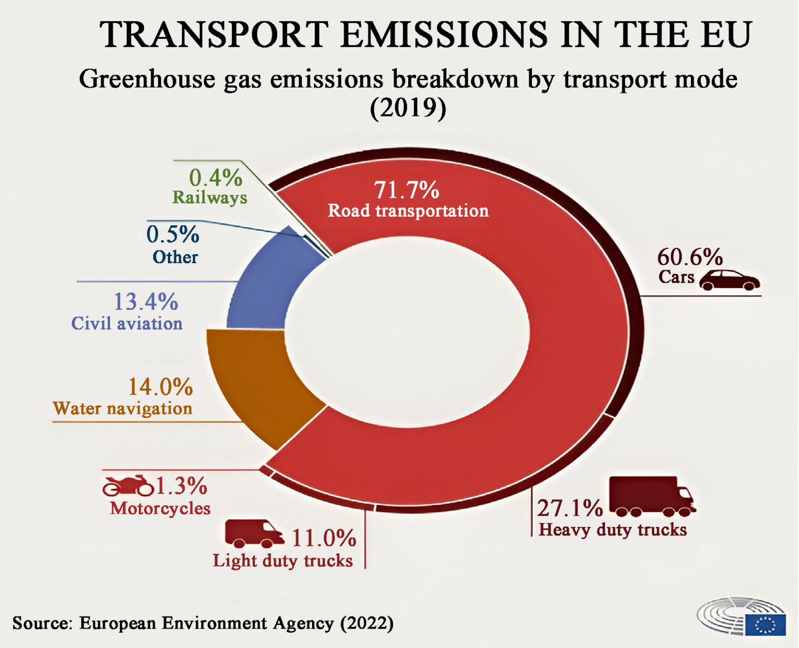

Figure 2. CO_2 emissions broke down by transport mode in the EU in 2019 [Source: European Environment Agency (2022)].

Atmospheric carbon dioxide emissions employed two methods: LR methods and CQR methods (Xu et al., 2021). The most frequently used LR methods in previous research examining the relationship between EVs and atmospheric CO_2 emissions using LR methods are four OLS, ARDL, FE, and RE. As a shred of evidence, Rauf et al. (2018); Sarkodi and Adams (2020); Warsame et al. (2021) utilized LR and, specifically, the autoregressive distributed lag to examine the impact of EVs and atmospheric CO_2 emissions. In contrast, the CQR method was also employed by many researchers to estimate the relationship between EVs and atmospheric CO_2 emissions. As evidence, Xu and Lin (2018) employed CQR to examine the variations in atmospheric CO_2 emissions of transportation across regions in China.

2.2. Actual CO_2 Emissions Reductions in Terms of Car Energy Types by Numbers Based on Gamber

In 2022, Gimbert (2022) conducted a laboratory study to answer the question, "How much CO_2 can electric cars really save compared to diesel and gasoline cars?". To explain how it works, he created an application that consolidates every piece of recent data on CO_2 emissions associated with the utilization of an electric, diesel, or petrol engine. Moreover, the application calculates how much CO_2 each car emits in grams per kilometer based on whether it is (Gasoline, Diesel, full hybrid, plug-in hybrid, or battery electric). Gimbert (2022) found that in Europe, EVs release over three times less CO_2 in comparison with petrol vehicles. LCA analysis results were done by Gimbert (2022) revealed that medium Hybrid electric vehicles (HEVs) reduce 21% of atmospheric CO_2 in comparison to same-size fuel cars. Whereas, Pug-in hybrid electric vehicles (PHEVs) reduce

26% of atmospheric CO_2 in comparison to the same size fuel cars. In addition, the results of the LCA analysis for BEVs revealed that they are the cleanest among all the vehicles, with 2.4 times fewer emissions than PHEVs. This means BEVs emit 62.4% less CO_2 into the atmosphere than PHEVs as shown in **Figure 3**.

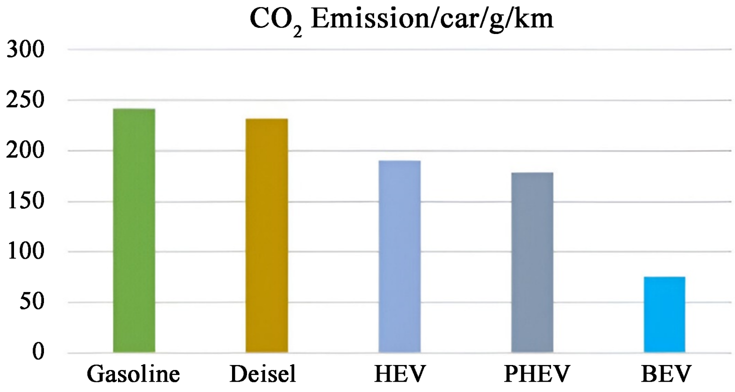

Figure 3. Car CO_2 g/km emissions by car energy type [Source: Own elaborations based on Gimbert (2022)].

2.3. Environmentally Friendly E-Mobility in Hungary as a Climate Change Workaround

In the past few years, Hungary has witnessed a significant shift in its transportation sector, with the number of BEVs and EVs, in general, increasing significantly (NEA, 2021). The main driver behind this shift is the Hungarian government's embracement of the National Energy and Climate strategy to achieve carbon neutrality (NEA, 2021). One of the strategy's primary goals is environmental protection and the carbon neutralization that can be attained by shifting to BEVs and EVs. However, the e-mobility law was passed in the last 10 years, encouraging the use of electric vehicles as well as charging facilities (NEA, 2021).

In 2020, The Hungarian Ministry of Innovation and Technology implemented the "Climate and Nature Protection Plan" shown in **Table 2** to achieve CO_2 neutralization. The Climate and Nature Protection Plan was founded based on eight pillars Hungarian Ministry of Innovation and Technology (2020).

Table 2. Hungarian climate and nature protection plan pillars.

Number of Pillars	Description
Pillar I	Eliminate illegal landfills and punish polluters.
Pillar II	Ban the sale of disposable plastics and facilitate the return and recycling of glass, plastic bottles, and metal cans.
Pillar III	Protect the country's rivers from waste coming from outside the country.
Pillar IV	Force multinational companies operating in Hungary to use environmentally friendly technologies.
Pillar V	Ten trees will be planted for every newborn baby.

Continued

Pillar VI	A six-fold increase in the capacity of solar power plants in the next 10 years.
Pillar VII	Market affordable electric cars to increase EVs.
Pillar VIII	Launch green government bonds with the proceeds used to invest in environmentally friendly technologies.

Source: Own elaborations based on Hungarian Ministry for Innovation and Technology (2020).

According to the seventh pillar of the Climate and Nature Protection Plan shown in **Table 2**, the Hungarian government intends to "bring affordable electric cars to market, with a strong emphasis on subsidizing small and cheap cars, while also transitioning urban public transportation to electric vehicles." Since then, the BEVs in 2020 increased to reach 6101, 10626 in 2021, and 18800 in 2022 (Medve, 2022).

3. Methodology

This section focuses on the study's statistical analysis results. The secondary data for this study was obtained from Statista (2023), which was used to demonstrate the variation in BEVs and the amount of CO_2 emissions reduction in Hungary between 2016 and 2022 compared to gasoline, diesel, HEVs, and PHEVs. Furthermore, the time series simple exponential smoothing (SES) method was used since it permitted the accurate prediction of the number of BEVs that will be achieved in 2030, as well as the calculation of the amount of CO_2 emissions that will be reduced based on the Gimbert (2022) tool.

According to the Gimbert tool, each passenger BEV emits 75 g/km of CO_2, each gasoline passenger vehicle emits 241 g/km; each diesel passenger vehicle emits 231 g/km; each HEV emits 190 g/km; each passenger PHEV emits 178 g/km of CO_2. The objective of this study is to predict the future numbers of battery electric vehicles (BEVs) and their corresponding CO_2 reduction in Hungary for the next seven years.

To accomplish this, the research utilized time series data sourced from Statista (2023), spanning the years 2016 to 2022. The time series data was disintegrated into its three key components: trend, seasonal, and error. The SES technique was applied to model the time series data, accounting for both the trend and seasonal components. The smoothing constant, alpha, and the seasonal smoothing constant, gamma, were optimized to minimize the Mean Squared Error (MSE) of the model. Finally, the model was employed to predict the BEVs number and CO_2 reduction in g/km for the time period between 2023 and 2030. The SES formula was used in this process.

$$F_t = \alpha A_{t-1} + (1-\alpha) F_{t-1}$$

- F_t : Forecasted value for the next period;
- α: Smoothing constant;
- A_{t-1} : Actual value for the previous period;
- F_{t-1} : Forecasted value for the previous period which is 10,622.20 for the pre-

vious period.

In this formula, F_t represents the forecasted value for the next period, A_{t-1} represents the actual value for the previous period, and F_{t-1} represents the forecasted value for the previous period.

The alpha (α) in the formula is the smoothing constant, which determines the weight given to the most recent observation versus the previous forecast. A higher alpha value gives more weight to the most recent observation, while a lower alpha value gives more weight to the previous forecast.

The goal is to find the value of alpha that minimizes the sum of squared errors between the predicted values and the actual values.

The formula to calculate the alpha value using the method of least squares is as follows:

$$\alpha = 1 - \frac{\Sigma\left(Y_t - S_{t-1}\right)*\left(Y_t - S_t\right)}{\Sigma\left(Y_t - S_{t-1}\right)^2} \quad \text{(Brown, 1956)}$$

where:

- α (alpha) is the smoothing factor or weight.
- Y_t is the actual value at time *t*.
- S_t is the predicted (smoothed) value at time *t*.
- S_{t-1} is the predicted (smoothed) value at the previous time period ($t-1$).
- Σ denotes the sum across all time periods.

The number of periods (N) = 7.

The numerator of the formula;

$$\begin{aligned} &\Sigma\left(Y_t - S_{t-1}\right)*\left(Y_t - S_t\right) \\ &= \left(Y_1 - S_0\right)*\left(Y_1 - S_1\right) + \left(Y_2 - S_1\right)*\left(Y_2 - S_2\right) + \left(Y_3 - S_2\right)*\left(Y_3 - S_3\right) \\ &\quad + \left(Y_4 - S_3\right)*\left(Y_4 - S_4\right) + \left(Y_5 - S_4\right)*\left(Y_5 - S_5\right) + \left(Y_6 - S_5\right)*\left(Y_6 - S_6\right) \\ &\quad + \left(Y_7 - S_6\right)*\left(Y_7 - S_7\right) \\ &= 33187479 \end{aligned}$$

the denominator of the formula;

$$\begin{aligned} \Sigma\left(Y_t - S_{t-1}\right)^2 &= \left(Y_1 - S_0\right)^2 + \left(Y_2 - S_1\right)^2 + \left(Y_3 - S_2\right)^2 + \left(Y_4 - S_3\right)^2 \\ &\quad + \left(Y_5 - S_4\right)^2 + \left(Y_6 - S_5\right)^2 + \left(Y_7 - S_6\right)^2 \\ &= 79779266 \end{aligned}$$

the alpha value $\alpha = 1 - (\text{numerator}/\text{denominator})$;

$$\text{alpha} = 1 - \frac{\text{numerator}}{\text{denominator}}$$

$$\alpha = 1 - \frac{33187479}{79779266}$$

$$\alpha = 0.584$$

Essentially, the formula is used to update the forecast for the next period based on the actual value from the previous period and the forecasted value from the previous period, with the smoothing constant determining the weight given to each component. This iterative process is repeated for each period in the time series, producing a forecast for each period based on the actual and forecasted values from the previous periods.

4. Results and Discussion

4.1. Number of BEVs Variation and Amount of CO_2 Emissions Reduced Since 2016

The graphs below show the variation in the number of BEVs between 2016 and 2022 based on the data collected from Stata, as well as the amount of CO_2 emission in g per km and the estimated.

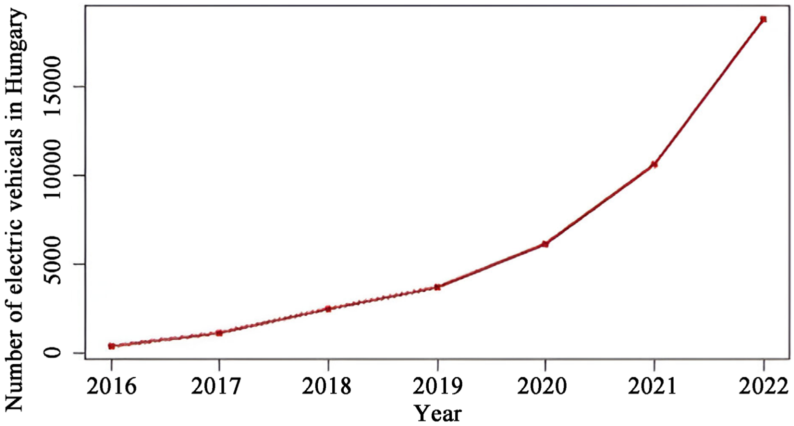

Figure 4. Number of BEVs in Hungary between 2016 and 2022 [Source: Own elaborations based on Statista (2023)].

According to the line graph above **Figure 4**, the number of BEVs in Hungary has increased significantly over the last seven years. The BEVs first appeared in Hungary in 2016, with approximately 405 BEVs, which is considered the start of the BEVs in Hungary. After 2016, there was a significant increase in the number of BEVs in Hungary, with 1153 new BEVs recorded in 2017, 2460 in 2018, 3696 in 2019, 6101 in 2020, 10,626 in 2021, and 18,800 in 2022.

The graph compares the CO_2 emissions g/km of battery electric vehicles (BEVs), diesel vehicles, gasoline vehicles, PHEVs, and HEVs in Hungary from 2016 to 2022. The graph helps calculate the CO_2 emissions and reduction in g/km reduced by BEVs each year compared to other commonly used energy vehicle types.

Based on **Figure 5**, however, if the same number of battery electric vehicles (BEVs) is replaced with different types of vehicles, the emissions would vary. Based on the Gimbert tool, if the same number of battery electric vehicles (BEVs) are replaced with gasoline vehicles, the gasoline vehicles would emit 97605 g/km. While diesel vehicles would emit 93555 g/km, hybrid electric vehicles (HEVs) would emit 76950 g/km, and plug-in hybrid electric vehicles (PHEVs) would emit 72090 g/km. These comparisons indicate that using 405 BEVs instead of the other vehicle types resulted in an average reduction of 54675 g/km of CO_2.

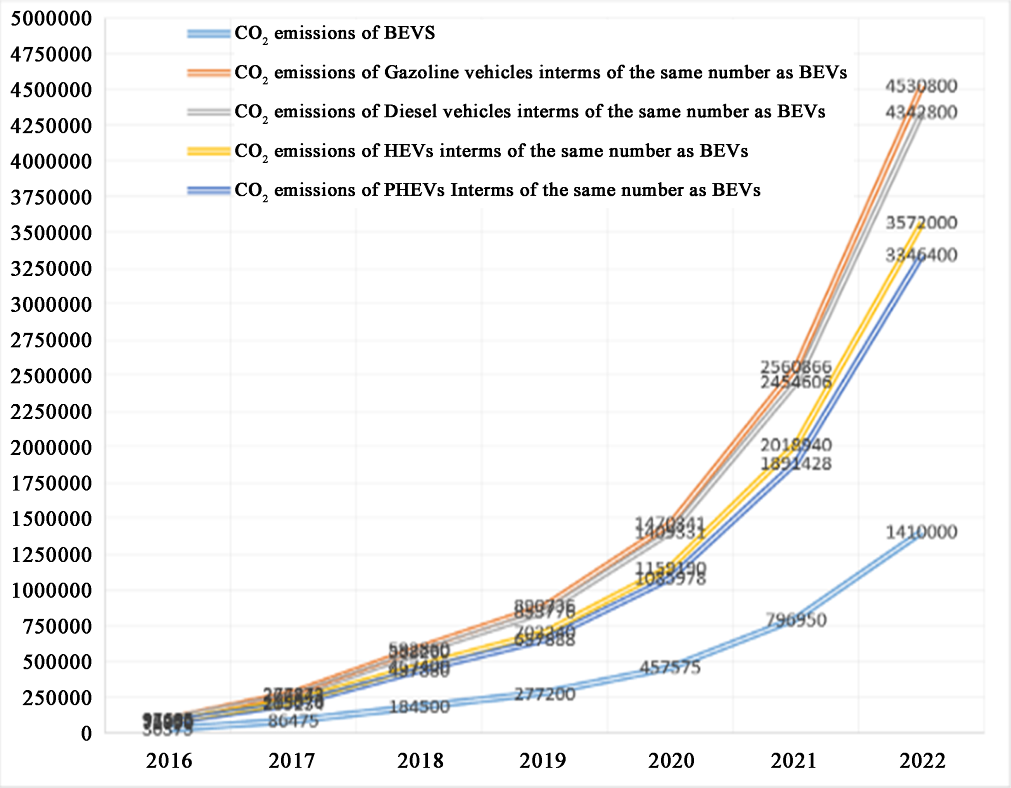

Figure 5. CO_2 emissions g/km of BEVs/ Diesel vehicles, Gasoline vehicles, PHEVs, and HEVs in case of the same number of BEVs registered between 2016 to 2022 and BEVs CO_2 emissions reduction in Hungary [Source: Own elaborations based on Gimbert's (2022) tool].

In 2017, as shown in **Figure 5**, using 1153 BEVs instead of the other types of vehicles led to an average reduction of 155,655 g/km of CO_2.

In 2018, using 2460 BEVs instead of the other vehicle types resulted in an average reduction of 332,100 g/km of CO_2.

Moreover, in 2019, as demonstrated in **Figure 5**, using 3696 BEVs instead of the other types of vehicles led to an average reduction of 498,960 g/km of CO_2.

In 2020 as revealed in **Figure 5**, using 6101 BEVs instead of the other vehicle types results in an average reduction of 823,635 g/km of CO_2.

In 2021, as illustrated in **Figure 5**, using 10,626 BEVs instead of the other types of vehicles led to an average reduction of 1,434,410 g/km of CO_2.

In 2022 as shown in **Figure 5**, using 18,800 BEVs instead of the other vehicle types results in an average reduction of 2,538,000 g/km of CO_2.

4.2. Simple Exponential Smoothing (SES) Assumptions Testing

Before applying any statistical model, it is important to understand the assumptions that underlie the model. The same holds true for the exponential smoothing method, which is widely used for SES time series forecasting. SES assumes that the time series data is stationary, has constant variance (homoscedasticity), and that the errors follow a normal distribution. These assumptions are crucial for accurate forecasting, as violating them can lead to biased and unreliable results. Therefore, it is important to test these assumptions before applying the SES method to ensure the validity of the model. In this regard, various statistical tests can be used to check for violations of these assumptions, and corrective measures can be taken accordingly to improve the accuracy and reliability of the forecasting model.

4.2.1. Stationarity Assumption

To test the stationarity assumption, an Augmented Dickey-Fuller (ADF) test on the original time series data for the number of BEVs in Hungary was performed. As shown in **Table 3**, the result reveals that the data is non-stationary, which implies that the mean and variance of the data are changing over time. This means that the time series data has a trend component that should be removed to make the data stationary. However, as the ADF statistic is greater than the 1% critical value and the p-value > 0.05, it was not possible to reject the null hypothesis that the time series has a unit root and is non-stationary, so further investigations are needed.

Table 3. Augmented Dickey–Fuller test (1).

ADF Statistic	p-value	1% Critical Value	5% Critical Value	10% Critical Value
4.425231	1.0	−6.045	−3.929	−2.987

Source: Own elaborations based on Statista using Python, https://www.statista.com/statistics/1188385/hungary-number-of-battery-electric.

To address this issue, the Logarithmic transformation and differencing transformation were used consecutively. Logarithmic transformation was used to stabilize the variance of the data and can reduce the magnitude of the trend, and differencing, on the other hand, was used to remove the trend and seasonality from the data. By combining these two techniques, we created a stationary time series that is suitable for forecasting using SES or other time series models, shown in **Table 4**. However, as the ADF statistic is less than the 1% critical value and the p-value< 0.05, we were able to reject the null hypothesis that states that the time series has a unit root and is non-stationary.

Table 4. Augmented Dickey–Fuller test (2).

ADF Statistic	p-value	1% Critical Value	5% Critical Value	10% Critical Value
−11.317	0.000	−7.355	−4.474	−3.127

Source: Own elaborations based on Statista using Python, https://www.statista.com/statistics/1188385/hungary-number-of-battery-electric.

4.2.2. Homoscedasticity Assumption

To test the homoscedasticity assumption (constant variance), a residuals plot was developed to check the pattern of the residuals. The scatter plot **Figure 6** shows a random scatter of points around the horizontal line at zero, indicating that the variance of the residuals is constant across the range of time series.

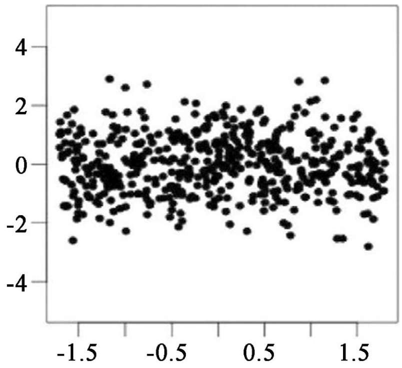

Figure 6. The variance scatter plot [Source: Own elaborations based on Statista using Python, https://www.statista.com/statistics/1188385/hungary-number-of-battery-electric].

4.2.3. Normality of the Errors in the Forecasting Model

Based on **Table 5**, the Shapiro-Wilk test statistic is 0.98, which is close to 1. This suggests that the sample is not significantly different from a normal distribution. The Shapiro-Wilk test p-value < 0.05, assuming that the null hypothesis is true. This suggests that there is insufficient evidence to reject the null hypothesis that the sample is normally distributed. Therefore, based on the Shapiro-Wilk test results, there is no strong evidence to suggest that the sample is not normally distributed. However, the interpretation of the Shapiro-Wilk test results should be considered in conjunction with other statistical diagnostics, such as visual inspection of the data, as shown in **Figure 7**.

Table 5. Shapiro-Wilk Test.

Shapiro-Wilk test	
Shapiro-Wilk test statistic	0.988
p-value	0.512

Source: Own elaborations based on Statista using Python, https://www.statista.com/statistics/1188385/hungary-number-of-battery-electric.

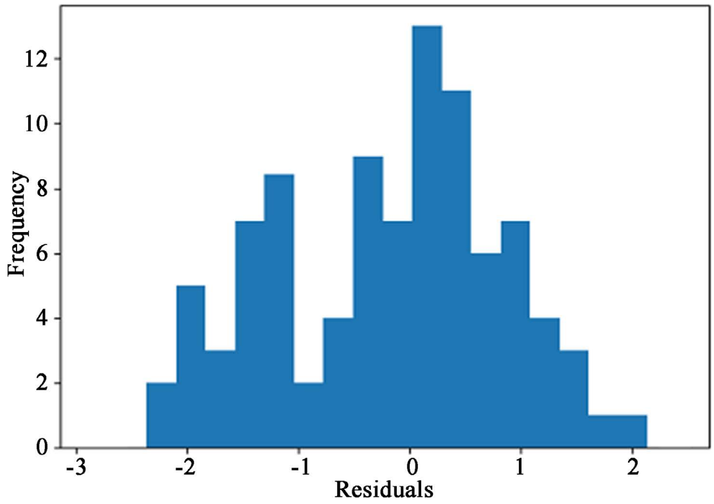

Figure 7. Error distribution [Source: Own elaborations based on Statista using Python, https://www.statista.com/statistics/1188385/hungary-number-of-battery-electric].

As shown in the histogram in **Figure 7**, the error distribution formed symmetric and bell-shaped, suggesting that the error in the forecasting model is likely to be normally distributed.

4.2.4. Absence of Seasonality

Seasonality is a crucial assumption in time series analysis, which suggests that there are periodic patterns in data at regular intervals. Such patterns can affect the reliability of forecasts generated by SES. Hence, it is necessary to detect and address seasonality to enhance forecasting accuracy. This can be achieved by studying the data for repetitive patterns and making adjustments in the forecasting model accordingly.

According to **Figure 8**, the residual plot shows that there is no trend or cyclical behavior in the pattern, which suggest a lack of seasonality. Moreover, the ACF plot is used to analyze the correlation between the observations in a time series at different lags. If the ACF plot shows no significant correlation beyond the first lag, it indicates the lack of seasonality in the data. However, if there is a significant correlation after the first lag suggests the presence of seasonality in the data. Thus, when both the residuals plot and ACF plot exhibit no pattern or significant correlation beyond the first lag as shown in **Figure 9**, it can be concluded that the assumption of absence of seasonality is valid and the model is appropriate for forecasting purposes.

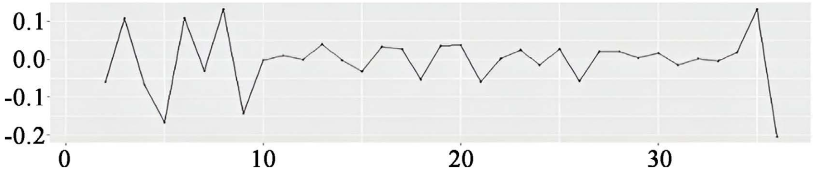

Figure 8. Residuals Plot [Source: Own elaborations based on Statista using Python, https://www.statista.com/statistics/1188385/hungary-number-of-battery-electric].

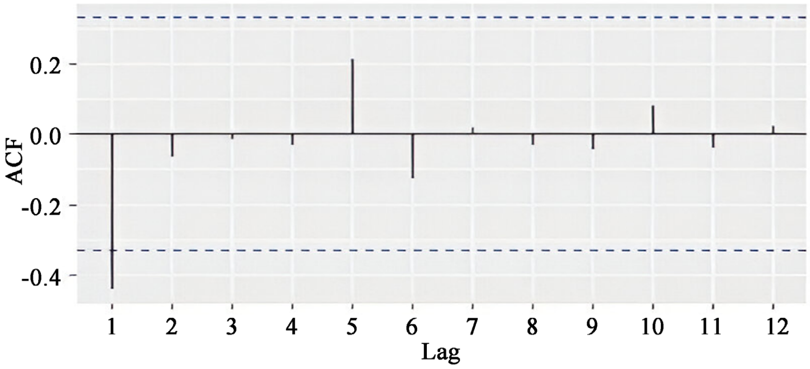

Figure 9. Autocorrelation Function (ACF) Residuals plot.

4.2.5. Actual vs Predicted

Actual vs predicted refers to comparing the actual or observed values of a target variable with the predicted values of the same variable using a model. The purpose of this comparison is to evaluate the accuracy and performance of the model. In other words, the closer the predicted values are to the actual values, the more accurate the model is considered to be. This information can be used to make predictions or decisions based on the data.

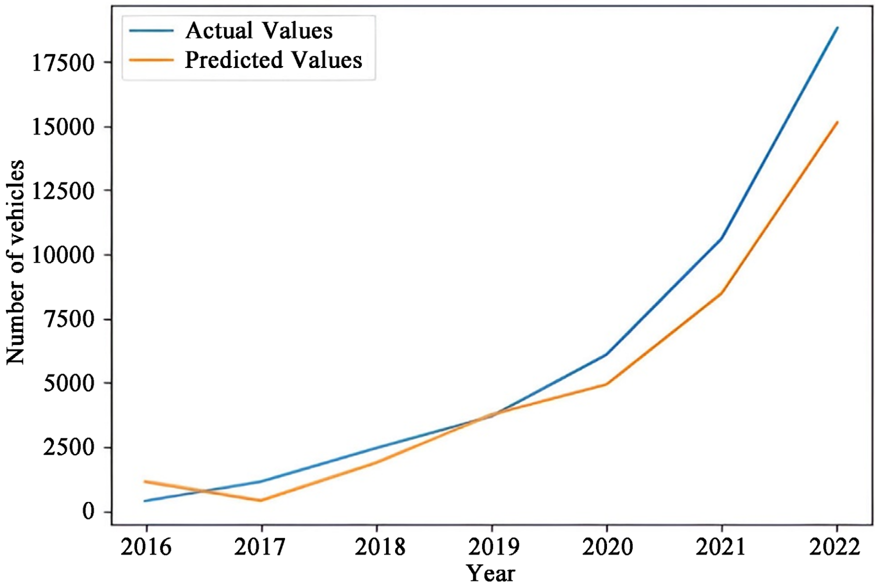

Figure 10. Actual vs Predicted [Source: Own elaborations based on Statista using Python, https://www.statista.com/statistics/1188385/hungary-number-of-battery-electric].

The actual vs predicted graph shown in **Figure 10** shows two lines: one representing the actual values of vehicles over the years and the other representing the predicted values of vehicles using the SES method. The plot shows that the predicted values are close to the actual values, but there are some differences between them. The actual values show an increasing trend over the years, and the predicted values follow this trend but with some fluctuations.

4.3. Predicted Number of BEVs over the Next Seven Years along with the Amount of CO_2 to Be Reduced in g/km in Hungary

The graphs below represent the forecasted number of BEVs over the next 7 years, and the amount of CO_2 will be reduced, and the amount of CO_2 reduced in g/km based on the SES time series analysis performed in this study. The SES time series analysis forecast was developed based on data retrieved from Stata. Conversely, the amount of CO_2 will be produced and reduced was estimated using the Gimbert (2022) tool.

Based on the time series analysis done in this study, the number of BEVs from 2023 to 2030 is predicted. According to the forecasting graph above, shown in **Figure 11**, the number of BEVs in Hungary will reach 26,974 by 2023. Furthermore, the number of BEVs in 2024 will be 35,148. The number of BEVs is expected to reach 43,322 by 2025. In 2026, 51,496 new BEVs are expected to be on the road. Furthermore, the number of BEVs is expected to reach 67,844 by 2028. While 67,844 new BEVs are expected in 2029, 84,192 new BEVs are expected in 2030.

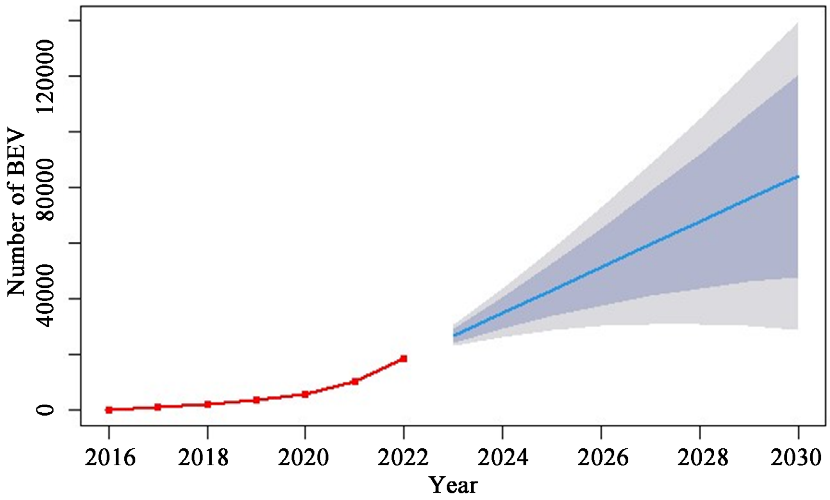

Figure 11. Forecasted number of BEVs in Hungary over the next 8 years [Source: Own elaborations based on Statista using R-studio, https://www.statista.com/statistics/1188385/hungary-number-of-battery-electric].

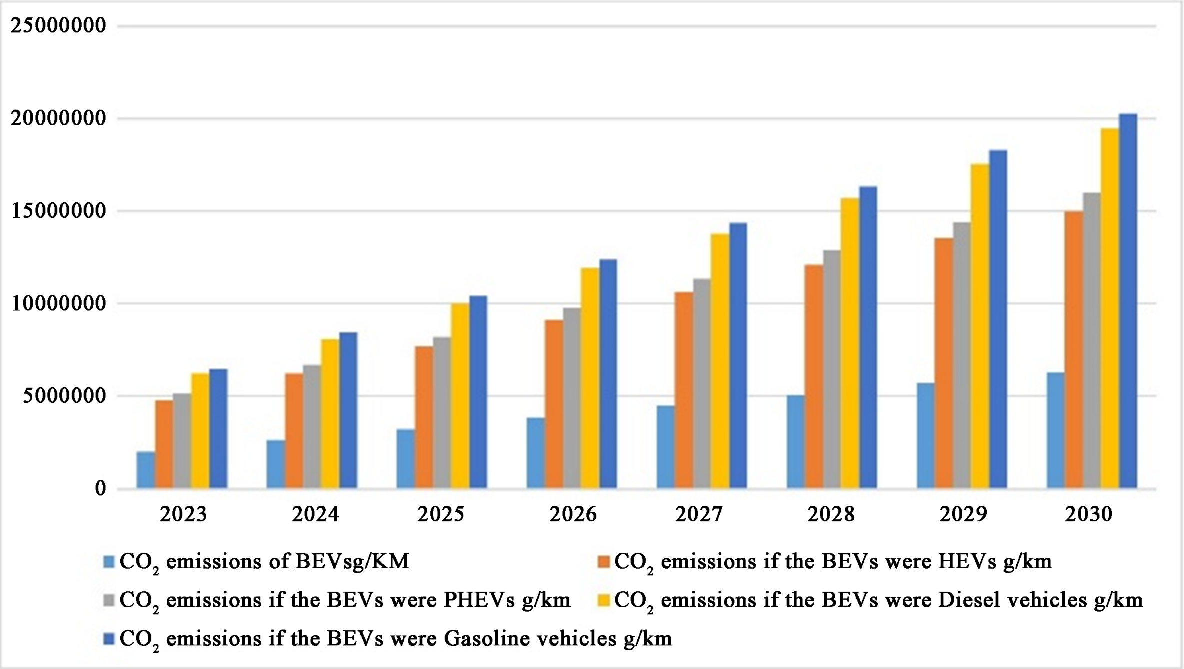

Figure 12. CO_2 emissions g/km of BEVs/ Diesel vehicles, Gasoline vehicles, PHEVs, and HEVs in case of the same number of BEVs predicted between 2023 and 2030, and BEVs estimated CO_2 emissions reduction in Hungary [Source: Own elaborations based on Gimbert (2022) tool].

Figure 12 clearly illustrates the predicted CO_2 emissions in g/km of BEVs, Diesel vehicles, Gasoline vehicles, PHEVs, and HEVs for each year from 2023 to 2030 based on the predicted numbers of BEVs for the next 8 years in Hungary. The graph compares the CO_2 emissions in grams per kilometer of different energy source vehicles in the case of the same number of BEVs predicted each year to estimate and compare the CO_2 emissions and reduction in grams per kilometer by BEVs each year in comparison to other widely used energy vehicle types.

According to the time series forecast in **Figure 11**, the number of BEVs in Hungary in 2023 will reach 26974, with expected CO_2 emissions of 2,203,050 g/km, indicating an average CO_2 emissions reduction of 4,477,684 g/km in comparison to gasoline, diesel, HEVs, PHEVs in the case of the same number of vehicles.

Moreover, **Figure 11** shows that in 2024 the number of BEVs will increase to 35,148, with expected CO_2 emissions of 2,636,100 g/km and an average CO_2 emissions reduction of 5,834,568 g/km compared to gasoline, diesel, HEVs, and PHEVs in the case of the same number of vehicles.

In 2025 the number of BEVs in Hungary is expected to increase to 43,322, with estimated CO_2 emissions of 3,249,150 g/km, indicating an average of 7,191,452 g/km of CO_2 emissions reduction compared to gasoline, diesel, HEVs, and PHEVs in the case of the same number of vehicles.

Furthermore, the number of BEVs in Hungary is expected to reach 51,496 in 2026, with expected CO_2 emissions of 3,862,200 g/km and an average CO_2 emissions reduction of 8,548,336 g/km compared to gasoline, diesel, HEVs, and PHEVs in the case of the same number of vehicles.

In 2027 the number of BEVs in Hungary is expected to increase to 59,670, with estimated CO_2 emissions of 4,475,250 g/km, indicating an average of 9,905,220 g/km of CO_2 emissions reduction compared to the same number of Gasoline vehicles.

The number of BEVs in Hungary is expected to reach 67,844 by 2028, with estimated CO_2 emissions of 5,088,300 g/km and CO_2 emissions reduction of 11,262,104 g/km compared to gasoline, diesel, HEVs, PHEVs in the case of the same number of vehicles.

In 2029 the number of BEVs in Hungary is expected to reach 76,018, with expected CO_2 emissions of 570,135 g/km, indicating an average 12,618,988 g/km of CO_2 emissions reduction compared to gasoline, diesel, HEVs, and PHEVs in the case of the same number of vehicles.

Finally, the number of BEVs in Hungary is expected to increase to 84,192 by 2030, with estimated CO_2 emissions of 6,314,400 g/km and CO_2 average emissions reduction of 13,975,872 g/km compared to gasoline, diesel, HEVs, and PHEVs in the case of the same number of vehicles.

4.4. Comparative Analysis with Existing Studies

The findings from this case study in Hungary align with several previous studies that have demonstrated the potential for battery electric vehicles (BEVs) to reduce CO_2 emissions compared to conventional gasoline and diesel vehicles. Our time series analysis predicts that the number of BEVs in Hungary will reach 84,192 by 2030, resulting in an estimated reduction of up to 13,975,872 g/km of CO_2 emissions compared to an equivalent number of gasoline, diesel, hybrid, and plug-in hybrid vehicles. This significant reduction is consistent with the

68.88% lower CO_2 emissions for BEVs reported by Doucette and McCulloch (2011) in their study in China. Similarly, Hofmann et al. (2016) found BEVs could lower CO_2 emissions by 25% in China, while our estimated reduction for Hungary is even higher at around 62.4% less than plug-in hybrid vehicles by 2030. The CO_2 reduction potential aligns with Casals et al. (2016), who highlighted BEVs' ability to decrease emissions in densely populated European regions like Hungary's capital Budapest.

However, our projected BEV growth rate of 2.21% from 2022 to 2030 is relatively modest compared to some countries. For instance, Mishina and Muromachi (2017) estimated higher future CO_2 reductions from BEV growth in Japan. This discrepancy could be attributed to differences in government policies, incentives, and infrastructure development for EVs between Hungary and other nations. Nonetheless, our findings underscore the importance of increasing BEV adoption as a viable strategy for Hungary to achieve its climate goals and align with the European Union's emission reduction targets outlined in its long-term strategy.

5. Findings

The transition to Battery Electric Vehicles (BEVs) presents a significant opportunity for Hungary to reduce carbon emissions and improve air quality within its transportation sector. Analyzing data up to 2022 and employing forecasting techniques, it is evident that BEVs are poised for substantial growth in the coming years. This growth trajectory underscores the importance of policy interventions aimed at promoting BEV adoption, particularly those focused on cost reduction.

As of 2022, BEVs accounted for a mere 0.4% of Hungary's total registered passenger cars, with 18,800 BEVs among a total of 3.8 million registered vehicles. Despite their low penetration, BEVs have exhibited remarkable growth, increasing from a mere 405 in 2016. Simple Exponential Smoothing (SES) forecasts project a promising future, estimating that the number of BEVs in Hungary will reach 84,192 by 2030, signifying a substantial increase over the next eight years.

The Hungarian Ministry of Innovation and Technology's strategy to reduce BEV costs could catalyze a transformative shift. If successful in increasing BEV penetration to 10%, it could translate to 463,600 BEVs by 2030. This intervention holds the potential to significantly mitigate carbon dioxide (CO_2) emissions, with an estimated reduction of 76,957,600 g/km compared to conventional gasoline, diesel, hybrid electric vehicles (HEVs), and plug-in hybrid vehicles (PHEVs).

The environmental benefits of BEVs are undeniable. Previous empirical studies have demonstrated that BEVs emit substantially lower levels of CO_2 compared to traditional fuel vehicles. With BEVs emitting only 75 g/km of CO_2, while gasoline and diesel vehicles emit 241 g/km and 231 g/km respectively, the potential for emissions reduction is profound. Furthermore, BEVs offer the potential to decrease harmful emissions, particularly in densely populated urban areas, thereby improving overall air quality and public health outcomes.

The findings underscore the critical role of BEVs in Hungary's efforts to transition towards a sustainable and environmentally conscious transportation system. The projected growth of BEVs presents a significant opportunity for reducing CO_2 emissions and improving air quality. Policy interventions aimed at reducing the cost barriers associated with BEVs are essential to unlocking their full potential. By fostering an enabling environment for BEV adoption, Hungary can accelerate its progress towards achieving its climate and environmental sustainability goals while fostering innovation and economic growth in the automotive sector.

6. Conclusion

The assessment of data collected from stata.com has revealed that the number of battery-electric vehicles (BEVs) in Hungary has been on the rise, reaching 18,800 in 2022. This represents 0.4% of the total number of registered passenger cars in Hungary, which stands at 3.8 million, as reported by Statista (2023). However, a time series forecast using the SES method has projected that the number of BEVs in Hungary will reach 84,192 by 2030, indicating a percentage increase of 2.21% over the next eight years. While this rate of increase is modest, it is a positive start.

Further progress can be made with the help of the Hungarian Ministry of Innovation and Technology, whose seventh pillar strategy aims to reduce the cost of BEVs to make them more affordable for people. If successful, this initiative could result in a 10% increase in the percentage of BEVs, bringing the number of BEVs in Hungary to 463,600. Such a development would have a significant impact on the environment, reducing up to 76,957,600 g/km of CO_2 compared to an equivalent number of other fuel-type vehicles.

If more serious efforts are made in Hungary to increase the adoption of BEVs, the number of BEVs could increase two, three, or even four times, assisting in controlling at least 25% of this social-environmental phenomenon that has a negative impact on the entire society.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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