Statistical analysis of the predictors of annual electric vehicle mileage

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Article Info

Article history:

Received Sep 13, 2022
Revised Nov 3, 2022
Accepted Jan 11, 2023

Keywords:

Correlation
Electric transport
Electric vehicle mileage
Factor analysis
Regression
Statistical analysis

ABSTRACT

This study evaluates the impact of technical and economic factors related to electric vehicles and the impact of socio-demographic factors related to electric vehicle owners on annual electric vehicle mileage from a statistical perspective. The data set was analyzed using regression and correlation analyses using Ms Excel and several Python libraries. The influence of the socio-demographic characteristics of the respondents was estimated as minimal and requiring reassessment. It was shown that among the socio-demographic factors considered, only the age of vehicle owners correlates with the annual mileage of electric vehicles. It is shown that technical and economic parameters are much more closely related to the annual mileage of electric cars than socio-demographic parameters. Significant factors among the technical and economic ones were battery capacity, power consumption of the electric car, and the size of the respondent's locality.

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1. INTRODUCTION

The electric vehicle market is growing worldwide. It reduces greenhouse gas emissions and dependency on oil caused by conventional fuel-powered vehicles. Electric vehicles generate comparatively less or no exhaust emissions and have higher fuel efficiency than vehicles with internal combustion engines [1], [2]. These are alternative fuel vehicles that run partly or fully on electricity. Electric vehicles are primarily understood as battery electric vehicles, although there are also hybrid electric vehicles and plug-in hybrid electric vehicles (which can be recharged from external electric power sources, such as home wall outlets). The differences in energy consumption can affect the driving style to some degree.

Clearly, electric vehicles stimulate functional innovations, such as better fuel efficiency, reduced exhaust emissions, and the absence of road noise. All these add up to improving the overall perception of road transport. What is more, energy efficiency, lower electricity costs, and social and political incentives based on the use of electric vehicles improve the economics of electric vehicles. Along with that, technological advances mean that electric vehicles require less maintenance than conventional ones [3], [4]. The importance of socio-psychological factors that encourage people to choose electric when it comes to buying a car (such as self-identification, participation in public life, and display of personal status) should not be underestimated. Electric vehicle owners often indicate additional personal connotations, such as ethics, maturity, and caring for others [5].

Several studies [6], [7] provide a detailed description of the criteria for choosing an electric vehicle and general attitude of society towards electric vehicles based on the assessment of psychological and techno-economic factors. For example, they reveal that some consumers are concerned about the range of electric vehicles and charging-related issues, including the recharge time and availability of charging stations. The researchers make a conclusion that Chinese users tend to use electric vehicles in large cities with developed infrastructure [7].

One of the most common technical barriers for consumers is the concern about the driving range. Travel distance stress is often viewed as the fear of being stranded in the middle of a trip due to an empty battery [8], [9]. The phenomenon of range anxiety is best described as a specific form of stress that develops in response to actual or expected critical range situation, when a driver has a fear that his/her electric vehicle has insufficient energy storage to cover the remaining road distance [10]. Electric vehicles owners have also been shown to overestimate the range needs for their daily trips, and this tendency is reflected in their electric vehicle preferences. The availability of charging infrastructure and battery performance are key parameters that affect the driving style of electric vehicle owners [9], [11].

Few studies have examined the role of various psychological factors influencing the driving behavior of electric vehicle owners. Moreover, Russian transportation and urban planning departments are still unaware of how electric vehicles can change the behavior of their owners in urban traffic. The success of electric vehicle mainstreaming is highly dependent on the post-purchase use of electric vehicles. The latter is critical for the assessment of energy consumption and emissions reductions. In addition, gaining an understanding of the use patterns of electric vehicles on the roads is critical for accurate travel forecasting. Moreover, these data will be valuable for the support of electrified transportation systems, which in fact are an important factor in predicting energy demand and the need for transport infrastructure.

Considering the above, the researchers channeled their efforts into the assessment of the influence of various socio-demographic factors associated with the use of electric vehicles and the influence of the owners' characteristics on the final annual mileage of electric vehicles. The use of electric vehicles was characterized based on the approximate annual mileage, since this parameter is indicative of the driver's statistics [12]. For this largely empirical analysis, a survey was conducted among Russian owners of electric vehicles. Given the rapidly developing market for electric vehicles, the relevance of this study is based on the elucidation of aspects, which are significant for the prediction of the annual electric vehicle mileage (i.e., consumer behavior) in Russian cities.

An individual's behavior depends on the combination of the intention and control exerted over that particular behavior. Accordingly, studies show that people have different beliefs and perceptions associated with electric vehicles, which play an important role in the decision to buy an electric vehicle [3], [13], [14]. Studies conducted in the USA [15] have demonstrated that people tend to use private cars even when offered a cheaper transportation alternative. Electric cars are not only a transportation option. They symbolize ideas and convey global meaning. In European countries [16], [17], the ownership of an electric car symbolizes the widely recognized ideas of a better attitude towards the environment, moving past conflicts over natural resources, personal status, self-identification, and a sense of mobility. Indeed, the chances of satisfying the individual's needs are higher when the product image is consistent with his/her self-image [3].

Environmentally friendly approaches and consumer awareness of environmental issues stimulate the widespread adoption of electric vehicles [3], [6]. Consequently, environmentally conscious consumers may associate the purchase and use of electric vehicles with their involvement in environmentally friendly initiatives. The choice of an electric vehicle gives the impression of contributing to the reduction of environmental pollution and energy consumption. Moreover, both the automotive industry and politicians are promoting the environmental contribution of electric vehicles to attract consumers. When electrified, transportation is considered "green" and sustainable. As a rule, drivers are unsure about the efficiency of driving an electric vehicle. They are concerned over safety since electric vehicles are relatively new on the market and little is known about their performance, accident history and reliability.

Techno-economic aspects refer to the perceived economic cost of using electric vehicles. The economic cost reflects not only the purchase price, but also the expected depreciation and maintenance costs. The interest of western consumers (Netherlands, Norway, and USA) [17]–[19] expressed in financial terms has a strong influence on the driving manner. However, monetary costs involved in passenger transportation consist of both the cost of vehicle ownership and the cost of vehicle use.

Nevertheless, it is important to know how consumers actually use various techno-economic benefits for driving their electric vehicles. The researchers assume that the analysis involving techno-economic predictors would highlight the role of the latter beyond the purchase decision. Previous studies performed in the USA and Germany indicate that increased energy efficiency increases the demand for travel as the former reduces the cost of driving [19], [20]. According to these theories, higher energy efficiency of using electric vehicles is expected to increase the demand for travel. Not surprisingly, the lower operating costs of public transport discourage the use of and demand for electric vehicles.

Significantly increased electric vehicle mileage triggers the growth in electricity consumption and a rising demand for transport activity. Depending on the availability of energy resources, roadways capacity and quality, an increase in electric vehicle mileage can result in an increase in carbon dioxide emissions, dependency on fossil fuels used to generate electricity, and traffic congestions. Alternatively, other researchers [20], [21] state that electric vehicles must have relatively high mileage to provide environmental benefits as compared to internal combustion engine cars. Emitting only small amounts of carbon dioxide over their lifetime, high-millage vehicles compensate for the production-related emissions (in this regard, the production of batteries is of particular concern).

The growing number of electric vehicles on the road can have multiple advantages, including the reduction in fossil fuels reliance and carbon dioxide emissions. Meanwhile, charging a large number of electric vehicles at a time will have a huge impact on power grid. A promising way to mitigate this impact was shown by [22], who suggested taking advantage of neural network technologies for the efficient electricity distribution and using local renewable energy sources. To sum up, the total cost of an electric vehicle ownership includes both the initial purchase price and the annual maintenance cost, which in turn depends on the vehicle's mileage [20]. Therefore, to compensate for the higher purchase price as compared to conventional cars, electric vehicles should offer higher mileage.

In the light of the foregoing, one can conclude that socio-demographic factors play an important role in the choice of an electric vehicle instead of a conventional one. Logically, these factors can affect the frequency of use of an electric vehicle. Therefore, a hypothesis was put forward that personal characteristics also have an impact on the driving behavior of electric vehicle users. In this regard, the assessment of the dependency between techno-economic parameters and the mileage of electric vehicles was also listed as a purpose of this paper.

Considering the above, one can conclude that socio-demographic factors play an important role in the choice of an electric car to replace a conventional one. Logically, these factors can influence the frequency of electric vehicle use. In turn, technical and economic indicators should have a direct impact on the mileage of an electric vehicle. The purpose of this paper was to investigate the effect of various factors on annual vehicle mileage. This information can provide opportunities for forecasting the necessary energy resources and initial data for the design of infrastructure for electric vehicles in populated areas.

2. METHOD

2.1. Sample

To form a sample, an online survey was conducted among the owners of electric vehicles. The respondents indicated their personal characteristics (gender, age, education, occupation, average, and income/month) and techno-economic information (vehicle brand, date of vehicle registration, distance the vehicle can drive without recharging a battery, and battery efficiency), as well as the population of the city/town/settlement where they resided. If it was possible to restore the missing data, it was done from the manufacturer's specification. Only those rows were selected in the obtained dataset in which all values were indicated. Thus, a sample of 1,098 data vectors was formed.

The sample consisted of 42% males and 58% females. At the time of the survey administration, 98% of the responders had the status of employees and/or students. Most of the respondents lived on incomes, with 73% having an income of $1,000 or more. The surveyed individuals were well-educated: 69% of the respondents obtained higher education and had a bachelor's degree or higher, the remaining 31% completed secondary or vocational education.

The requests to fill a survey were sent to people who published advertisements on Russian car sales websites. Invitations to take part in the survey were sent out to randomly and independently selected users. Thus, the sample is considered fairly representative. The survey was available for three months. Then data array was prepared and processed. The annual vehicle mileage in thousand km was chosen as a dependent variable. The respondents were asked to record this value as displayed on the odometer.

2.2. Data preparation and statistical analysis

Answers to the questions of a qualitative nature were replaced by numerical designations. The following qualitative factors were included: gender (man-1; woman-2), education (doctoral/doctoral candidate's degree-1, master's degree-2, bachelor's degree-3, vocational education-4, secondary education-5), occupation (employed-1, student-2, temporarily/permanently away from work or study-3). The quantitative variable "year of vehicle registration" was replaced by the service life (the number of years that have passed from the year of registration to 2022). Other variables (age, number of inhabitants in the respondent's city of residence, battery capacity, income, battery efficiency) were left unchanged.

Only quantitative variables were used for the regression and correlation analyses. The statistical analysis was performed on a personal computer. For this purpose, the following tools were used: MS Excel and Python (run in Jupyter Notebook). The following Python libraries were used for the regression and correlation analyses: pandas, statsmodels.api and numpy for creating a dataframe and statistical data processing, matplotlib and seaborn for visualization. For qualitative factors, the average mileage covered by each class of respondents was estimated.

3. RESULTS AND DISCUSSION

3.1. Qualitative parameters

The impact of gender, education and occupation was evaluated by comparing the average annual electric vehicle mileage covered by the corresponding group of respondents. Figure 1 shows the results. Apparently, the gender of respondents does not affect the mileage in any way. Occupation and education have a more significant impact. Unexpectedly, respondents who were not busy with work or study indicated the highest average mileage. However, there were 12 (1%) of these among the responders, which cannot be considered a reliable result and requires a more thorough investigation. Education affects average mileage, but the effect appears to be non-linear. In general, the difference in the average mileage covered by different groups is not too large and lies within ±18-19% of the average value (13.92 thousand km/year) for all respondents.

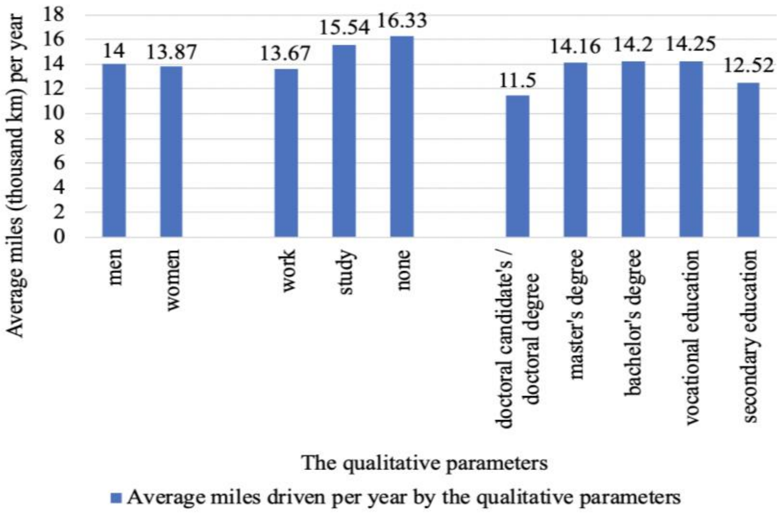

Figure 1. The average annual electric vehicle mileage covered by the respondents by gender, occupation, and education

3.2. Quantitative parameters

First, a regression analysis was carried out using the ordinary least squares (OLS) model from the statsmodel.api plugin of the Python language. The results are shown in Table 1. The purpose of the regression analysis was to obtain the values that would help draw conclusions about the dataset. The results can be assessed as follows:

a. R-squared is not much different from the average R-squared, which is a good sign, but these values are not high enough. In fact, this dataset explains only 51% of the variance. Building a regression model requires the inclusion of additional significant factors in the dataframe.
b. F-statistic is significantly higher than 4 as it is supposed to be.
c. The p-value must be less than 0.05, which is only true for "population," "age" and "driving range."
d. Skew is a measure of data symmetry. Here, the value of -0.083 is close to zero, indicating that the residuals are normally distributed.
e. Kurtosis is a measure of the lack of data symmetry. The value of 2.812 indicates the presence of outliers.
f. Cond. No. refers to multicollinearity. Here, the value of 17,400 is significantly higher than the expected value of 20. It suggests a high correlation between the independent variables.
g. The test for autocorrelation in the residuals (Durbin-Watson) yielded values below the expected values of 1.5-2.5. This may be indicative of serial correlation in the residuals.

Table 1. The results of the regression analysis performed by means of Python libraries

```
OLS regression results
==============================================================================
Dep. variable: mileage, km R-squared: 0.514
Model: OLS Adj. R-squared: 0.511
Method: least squares F-statistic: 192.2
Date: Thu, 18 Mar 2022 Prob (F-statistic): 5.56e-167
Time: 14:03:54 log-likelihood: -2747.1
No. observations: 1098 AIC: 5508.
Df residuals: 1091 BIC: 5543.
Df model: 6
Covariance type: nonrobust
==============================================================================
coef std err t P>|t| [0.025 0.975]
------------------------------------------------------------------------------
const 2.5358 0.827 3.066 0.002 0.913 4.159
Age -0.0746 0.011 -6.954 0.000 -0.096 -0.054
Population, thousands 0.0084 0.000 28.591 0.000 0.008 0.009
Service life -0.0591 0.043 -1.365 0.172 -0.144 0.026
Driving range, km 0.0206 0.001 16.047 0.000 0.018 0.023
Average income, US dollars -0.0001 0.000 -1.439 0.150 -0.000 5.33e-05
Energy consumption, kWh/km 0.0026 0.003 0.764 0.445 -0.004 0.009
==============================================================================
Omnibus: 2.812 Durbin-Watson: 0.962
Prob (Omnibus): 0.245 Jarque-Bera (JB): 2.745
Skew: -0.083 prob (JB): 0.254
Kurtosis: 2.820 cond. No. 1.74e+04
==============================================================================
```

The regression model is presented in Figure 2. The conclusions made based on the data provided in Table 1 are visually confirmed. The range of values is relatively narrow (although some outliers are observed). This means that the linear model is applied properly to explain the dependencies between the mileage and pre-specified factors. Generally speaking, a trend is observed, although more accurate simulation is required. Thus, it is possible to offer a linear model for predicting the annual mileage which would include some additional factors.

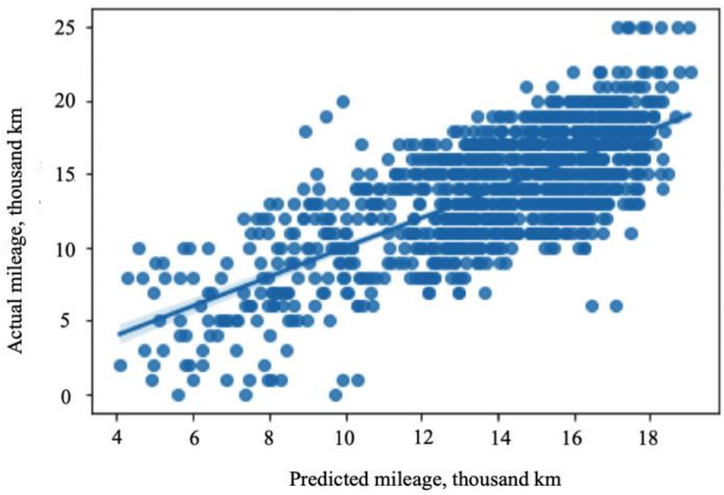

Figure 2. The linear regression model of annual mileage (thousand km)
Note*:* the vertical axis is the actual mileage; the horizontal axis is the predicted mileage. The line reflects the overlap between the actual and predicted mileage

Figure 3 illustrates the scatter matrix for significant factors for which the null hypothesis (“population,” “age” and “driving range”) is refuted according to Table 1. The points which represent the factors affecting the mileage are clearly concentrated. The distribution of the annual mileage has a pronounced “bell” top at a value of 14-17 thousand km/year. The age distribution of the respondents is about 30 years. Further, using the corr function of the pandas module, the correlation coefficients were obtained. Importantly, qualitative factors were also included in the analysis (Table 2).

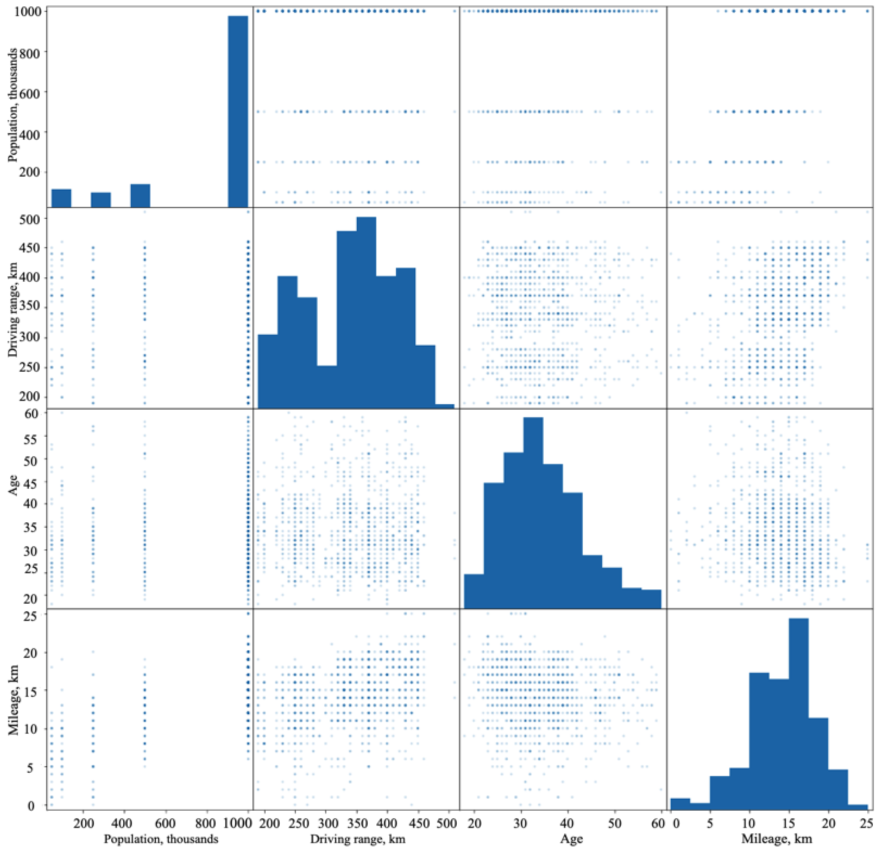

Figure 3. Scattering matrices for the combination of the most significant factors

Table 2. Correlation coefficients for the original dataset

Age	Education	Gender	Occupation	Population (thousands)	Service life	Driving range (km)	Average income (US dollars)	Energy consumption (kWh/km)	Mileage (km)
1.000	-0.015	0.098	-0.080	0.087	0.055	-0.011	0.128	-0.076	-0.107
-0.015	1.000	0.110	0.235	-0.026	-0.012	-0.014	-0.129	0.017	-0.034
0.098	0.110	1.000	0.142	-0.082	-0.019	0.029	-0.034	-0.026	-0.015
-0.080	0.235	0.142	1.000	0.012	0.005	0.029	-0.088	0.009	0.153
0.087	-0.026	-0.082	0.012	1.000	0.001	-0.001	0.074	-0.005	0.591
0.055	-0.012	-0.019	0.005	0.001	1.000	0.107	0.042	0.046	0.002
-0.011	-0.014	0.029	0.029	-0.001	0.107	1.000	-0.016	0.367	0.371
0.128	-0.129	-0.034	-0.088	0.074	0.042	-0.016	1.000	-0.048	-0.012
-0.076	0.017	-0.026	0.009	-0.005	0.046	0.367	-0.048	1.000	0.160
-0.201	-0.034	-0.015	0.153	0.621	0.002	0.408	-0.012	0.160	1.000

Having analyzed Table 2, the researchers concluded that the annual mileage significantly depends on the population of the respondent's city, town, or settlement (regarded as a measure of the city, town or settlement size). In addition, the distance that an electric vehicle can travel without recharging was of importance (the higher driving range is, the higher is the mileage). This may be explained by the fear of drivers going on a long journey with a low-capacity battery. The influence of the driver's occupation and vehicle energy consumption was negligible. A weak negative correlation was observed for the age factor, with older people driving somewhat less. Multicorrelation in the regression analysis can be explained by some dependence between the driving range and energy consumption.

3.3. Evaluation of the results

The factors were evaluated by the dataset regression. The model has a relatively satisfactory R2 value and a statistically significant F-statistic (Table 1). The predictors are able to explain 51% of the variance in the annual electric vehicle mileage estimates. This fact confirms the relative statistical significance of the resulting dataset. The results confirm that the techno-economic aspects of electric vehicle use considered in this manuscript have a positive impact on the annual mileage. Of particular importance are the energy consumption of electric vehicles and the size of the city/town/settlement in which the electric vehicle owner lives. At the same time, the social profile of the electric vehicle owner has only a minor influence.

The data presented above could mean that lower marginal driving costs and confidence in battery levels increase the demand for travel among electric vehicle owners. This suggests that various policies aimed at expanding the network of charging stations, which will increase the availability of charging points for electric vehicle owners, can stimulate the annual mileage in the long term. Small towns (100-250 thousand inhabitants) should have such incentives implemented in the first place. Due to the range concerns, longer charging times and lack of charging stations, the respondents tend to drive less. Overall, an increase in the annual electric vehicle mileage covered can reduce the burden on public transport and the need for fuel. The convenience of using an electric vehicle can increase the demand for electric vehicles and, consequently, improve the environment in Russia.

The number of consumers purchasing electric vehicles as their primary means of transportation is growing rapidly in many countries, including Russia. Currently, the market share of electric vehicles is relatively high. However, the growth of this market segment is difficult to predict due to the new technological orientation. Obviously, a variety of factors play an important role in the decision to buy an electric vehicle, but not all of them ultimately affect the manner of its post-purchase use. This study explored the impact of some factors on annual mileage.

The statistical analysis found that the socio-demographic profile of the owner has a slight effect on the electric car mileage. These findings contradict those obtained in Norway [23]. To clarify, Norwegian researchers showed that psychological and personal factors affect the vehicle mileage. This disagreement may be partially attributed to different lifestyles and socio-economic performance indicators in Norway and Russia. It is also worth noting that the results of the OLS regression analysis are indicative of the fact that Byun *et al*. [19] can only explain 21% of the variance, while the dataset used in the present study has 51% of the variance explained, which may indicate a better choice of predictors. As a result, the researchers admit the role of personal factors in the choice of an electric vehicle but consider them a weak argument in the context of driving style, expressed in terms of annual mileage.

The relatively strong positive impact of techno-economic parameters on the electric vehicle mileage has been demonstrated in other studies [24]–[26]. The latter show an increasing demand for travel. This is seen as the result of driving costs lowering due to improved energy efficiency. Research by [7], [11] exhibit that electric vehicles are more frequently used in large, developed cities than in suburbs or small towns. These observations are consistent with those made in this study. Indeed, the population of the respondent’s city/town/settlement was seen to have the highest correlation with the annual electric vehicle mileage.

An assumption has been made that opportunities for longer journeys will trigger an increase in the demand for electricity. As a consequence, the world will face an increased demand for primary energy (oil, gas, coal, and renewable energy). Obviously, the energy balance should be maintained in the process of electricity generation, which indicates the environmental benefits of driving an electric car. This opinion is largely consistent with the views expressed by [27]. Clearly, the initial results of technological advances (increasing the energy efficiency of cars, developing charging infrastructure) will be the most prominent for the transport sector (for example, reduce the burden on public transport) and the environment. The positive effect may be reduced over time, and other types of problems may arise (traffic jams, increased power consumption).

The owners of electric vehicles were found to drive an average of 13.92 thousand km/year (about 38 km/day). Research by Pasaoglu *et al.* [28] show that the average daily distance traveled by conventional cars in European countries (United Kingdom, Poland, Germany, Italy, Spain, and France) ranges from 40 km to 80 km. A significantly lower result can mean a lack of comfort and anxiety during the trip due to uncertainty about the battery charge and inability to recharge the vehicle on the road. Therefore, the development of urban infrastructure can be of key importance for Russia. In addition, the ultimate success of the mass adoption of electric vehicles depends on the improvement of technologies related to driving range and building of a sufficient number of fast charging stations.

Some findings presented in this study are useful for gaining a better understanding of the variables that affect post-purchase electric vehicle use. However, further research may be focused on the development of an accurate regression model enabling predicting the estimated annual mileage of electric vehicles and estimating the amount of electricity and the number of charging stations needed. Although the results of the statistical analysis are reasonably consistent with global experience, the dataset was seen to be insufficiently significant due to the limited data collection mechanisms. Several new factors (primarily techno-economic ones) will be used by the researchers in further studies, and a better balance between the groups of respondents will be achieved. This will allow more accurate assessment of the impact of qualitative factors on the vehicle mileage.

4. CONCLUSION

The manuscript explored the impact of some factors associated with electric vehicles and their owners on the annual electric vehicle mileage. For this, a statistical analysis was undertaken based on the results of the survey. The results of this study indicate that the use of electric vehicles depends more on the techno-economic parameters of a vehicle than on the personal characteristics of a vehicle owner. For example, the researchers demonstrated that the most significant factors are the population of the city/town/settlement where the vehicle owner lives, the battery capacity and energy consumption. To a much lesser extent, mileage also depends on the owner's age and occupation/education.

The battery characteristics were confirmed to have a psychological impact on the owner. Thus, the respondents who have electric vehicles with lower battery capacity were less willing to go on long trips. This is due to the lack of confidence in the ability to recharge the battery on the road. The above findings suggest the need to improve the functionality of electric vehicles and develop charging infrastructure. These measures will help attract those consumers who have a negative perception of electric vehicles. In the long run, the switch to electric vehicles will improve the urban environment and reduce the burden on urban transport.

Following this study, the researchers suggested elaboration of a more accurate model that would describe the demand for trips among electric vehicle owners. This model is needed for more accurate forecasting of energy needs and taking the necessary steps for building charging infrastructure in Russian cities, towns, and settlements. To develop the desired model, an additional set of factors should be identified that can influence the annual mileage of electric vehicles, and the subsequent regression analysis should be performed.

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