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Determinants of Electric Cars Purchase Intention in Poland: Personal Attitudes v. Economic Arguments

Katarzyna Sobiech-Grabka, Anna Stankowska * and Krzysztof Jerzak

Department of Innovative City, Warsaw School of Economics, 02-554 Warsaw, Poland; ksobie1@sgh.waw.pl (K.S.-G.); kj84108@student.sgh.waw.pl (K.J.)
* Correspondence: astanko@sgh.waw.pl

Abstract: Urban e-mobility, seen as a part of complex and multidimensional European Green Deal plan, is essential for cities. However, it cannot be implemented without a common social commitment accompanied by a shared, strong belief in its advantages. Even if urban authorities and central governments would encourage their citizens to buy or share an electric vehicle (EV), the shift to EV will not be significant without people convinced that the idea of becoming zero-emission is economically viable and rational to them privately. This is especially true and important in countries like Poland—which is classified as an "EV readiness straggler". The main purpose of this study is to develop a robust forecasting model with the aid of advanced machine learning methods. Based on the survey conducted, we identified factors useful for predicting consumer behaviour in terms of willingness to purchase an EV. The proposed machine-learning tool (specifically, the Random Forest algorithm) will allow automotive companies to more effectively target factors supporting the promulgation of urban individual e-mobility.

Keywords: electric vehicles market and policy; electric vehicles; purchase intention; e-mobility; consumers preferences; consumer decision making; social values; delay discounting; cultural factors; economic factors; machine learning methods; sustainability

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1. Introduction

Humanity is currently finding itself at a crossroads, challenged by the transformation towards greener and more sustainable economy, especially in terms of energy consumption. During previous oil crises in the 1970s, societies and authorities missed the opportunity to reduce oil-dependence, they did not discern the warning signs of negative consequences of relying on fossil fuels delivered mostly by autocratic countries. At that time, this sin of omission was partially explained by ineffective, immature technologies. Today the world is in a different situation, as renewable technology is widely available. It seems that consumers' willingness to buy electric cars (EVs) might be the most serious obstacle now.

The significant consequences of fuel-dependence are clearly visible especially today, as people around the world suffer the economic consequences of war in Europe (Russian aggression towards Ukraine [1]). The associated migration and economic crises (economic sanctions and general economic instability caused by the war) undermine the global sustainability, already endangered by the climate disaster and the COVID-19 pandemic.

"If we do not get rid of cars, then we must make our cars better" [2]—this direct quote from Gary L. Brase addresses the choice faced by contemporary societies both in developed and developing countries: on one hand consumers around the world are not ready for substantial changes in their consumption patterns (i.e., consume less, share instead of own, recycle), on the other hand it is impossible to maintain those consumption patterns unchanged at a worldwide scale. The recipe provided by Brase is an attempt to compromise: if humanity is not ready to give up individual cars (as people are too used to the comfort and convenience provided by them), it should be ready to make them less polluting.

Which specific technology will dominate the alternative-fuel cars market in the years to come is in some ways irrelevant: no matter if it is solid fuel cells, hydrogen in gas or paste form, etc.—the more important issue is people's willingness and readiness for this change. This paper will focus on alternatively-fuelled cars such as battery electric vehicle (BEV) and hydrogen cars. It will not take into consideration hybrid electric vehicle (HEV) or plug-in hybrid electric vehicle (PHEV) as those types still require fossil fuels to drive.

Given that the contemporary world is mostly urban [3], it is especially important to make cities more sustainable in terms of transportation. Cities are those spatial structures that are largely responsible for climate disaster. City dwellers produce pollution (mainly as negative externalities of urban transport and inefficient, obsolete heating systems) but they are also vulnerable to urban pollution. As traditional transport, fossil fuel combustion emits particulate matter ($PM_{2.5}$) harmful to public health [4], limiting internal combustion engine (ICE) cars appears to be one of desired directions in changes of urban landscape (the others are: zero emissions zones, massive switch towards public transport, and priority for pedestrians and cyclists).

The definition of "sustainable city" coined by Gehl [5] is based on its transport means: "the sustainable city is strengthened generally if a large part of the transport system can take place as "green mobility", that is travel by foot, bike or public transport. These forms of transport provide marked benefits to the economy and the environment, reduce resource consumption, limit emissions, and decrease noise levels." Urban transport is a particularly important component because it is responsible for a large share of energy consumption, which results in substantial pollution and carbon emissions.

Air pollution is one of the largest challenges in Poland, and is responsible for around 93,000 premature deaths annually [6]. As indicated by European Environment Agency, Polish citizens are highly (above EU standards) exposed to selected air pollutants (namely: PM_{10}, $PM_{2,5}$, O_3, NO_2 and BaP): in 2018 the 100% of population was overexposed to benzopirene and 82.3% of population was overexposed to PM_{10} [7]. While Poland may be an extreme case, many other locations around the world—especially urban areas—face similar challenges.

In Poland the average age of a car is over 12 years, and the motorization rate is 747 (747 cars for 1000 inhabitants—which is the second highest result in Europe) [8]—but only 25 thousand (out of 24.3 million [9]) were PHEV and BEV cars as of 2021 [10]. The existing inefficient and outdated car fleet is a significant source of pollution harmful to the health of city dwellers, as well as excess carbon emissions harmful to the globe. Therefore, it is clear that substantial transition is needed in this field. One possible and desirable change is a shift towards electric passenger cars. Unfortunately, both Italy and Poland are classified as "EV readiness stragglers". In 2020, Poland was the third-worst European state in terms of EV registration rate (0.12 EV/1000 inhabitants) [11].

Despite noticeable dynamics of new EV registrations in 2021, the promulgation of zero-emission passenger cars in Poland is still a thing of the future. Even if urban authorities and the central government would encourage their citizens to buy or share an electric vehicle, the shift towards electric vehicles will not be a massive wave without people convinced that the idea of becoming zero-emission is economically viable and rational to them privately. The annual "New Mobility Barometer" [12] discovered a growing share of Poles who would consider EV while purchasing a new car (in 2017: only 12%, in 2018: 17%, in 2019: 28%, in 2020: 29% and in 2021: almost 33%). However, considering an EV during the market search for a new car does not necessarily translate into practice—the purchase of EV.

Societies around the world share similar reservations regarding the features of EVs. According to various studies, potential buyers question: range [13] (sometimes described as range anxiety), availability of public charging points [14,15], the cost of ownership (and the cost of buying). Usefulness and ease of use of electric vehicle is also questioned [16]. As Nordhaus [17] underlines, energy-cost myopia may be a substantial obstacle in one's decision-making process: consumers do not fully value future savings from energy efficiency improvements, and they prefer spending less money today than saving more in the future [17]. The purchase of an EV is characterised by delayed returns—it means that a higher up-front cost for an EV is later compensated by lower operating costs [18]. However, there is already an extensive psychological and economic knowledge on how individuals differ in their perception of discounting future returns and valuating them [2]. Moreover, one also should bear in mind that sometimes some people simply don't have the money now. Even if they properly valued future returns, their cash flow situation is too difficult now to act on it. In the light of this reservation, a well-tailored subsidy system that would ameliorate the financial situation of the less well-off, is a great challenge for public administration. The authors will address this issue later in the text.

The 'delayed returns aspect' leads to a conclusion, shared by Tu and Yang, that electric vehicles need increased publicity in order to attract consumers [19] and convince them that e-mobility is a part of solution to prevent the world from climate disaster (or losing in the climate casino—to use Nordhaus' metaphor). This publicity will be effective and efficient only to the extent that academia and the business world deeply understand the values and priorities of potential EV customers.

Beyond carbon emissions and other pollutants associated with urban mobility, it is important to mention the rare metal issue [20]: there is a danger that, as demand for the rare earth elements needed to produce EVs, wind turbines, photovoltaic panels, etc. increases, humanity will find itself dependent on fixed supplies of these metals. In other words, dependence on fossil fuels will change to dependence on rare earths. Metal mining is not indifferent to the environment. It also raises serious social effects and associated ethical risks [21]. As Sobiech-Grabka [22] pointed out, there are three approaches to address this issue: effective recycling, technological innovations (such as solid fuel cells) or a war for rare metals (the last one is not acceptable from moral and human point of view).

Another substantial challenge, related to the "dirty" production of electricity from coal, is presented at greater length in the literature review section.

On the basis of the above initial observations and literature review, the authors formulated research questions with the aim of describing the economic concerns and decision-making processes of Polish consumers: Do Poles perceive these same EV characteristics as disadvantages? Who is the most likely to buy an EV? Is it possible to predict the probability of EV purchase using machine learning techniques?

Those questions will be addressed in the present paper. With the use of a machine learning (ML) model followed by logistic and linear regression models, the authors discern the most influencing factors in the Polish case. These results will be helpful for EV manufacturers and car showrooms: the authors clearly point out what values are shared by their potential future customers in Poland, a promising EV market. This is also very important due to the fact that in 2021 Poland was only ranked 15th among EU countries in terms of sustainable energy development (SISED) [23].

The subject of the paper is relevant and current, as there is a research gap regarding the economics and psychology of buying electric cars in Poland. Moreover, there are many other developing countries, like Poland where successful EV transitions are crucial to global sustainable energy transformation.

The paper also adds to the literature in terms of methods used; the authors confirmed that advanced machine learning methods are an important addition to previously used research tools.

The structure of this paper clearly addresses the questions posed above. The literature review in Section 2 describes significant additions to the scholarship achieved to date. Next, Section 3 provides the methods description and in the following section presents the core results. In the discussion the results are compared with earlier findings, and it also presents limitations and potential areas of future work. The paper concludes by summarising its contributions to scholarship in this area and providing some practical recommendations.

2. Background and Literature Review

2.1. Previous Research on EV Purchase Intention

In the first step, literature published between 1998 and early 2022, investigating EV adoption, EV diffusion and EV purchase intention, was analysed. The following databases were searched: *Science Direct*, *SpringerLink*, *Scopus*, *Semantic Scholar*, *Web of Science*, *ResearchGate* and *Google Scholar.* A "citation chaining" approach was applied for searching both backward and forward in the literature to find more relevant papers. The results were then filtered to exclude papers focusing on sophisticated technological issues.

Early investigations on consumers' adoption of electric cars were focused on Western countries (such as Norway, Belgium, Germany, the Netherlands, the UK or the US) that were vanguards in EV promotion at the moment (cf. [19,24–26], [16,18–22]). The rising popularity of the concept of zero-emission cars in developing countries (especially China and India) resulted in more studies in the field. However, the research of electric cars in post-communist countries such as Poland is still in the early stage, resulting in significant knowledge gaps.

Individual e-mobility adoption is strongly related to a decision-making theoretical framework. Previous researchers in the field applied various approaches: from traditional economic paradigms (such as rational choice theory, RC) to theories originating in environmental or social psychology, behavioural economics, ecological economics, marketing or innovation diffusion theories—just to name a few [17,18]. Rezvani et al. [26] concluded that consumer adoption of EVs has been investigated prevailingly within five categories of theoretical frameworks (Figure 1):

1. Ajzen's theory of planned behaviour (TB) [27] and rational choice theory;
2. normative theories (e.g., Stern's value-belief-norm theory, VBN [28]) and environmental attitudes;
3. symbols, self-identity and lifestyle (based on psychological and sociological theories such as: Saussure's sign model [29], self-image congruency theory by Sirgy [30], narratives of self by Giddens [31], and Miller's costly signalling theory [32];
4. diffusion of innovations theory (DOI) by Rogers [33] and consumer innovativeness;
5. consumer emotions—proposed by Moons and De Pelsmacker [34] to be treated as an additional dimension to the theory of planned behaviour by Ajzen.

On the basis of literature review it was possible to discern groups of factors influencing EV purchase decisions (Figure 2).

According to some research, economic factors (purchase price and maintenance costs) constitute a very powerful hurdle, resulting in low demand for EVs, despite ostensible interest in buying them [27,28]. Jensen et al. [35] investigated individual preferences of consumers who experienced an EV for a three-month trial. They concluded that even if environmental concerns influence the preference for EVs positively, it does not translates into a purchase decision. On the other hand, various studies reveal the existence of a large cohort of consumers who would pay a higher up-front cost with the aim of gaining lower fuel costs [36].

Another important aspect for the uptake of zero-emission vehicles is their residual value. Wróblewski et al. [37] made a pioneering attempt to forecast residual values of low-emission BEVs and PHEVs compared to ICEVs based on the expert method. To-date, the loss in residual value for Poland BEVs is very large, as compared to ICEVs. While beyond the scope of this study, the issue of residual value (like the issue of up-front costs and cash flow for the less affluent) could be addressed by policies (some of which are mentioned in Section 5).

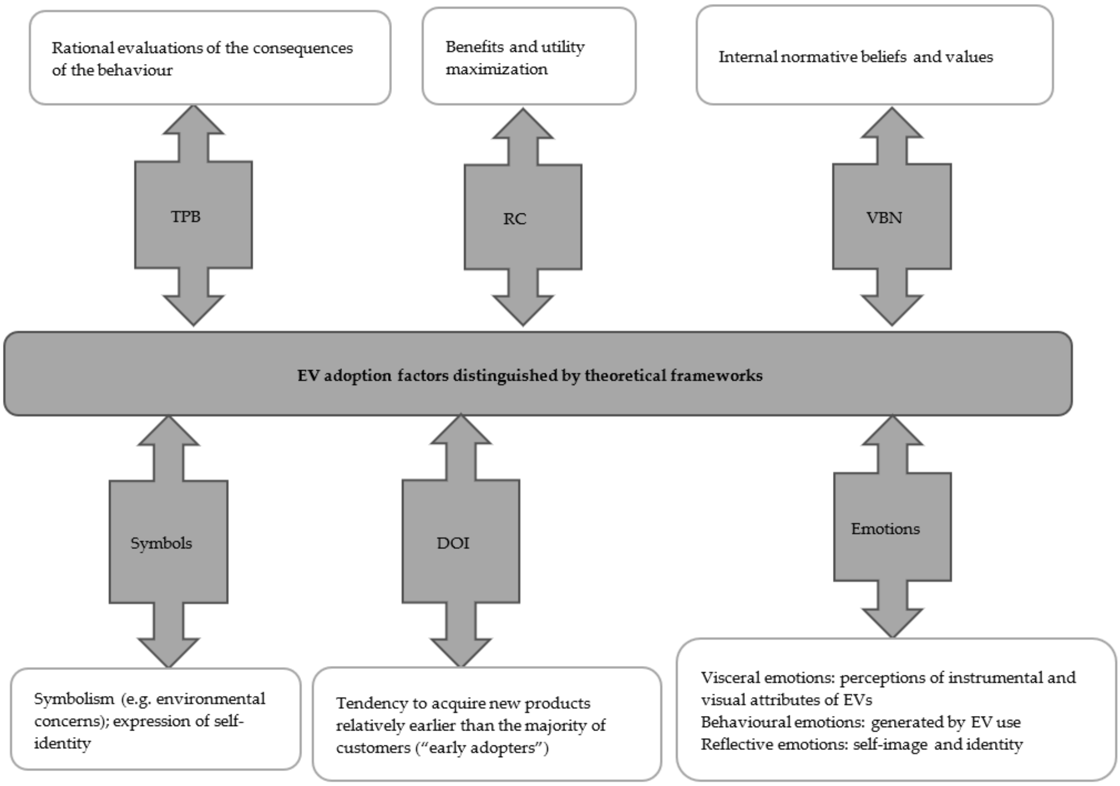


Figure 1. Basis of consumers' behaviour according to various theoretical frameworks. Source: own study, based on [26].

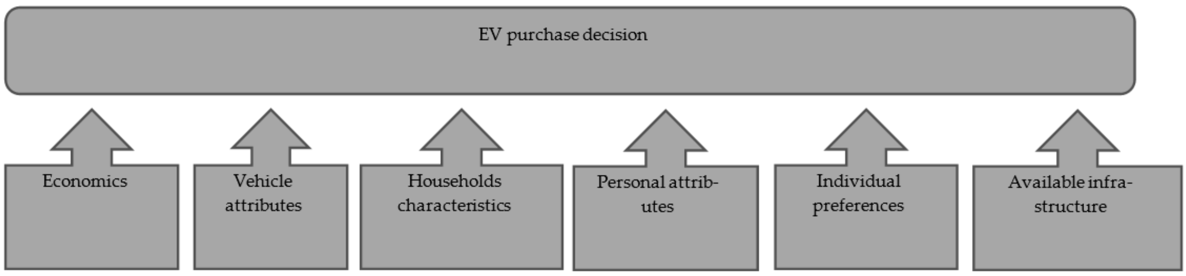


Figure 2. Groups of factors influencing EV purchase decisions.

Brase [2] investigated the perception of EV versus gasoline-powered vehicles in the US, using regression models. Respondents perceived the latter as "better" in terms of safety, performance, suitability for long trips and availability of fuel/charging stations. Electric cars were seen as "better" in terms of making a values statement, daily driving needs, energy independence and environmental conservation [2]. Based on the evidence, the author recommended focusing more on the vehicle-associated values and immediate performance issues in order to strengthen EV position in market share.

Norway, the European leader in EV implementation, is an especially interesting country to focus on. Haugenland and Hauge asked the Norwegians about their user experiences with e-mobility. The survey was conducted among a group of 3405 EV users/owners. The results shows that most of the respondents have used their EV for less than one year (60%), have higher education (76%) and have two cars in household (61%). Moreover, they are very satisfied as EV owners (91%), and most of them would buy an EV again (74%). In contrast, a survey of the entire Norwegian population shows that only 21% would consider an EV for their next car, and 35% would consider a plug-in hybrid. Current EV owners decided to buy an EV mainly for three reasons: save money (48%), save the environment (27%), and save time (12%). A smaller group (13%) decided to buy for reasons other than mentioned above. The researchers pointed out—as one of the most important conclusions—that one satisfied EV user can persuade three people to buy an EV [38].

Consumers' perceptions of EVs depend to some extent on EVs' features, but people's beliefs and identities also play a crucial role in EV adoption. Research by Schuitema et al. conducted in 2013 in the UK discerned that customers characterized by pro-environmental attitudes have positive perceptions of attributes of electric vehicles. As of 2013, intentions to purchase plug-in hybrid electric vehicles were stronger than battery-electric vehicles [39]. The 2013 observation of Schuitema et al. was confirmed by Mandys in 2021: the possibility of being an early EV adopter increases for people who are younger, better-educated, being a student, living in the more southern parts of the UK and being married [40]. Surprisingly, the very early adopters of EVs in Germany were middle-aged men living in suburbs or rural areas. Major German city dwellers, to whom pro-environmental identity may more likely be assigned, were not as keen on shifting towards zero emission cars [41].

A large-scale study by Novotny et al. [42] (on a sample of 21 countries), based on Hofstede's concept of different cultural dimensions (power distance, uncertainty avoidance, individualism vs. collectivism, masculinity vs. femininity, long-term vs. short-term orientation, and indulgence vs. restraint) aimed to determine the impact of culture on EV adoption through its role in innovative and environmentally conscious behaviour.

To-date China is the largest market for EVs and vast number of research studies were conducted there to determine factors influencing consumer behaviour while purchasing new cars. Ye et al. [43] developed an integrated approach to jointly study three psychological attributes (attitude, subjective norms, and perceived behavioural control) and four policy attributes (purchase subsidies, license plate control, preferential usage, and preferential driving) influencing consumers' EV purchase intention. Research was conducted in 2019 in China on 1087 respondents. They found that these psychological attributes can increase consumers' EV purchase intention, even without government action (e.g., purchase subsidies). What's more, the lack of psychological attributes causes a decline in interest in buying EV, even with government subsidies [43].

Li et al., on a sample of 2851 respondents from the US, analysed how factors like demographics, socioeconomic status, driving patterns, and attitudes have an influence on alternative-fuel vehicles purchases using on the maximum-likelihood estimation method. General findings were that flexible-fuel or hybrid-electric vehicle consumers were characterised by: concerns about the cost of gasoline, concerns of the effect of oil imports on national security, and concerns about environmental impacts from cars. Their more detailed research with differentiation by vehicle type shows that longer formal education time has a more positive impact on the decision of buying a flexible-fuel vehicle than a hybrid-electric vehicle [44]. However, this is not surprising, given that more highly educated people tend to have higher incomes and can therefore more easily consider buying these more expensive vehicles.

With the use of Structural Equation Modelling, Krishnan and Koshy [16] evaluated the influence of various attitudinal factors on EV purchase intention of people in India. They revealed that perceived benefits, social influence, price acceptance, performance, technological consciousness, and marketing have positive effects on EV purchase intention [16]. Those findings were confirmed by Gurudath and Rani who conducted research on the factors influencing the decision to buy an electric vehicle on 125 people from Bengaluru (India). The results show that the following factors are very important in electric cars for the respondents: Service Warranty, Price, Safety, Life Span, Speed and other important factors like: Test Ride, Low noise, Trend, Delivery Time, Ability to Upgrade. Other findings from the study are that highly satisfying factors in electric cars are: Environment Friendliness, New Technology, and somewhat satisfying factors include Resale Value, Charging and Vehicle Capacity [45].

In the years to come, especially after Russia's aggression on Ukraine that resulted in serious concerns about imported petroleum security, the speed of up-take of electric vehicles may increase. However, this would require some support (including financial incentives and huge infrastructure investments). To the authors' best knowledge, there is a visible lack of extensive studies investigating the role of state and international regulators in EV diffusion. Given that the EU has adapted the Fitfor55 package that indicates electric mobility as a pillar for transport decarbonization (and simultaneously, the member states on their respective national levels), the impact of legislative changes on EVs adoption will be massive. However, the authors managed to find some papers dealing with the impact of regulatory issues. Some cities (in China for example) adapted license plate control policy as a tool to mitigate pollution in urban areas, and a 2019 study reported this policy to be more influential for Chinese consumers than a purchasing subsidy [46]. Tu and Yang [19] deliver additional recommendations on the role of government and car manufacturers who should consider increasing the publicity of EVs and introduce more attractive battery and charging schemes [19]. As underlined by Bobeth and Kastner [47], broader political support schemes are also needed to foster EVs adoption [47].

Apart from information campaigns postulated by the latter, the efficiency of subsidizing EV purchase policy should be of great research interest. A 2018 study in California (the state that accounted for 40% of EV purchase in the US and 10% of global EV purchase in 2018) estimated three crucial parameters of subsidizing policy: the rate of subsidy pass-through for the program, the impact on EV adoption, and the elasticity of demand for EVs among low- to middle-income customers. Muehlegger and Rapson estimated the demand elasticity between −3.2 and −3.4, to be interpreted that a subsidy decreasing the price of an EV by 10% has a potential to increase demand for EV by 32–34%. Even if this observation is remarkably promising at first glance, one should keep in mind the small baseline quantity, resulting in moderate increase of purchased EVs [48]. Nevertheless, these purchase subsidies may play a very important role in bringing low- and moderate-income people into the EV world. The case of Italy suggests that monetary incentives are the most effective measure for electric car promulgation. In that country, described by Danielis et al. [49] as "a country with limited but growing electric car uptake" subsidies appeared to have greater impact on consumers' purchase decisions than technological improvements. Research on electromobility development in Poland indicates that Polish consumers still perceive electric cars as expensive. According to Lewicki et al. [50], this implies the need for more active government action to support the demand side.

There are still some technological issues to be solved or clarified in coming years, and these solutions will be of great importance for future EV users and buyers. For instance, the time of charging, raised today so often by EV opponents, may be solved in various ways, including implementation of extra fast chargers or battery-swapping points. The unsuccessful attempt of Tesla to implement battery-swapping technology in 2013 [22] proved that American e-car drivers perceived faster (and free of charge) charging stations as a more compelling solution [51]. Meanwhile, as battery swapping services are promoted by the Chinese government, this model is likely to increase future electric vehicles adoptions [52].

The technological challenges are even more complex in places (like Poland) where most EVs are charged by electricity produced from coal (in 2021, over 75% of Polish-produced electricity was based on either hard or lower-grade brown coal [53]). So, while EVs are locally zero-emission (which is good for the places in which they're used), the overall carbon footprint is still substantial (i.e., the negative externality accrues to the coal power plant's location, as well as to the globe at large). Petrauskienė et al. [54] investigated assessment of BEV's performance with different electricity mix scenarios, built with the aid of scientific modelling for the years 2015–2050 for Lithuania.

Thus, a broader and more holistic green transformation of energy sources is crucial in this context. Polish consumers have recently achieved an incredible progress in becoming "*prosumers*" (i.e., people who produce energy at home using mainly photovoltaics (PV), consume the produced energy and add the surplus to a power grid). As of January 2022, Poland's installed PV power capacity is 8.1 GW, and PV has the biggest share (47%) among all green energy sources in Poland [55]. However, due to some technological constraints the future development of PV in Poland is likely to be slower. This issue will be detailed in Section 5 of this study.

Because an EV is still more expensive than an ICE car of a comparable size and standard of equipment, it may be assumed that in poorer EU countries such as Poland, EVs will be purchased by well-offs who pay more attention to their socio-economic status indicators. The symbolic motivations of this group may be more important than rational factors: the range and price of a car being less important than the message announced by it. Research in Portugal supports this claim: the probability of purchasing an EV is bigger in the higher-priced car segment. In the case of lower or middle car markets, the cost argument prevails and consumers prefer to buy conventional engine cars [56]. This observation suggests that, particularly in developing countries, EV purchase willingness of the well-off is driven more by "virtue-signalling" or "affluence-signalling" than by rational expectations. At the same time, the large remaining cohort of potential EV buyers is more limited by financial constraints. Rezvani et al. [26] also underline the need to explore the symbolic meanings attached to EVs in diverse cultures, as symbolic meaning is context-dependent.

The growing popularity of electric vehicles in Poland, despite unfavourable residual value data and a limited subsidy system (as indicated in Section 2.2), suggests that non-economic factors may be more important to consumers. This assertion is the foundation of the Hypothesis H1.

Electric car sharing has recently become a more popular and frequent scheme in urban areas, even if implemented with some substantial difficulties [22]. However, its growing popularity in various cities around the world results in more drivers who have already experienced driving an electric car. This provokes another research question—to which extent does previous experience with using an electric car result in growing readiness to buy an EV? Is there any positive correlation between EV trial and consumer response in a car showroom? The main objective of the research is to develop a robust predictive model using advanced machine learning methods. This also has a practical dimension, as such a model would allow automating the identification of customers buying electric vehicles and tailoring manufacturers' products to their customers' preferences and views on green solutions.

Consequently, based on literature review, the following research hypotheses were formulated:

Hypotheses 1 (H1). *In Poland personal values and beliefs play a more important role in EV purchase willingness (are significant predictors) than EV features such as range or price.*

Hypotheses 1 (H2). *Previous experience with electric car sharing has a positive impact on EV purchase decision: drivers who have already driven a shared EV are more likely to buy an EV in the near future.*

Hypotheses 1 (H3). *There are independent variables that, using machine learning methods such as Random Forest, will predict willingness to purchase an electric vehicle for personal use.*

2.2. Polish Government Subsidies

The Polish government adopted The National Policy Framework for the Development of Alternative Fuel Infrastructure in 2017. This framework implemented the EU Directive 2014/94/EU on the development of alternative fuel infrastructure [57]. Consequently, in 2018 the Ministry of Energy announced "Electromobility Development Plan in Poland 'Energy for the Future'" [58]. The subsidy scheme described below is part of a package aimed at supporting the development of electromobility in Poland.

In Poland, the electric car market is still at a very early stage of development. However, the COVID19 outbreak did not slow it down: as Rokicki et al. observed, the dynamics of introducing electric cars into use increased in 2021 in all EU countries, including Poland [18]. In 2021, an electric vehicle subsidy scheme called "My EV" ("Mój Elektryk" in Polish) was announced to promote zero-emission mobility. The main characteristics of this program are provided in Table 1.

Table 1. Details of "My EV" scheme for individual buyers, launched by the Polish government in 2021.

Feature	Data	Comments
Period of availability	1 May 2020–31 December 2025	Cars must be registered before 31 December 2025
Available amount of subsidy	18,750 PLN [1] /27,000 PLN [2]	Bigger subsidy for families with 3 and more children
Limit of car price	225,000 PLN [3]	No limit for families with 3 and more children
Eligible cars	EV, hydrogen	Around 37 models available in 2022, varying from Dacia Spring to Tesla 3 or Ford Mustang Mach-e
Weakness	Consumer must pay the whole price and then apply for a subsidy	Requires covering the whole cost initially

[1] Exchange rate (22 March 2022): 1 EURO = 4.7460 PLN; 1 USD = 4.2982 PLN. [2] Around 3950 EURO/5689 EURO or 4362 USD/6281 USD. [3] Around 47,408 EURO/52,347 USD. Source: own study, based on the program details [59].

At the very beginning there were only a few cars eligible for the subsidy [60]. With the widening of electric models available on the market, there are now around 37 models that could be co-financed by "My EV" scheme. The vast array of offers could account for increased dynamics of EV new registrations in Poland during the COVID-19 pandemic. However, these dynamics may be difficult to sustain in the years to come as continuous difficulties with supply chains and market shortages (especially regarding electronic components, crucial for the modern automotive industry) are still observed. Prolongation of the subsidy scheme beyond 2025 is likely to happen.

The authors of this study share the view of Sendek-Matysiak and Grys [61] that the system of supporting demand for electric cars in Poland is insufficient. The scope of required changes includes subsidies for EVs purchase regardless of their price, and tax relief defined as a significant reduction in the price of the car immediately at the time of purchase.

3. Materials and Methods

3.1. Recruitment of Participants and Study Procedure

This paper is a result of a larger project initiated in connection with the study of e-mobility in Poland (the project was carried out between 2019 and 2021). The research presented in this paper focuses on predicting the likelihood of purchasing electric cars by individuals. For this purpose, the authors set the following research hypotheses:

Hypotheses 1 (H1). *In Poland personal values and beliefs play a more important role in EV purchase willingness (are significant predictors) than EV features such as range or price.*

Hypotheses 1 (H2). *Previous experience with electric car sharing has a positive impact on EV purchase decision: drivers who have already driven a shared EV are more likely to buy an EV in the near future.*

Hypotheses 1 (H3). *There are independent variables that, using machine learning methods such as Random Forest, will predict willingness to purchase an electric vehicle for personal use.*

Choosing an adequate method to predict consumer behaviour in terms of propensity to purchase electric vehicles and evaluating the importance of different features is crucial to evaluate the classification process. Desk research was used to verify Hypothesis H1. On the other hand, linear regression and log-log regression models were used to test Hypothesis H2.

Then, to verify Hypothesis H3, an ensemble learning technique was applied by testing four popular algorithms. A Random Forest (RF) ensemble learning technique was chosen as the classifier because it can provide excellent classification performance in an efficient way and evaluate the importance of input features. Literature review revealed that no such advanced econometric modelling has been applied in the literature so far. In the literature, statistical methods used to evaluate social and economic factors to-date include: simple descriptive statistics [32], joint model estimation [30], application of discrete choice mode using adaptive Lasso methodology, binomial logit regression and ordered logit regression [34], and cross-tabulation analysis [38].

The empirical material used in this study was collected between January 2021 and August 2021 to describe the preferences of urban residents regarding e-mobility. An online survey questionnaire was used. The survey was developed using Survio software. Respondents were able to access the survey questionnaire via a link. The invitation to participate in the survey was posted on social media (e.g., the project's Twitter, FB and LinkedIn) on the university websites and sent from the email box of the university dean's office. The authors also used the snowball method [62,63], which involves non-random sampling and recruitment of participants by other participants to quickly increase the size of the research sample. This also allowed to reach respondents in the absence of a census. The authors are aware of the disadvantages of this method in terms of the representativeness of the research sample, but due to the nature of the study, this did not negatively affect the results. The criterion for inclusion in the research sample was age (over 18 years) and residing in Poland.

The survey consisted of 31 questions of closed and semi-closed type. Question 1 asked about a license to drive passenger cars. Questions 2–5 and 7–10 were metric questions. They were designed to elicit responses regarding the socio-demographic characteristics of the respondent such as: (1) gender, (2) age, (3) place of residence, (4) type of housing in the place of residence, (5) education, occupational status (working, retired, etc.), (6) sector of work, and (7) financial situation. Question 6 asked about the ability to charge an electric car at a residence. Questions 11–31 addressed, among other things, the modes of transportation used by respondents and the frequency, the type of propulsion system used for EVs, car sharing, factors that determine EV purchase, etc.

3.2. Study Participants

The research group (Table 2) included 198 residents of cities with a population of more than 50,000 (42.93% of them were men, 57.07% of them were women, 1.52% of them were non-binary persons), aged above 18 (the mean age was 33 years). The majority of respondents are from urban areas of more than 500,000 population (52.02%), of which 24.24% (54 respondents) are female and 24.24% (48 respondents) are male.

The research sample does not reflect the characteristics of the Polish population: better educated and wealthier people are overrepresented among the survey respondents. The predominance of women in the research sample is also apparent, as are student/unemployed respondents. For those reasons, the research presented here has some limitations, which are elaborated further in Section 5. However, the purpose of the survey conducted (data set in Table 2) among Polish respondents was not to obtain a representative sample. Instead, the purpose of the survey was to obtain as many respondents as possible who are characterized by different levels of interest in purchasing electric vehicles by 2024.

3.3. Research Tools

A survey examining respondents' preferences for purchasing an electric car and a sociodemographic metric were used to measure the variables included in the presented portion of the study.

First, a machine learning (ML) model was developed to predict willingness to purchase an electric car. The data for analysis was prepared using a method that involved removing variables with a high missing value coefficient and partially removing the effects of imbalance in the resulting set (oversampling). This allowed the training set to be trained to remove the effects of the imbalance. In this way, model estimation was possible.

Table 2. Selected socio-economic characteristics of the sample N (N = 198).

Category	Variable	N	%
gender	male	85	42.93
	female	110	55.56
	nonbinary	3	1.52
age	18–34	105	53.03
	35–44	56	28.28
	45–59	26	13.13
	≤60	11	5.56
population of respondent's place of residence	Countryside to 100 k *	62	31.31
	100–500 k *	33	16.67
	more than 500 k *	103	52.02
type of building that respondent lives in?	single-family house/terraced house/semi-detached house	99	50.00
	multi-family building	99	50.00
the highest degree or level of school	none/elementary school/vocational school	31	15.66
	high school degree	115	58.08
	University/college degree/Doctoral degree	51	25.76
employment status	student/Unemployed	52	26.25
	employed/Self-employed	116	58.59
	retired/pensioner/Rentier (a person of leisure)/other	10	15.15
subjective assessment of respondent's financial situation	Sometimes, we are not able to pay for costs of living (rent, utilities, etc.)	8	4.04
	We earn enough to cover the costs of living, and from time to time we can either save money or afford extra expenses.	96	48.48
	Every month we can afford extra expenses, and we can regularly save part of our income	94	47.47

* or a dormitory own/ suburbs close to the town of a given size.

The twelve steps of the statistical part of the research procedure are shown in Figure 3.

In the next step, logistic and linear regression models were performed. This allowed us to predict the reasons for purchasing an electric car based on factors such as: (1) age, (2) gender, (3) education, and (4) place of residence. In the last step with χ^2 test of independence, the research hypothesis was tested. The global significance level was $\alpha = 0.05$.

3.4. Data Analysis

Based on the literature review, the authors predicted that in countries with low levels of EV uptake (like Poland), it is the more affluent consumer groups that become EV early adopters. Their purchase decisions are often driven by non-economic factors (e.g., status signalling), without performing a financial profitability calculation (including total cost of ownership or residual value of a car). This is because the influence of values and beliefs of such consumers is greater, as well as the behaviours observed years ago by Thorstein Veblen (demonstration effect). This prediction was the basis for the formulation of the first hypothesis.

Due to the adoption of such an approach, the authors distinguished several factors to be included in the study, which described the values adhered to by the respondents. Furthermore, based on Hofstede's concept (the influence of the cultural dimension: masculinity vs. femininity), the authors attempted to determine whether the gender of the respondent would influence purchase decisions. Value-based factors were contrasted with other rationales for purchasing an EV (e.g., place of residence, access to a car charger). In addition, due to the authors' previous findings that experience with EV use can influence willingness to purchase an EV, the authors wanted to verify whether previous experience with electric car sharing would have a similar impact in the case of Poland.

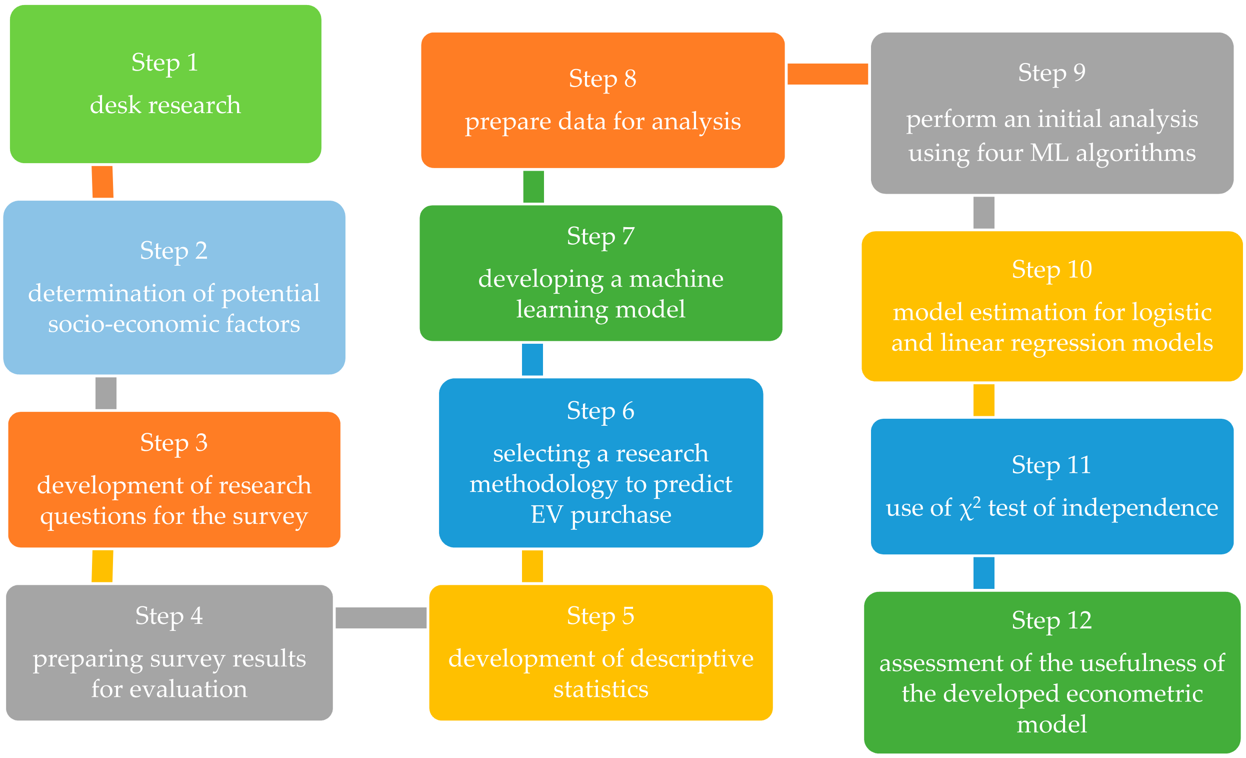


Figure 3. Multi-step research approach.

ML was conducted to answer Hypothesis H1 regarding the evaluation of the influence of personal values and beliefs have on the propensity to purchase electric vehicles.

The following factors were specified to verify the research Hypotheses H2 and H3:

(1) social: gender, age, place of residence, type of housing
(2) economic: access to a charger, subjective assessment of material situation, type of propulsion of the car used.

These variables were used for the logistic model and linear regression.

The R programming language and RStudio software [64] were used to perform the analyses and statistical calculations. Three packages: tidyverse [65], caret [66], and psych [67], were also imported to provide additional tools for the study.

4. Results

4.1. Machine Learning—An Algorithm for Predicting Electric Car Purchase Readiness

In order to predict the purchase of an electric car, machine learning (ML) techniques were used to develop a statistical model. The data extracted from the questionnaire was used for this purpose. First, variables (black dots in Figure 4) with more than 20% missing values (values below the red line in Figure 4) were removed from the dataset. The percentage of missing values is shown in Figure 4. The red line shows the 20% measurement cutoff value of the variables. Random Forest (RF) methodology is explained in detail in the literature [68–70].

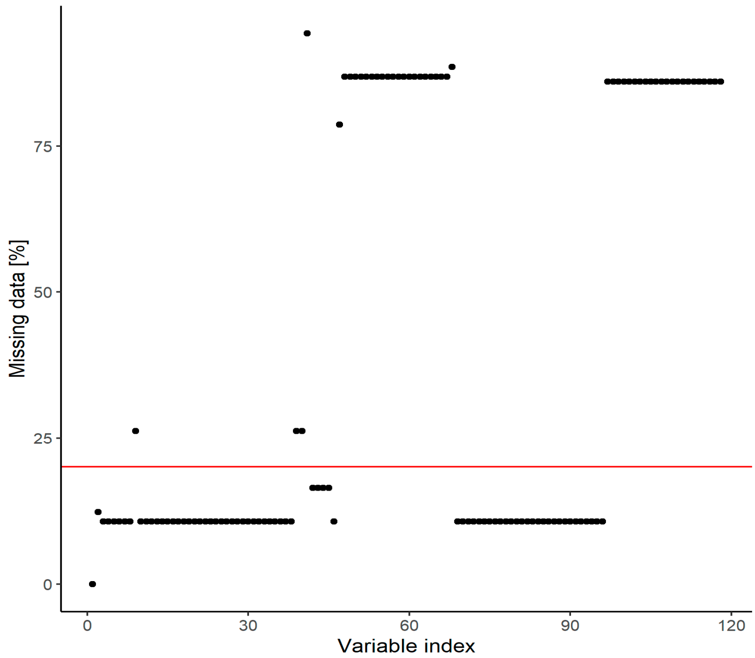


Figure 4. Percentage of missing values for each variable in the data set.

The survey also asked: Are you planning to buy an electric car by the end of 2024? Possible responses to the question about willingness to purchase an electric car were: (1) Yes, (2) No, (3) Hard to say. The following was taken as the explanatory variable (1): I plan to purchase an electric car by the end of 2024. Given this, all responses from group (3) were removed from the dataset. The other two classes were highly unbalanced, so the oversampling method was used. Then, the dataset was divided into a training (70%) and a test dataset (30%).

To develop an algorithm to predict of the readiness to purchase a private electric car, the algorithm with the best initial performance was used. For this purpose, a preliminary analysis was conducted using four popular machine learning (ML) algorithms. The following algorithms for the study were used:

(1) classification and regression trees (cart),
(2) k-nearest neighbour (knn),
(3) support vector machine (svm),
(4) random forest (rf).

The quality of the models was evaluated using measures of accuracy and kappa. All algorithms were run using 10-fold cross-validation. The Random Forest algorithm achieved the best performance, while the k-nearest neighbour algorithm achieved the lowest performance. Performance comparisons are shown in Figure 5.

The Random Forest algorithm obtained the best results with a mean accuracy of 98.67% and κ of 96.00%. Therefore, the Random Forest algorithm was selected for further analysis (Table 3).

The model was then tuned using the value of the mtry parameter (i.e., the number of variables randomly sampled as candidates at each split). The accuracy measures that depend on the value of the mtry parameter are shown in Figure 6.

The optimal value of the mtry parameter (number of variables randomly sampled as candidates at each split.) was 8. Finally, the model was fitted and its accuracy was evaluated. The confusion matrices on the training and test data sets are shown in Tables 4 and 5.

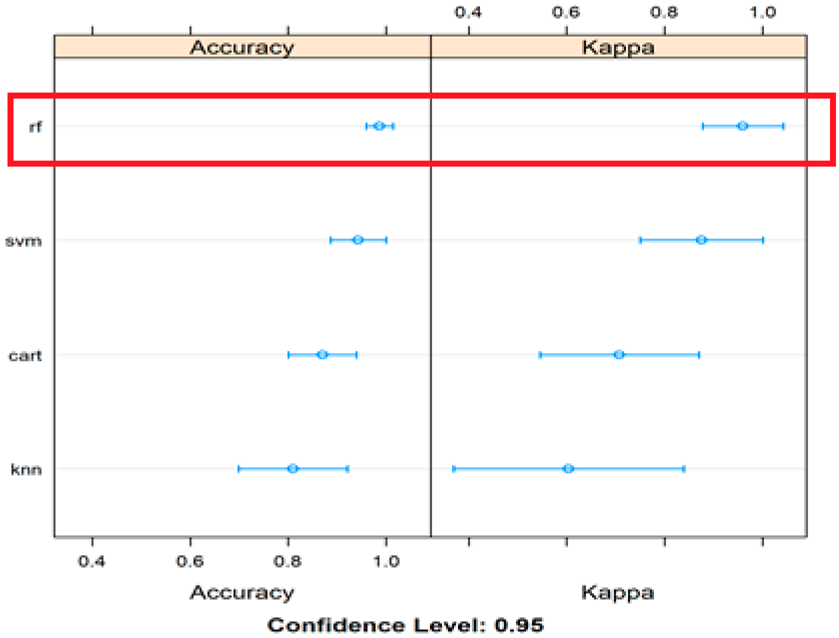


Figure 5. Comparison of different machine learning algorithms; rf—Random Forest, svm—Support Vector Machine, cart—classification and regression trees, knn—k-nearest neighbour.

Table 3. Results of accuracy and kappa values for algorithms: cart, knn, svm, rf.

			Accuracy				
Models	**Min**	**1st Qu**	**MD**	**Mean**	**3rd Qu**	**Max**	**Na's**
cart	0.5000000	0.6666667	1	0.8700000	1	1	0
knn	0.5000000	0.6666667	1	0.8300000	1	1	0
svm	0.5000000	1.0000000	1	0.9433333	1	1	0
rf	0.6666667	1.0000000	1	0.9866667	1	1	0
			Kappa				
cart	0	0.4	1	0.708	1	1	0
knn	0	0.4	1	0.644	1	1	0
svm	0	1.0	1	0.876	1	1	0
rf	0	1.0	1	0.960	1	1	0

Table 4. Training dataset—purchase of EV car—prediction and observation.

Training Dataset—Purchase of EV Car		**Prediction**	
		Yes	**No**
Observation	Yes	38	0
	No	0	38

Note: accuracy = 100.00%, 95% CI = [95.26–100.00%], specificity = 100.00%, sensitivity = 100.00%. Source: own study.

Table 5. Confusion matrix and model quality measures; test dataset.

Test Data Set—Prediction of Electric Car Purchase		**Prediction**	
		Yes	**No**
Observation	Yes	15	0
	No	1	16

Note: accuracy = 96.88%, 95% CI = [83.78–99.92%], specificity = 100.00%, sensitivity = 93.75%.

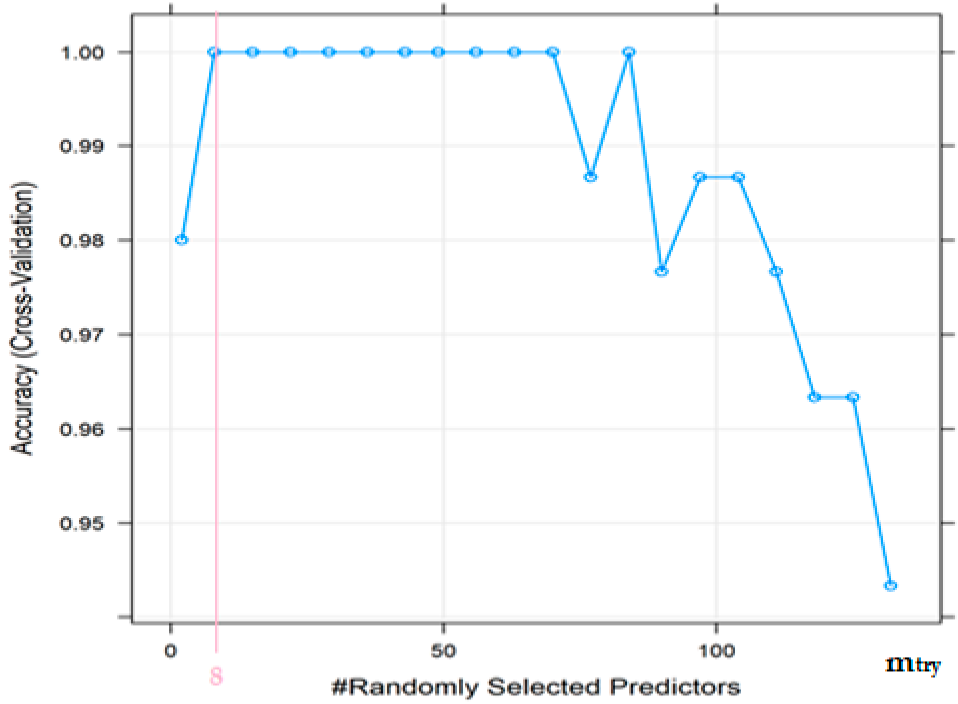
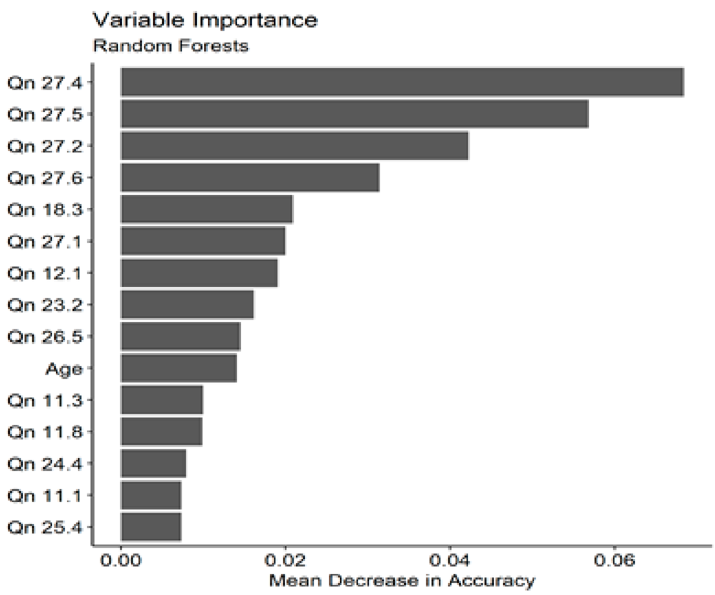


Figure 6. The accuracy of the Random Forest model as a function of the value of the mtry parameter.

Detailed accuracy and kappa values for the four algorithms tested are shown in Table 3.

The model fit was very good. Except for the test and training sets, the accuracy did not differ significantly, so no overfitting occurred. The selected parameters were then optimized to improve the performance of the algorithm. Fourteen variables with the highest predictive value in the model were plotted. This is shown in Figure 7. The greater the value of "mean Decrease in accuracy" (*x*-axis) is, the greater is the influence of the variable under study on the prediction of EV purchase intention.



Q_n—number of question.

Figure 7. Relative importance of variables in the final Random Forest model.

In turn, a description of the variables used in the study is presented in Table 6.

Table 6. Description of the relative importance of the variables in the final Random Forest model with variable importance.

Question [Qn]	Variable Name	Variable Importance
Qn. 27	**Respondents' response to the statements**	
Qn. 27.4	Choosing an electric car is pointless due to the "dirty" energy sources in our country.	**1**
Qn. 27.5	In 10 years, electric cars will replace gasoline (petrol) and diesel cars	**2**
Qn. 27.2	I would be better off travelling in a more environmentally friendly way	**3**
Qn. 27.6	If my employer would organize a ride for a few people from home to work, using electric vans (e.g., vanpooling), I would use this option regularly.	**4**
Qn. 27.1	Using cars causes many environmental problems	**6**
Qn. 18	**Have you ever driven an alternatively powered car**	
Qn. 18.3	100% electric	**5**
Qn. 12	**What form of transportation was used most often before COVID-19 to accomplish life activities.**	
Qn. 12.1	Running errands	**7**
Qn. 23	**Respondent's preferred model of organizing electric car sharing**	
Qn. 23.2	Part of an integrated transport system in a city, available for a single charge (so called Mobility as a Service)	**8**
Qn. 26	**Respondents' assessment of additional billing options with the electric car sharing operator**	
Qn. 26.5	Bonus (5 free minutes) for connecting the car to the charging station	**9**
Qn. 3	**Age**	**10**
Qn. 11	**Frequency of respondent's choice of a particular mode of transportation for daily travel (to work, shopping, etc.) prior to COVID-19 pandemic**	
Qn. 11.3	Streetcar	**11**
Qn. 11.8	Own bike/scooter/scooter	**12**
Qn. 11.1	Private car (as passenger)	**14**
Qn. 24	**Respondent's preferred method of payment for electric car sharing services**	
Qn. 24.4	Car sharing available as part of a mobility subscription (for all urban and shared transport modes), i.e., a Mobility as a Service (MaAS) that bundles a whole package of mobility services within a single application and fee. The fee depends on the profile/basket of services defined by the user.	**13**
Qn. 25	**Respondents' preferred method of billing the electric car sharing operator**	
Qn. 25.4	Payments based on time of use and distance travelled	**15**

The greatest relative importance of the variables in the final Random Forest model for predicting the willingness to purchase an electric car is described from 1 (greatest variable influence on the model) to 14 (least variable influence on the model).

4.2. Determinants of Electric Vehicle Purchase

The basic characteristics of the respondents and their relationship with the willingness to purchase an electric car for personal use are presented in Table 7.

Table 7. Respondents' stated plans to purchase an electric car for personal use.

Questions	Value	Yes	N%	No	N%	No Sure	N%
Are you planning to buy an electric car by the end of 2024?	**total**	29	15%	106	54%	63	32%
Gender	female	16	8%	56	28%	38	19%
	male	11	6%	50	25%	24	12%
	nonbinary	2	1%	0	0%	1	1%
	total	**29**	**15%**	**106**	**54%**	**63**	**32%**
Type of building that you living?	single-family house/terraced house/semi-detached house	18	9%	47	24%	34	17%
	multi-family building	11	6%	59	30%	29	15%
	total	**29**	**15%**	**106**	**54%**	**63**	**32%**
Age	18–34	9	5%	63	32%	33	17%
	35–44	13	7%	25	13%	18	9%
	45–59	6	3%	12	6%	8	4%
	<60	1	1%	6	3%	4	2%
	total	**29**	**15%**	**106**	**54%**	**63**	**32%**
The highest degree or level of school	none/elementary school vocational school	6	3%	17	9%	8	4%
	high school degree	13	7%	65	33%	38	19%
	University/college degree/Doctoral degree	10	5%	24	12%	17	9%
	total	29	15%	106	54%	63	32%
Place of residence	countryside to 100 k *	11	6%	32	16%	19	10%
	100 k–500 k *	5	3%	14	7%	14	7%
	more than 500 k *	13	7%	60	30%	30	15%
	total	29	15%	106	54%	63	32%
Subjective assessment of your financial situation	we are usually unable to cover basic costs of living/sometimes, we are not able to pay for costs of living	2	1%	2	1%	4	2%
	we earn enough to cover the costs of living, and from time to time we can either save money or afford extra expenses.	12	6%	52	26%	31	16%
	every month we can afford extra expenses, and we can regularly save part of our income	16	8%	51	26%	28	14%
	total	**30**	**15%**	**105**	**53%**	**63**	**32%**

* k—means a thousand.

The results obtained (Table 7) indicate that when it comes to planning a purchase of an electric car, only 15% of the respondents are planning such a purchase by 2024 and 32% have no opinion yet. As many as 54% of respondents (28% male and 25% female) responded that they are definitely not planning to purchase an electric car by 2024.

Among residents of multi-family buildings, 30% are definitely not planning to buy an electric car, and 15% have no opinion in this regard. In contrast, most 35–44 year olds plan to purchase an electric car, while as many as 32% of 18–34 year olds definitely do not plan such a purchase by 2024.

Among those living in cities over 500 K, as many as 30% do not have any plans to purchase an electric car, with 15% having yet to make a decision in this regard. Interestingly, as many as 52% of respondents describing their material situation as good (26%) and very good (26%) definitely do not plan to purchase an electric car by 2024, and only 14% declare their intention for such a purchase.

In order to further specify the determinants of electric vehicle purchase by individuals, logistic and linear regression analyses were conducted. This allowed us to determine whether factors such as gender, age, education, and/or place of residence (location) differentiate individuals' reasons for purchasing an electric vehicle. Coefficients of significance and r^2 were used as qualitative measures.

Questions 29 and 31 are nominal dichotomous variables that were answered 'yes' or 'no'. To assess the effect of independent variables on nominal variables, three models were tested: (1) age + gender, (2) education + gender, (3) location + gender. Ten linear models were shown to be statistically significant. Variables highlighted in yellow were found to be statistically significant, meaning that they are relevant to preferences (Table 8).

Table 8. Logistic regression results for the question about the decision to buy an electric car (for questions 29 and 31).

Dependent Variable	Independent Variables	Test χ^2	p (Probability Level)	Precision
Qn 29.1. Operating costs	Age + gender	2.59	0.274	0.67
	Education + gender	1.84	0.399	0.67
	Location + gender	1.78	0.410	0.67
Qn. 29.2. Ecology	Age + gender	4.01	0.134	0.80
	Education + gender	10.81	0.005	0.87
	Location + gender	2.66	0.264	0.80
Qn 29.3. Cost-offsets and benefits *	Age + gender	13.55	0.001	0.87
	Education + gender	11.74	0.003	0.87
	Location + gender	8.05	0.018	0.80
Q 29.4. Advantages advantages of electric propulsion **	Age + gender	5.03	0.081	0.73
	Education + gender	2.96	0.228	0.73
	Location + gender	2.84	0.242	0.73
Qn 29.5. Prestige/fashion	Age + gender	7.35	0.025	1.00
	Education + gender	7.35	0.025	1.00
	Location + gender	7.35	0.025	1.00
Qn 31.1. Purchase cost/price	Age + gender	4.51	0.105	0.87
	Education + gender	2.32	0.314	0.80
	Location + gender	2.61	0.271	0.80
Qn 31.2. Battery range/capacity	Age + gender	7.35	0.025	1.00
	Education + gender	7.35	0.025	1.00
	Location + gender	7.35	0.025	1.00
Qn 31.3. Appearance and design (color, aesthetics)	Age + gender	0.86	0.650	0.80
	Education + gender	0.69	0.709	0.80
	Location + gender	3.13	0.209	0.80
Qn 31.4. Environmental friendliness of the car	Age + gender	1.77	0.413	0.67
	Education + gender	3.22	0.200	0.80
	Location + gender	1.84	0.399	0.67
Qn 31.5. Equipment	Age + gender	1.57	0.455	0.80
	Education + gender	0.12	0.940	0.60
	Location + gender	0.06	0.969	0.60
Qn 31.6. Power, performance	Age + gender	0.46	0.795	0.53
	Education + gender	0.14	0.935	0.60
	Location + gender	1.94	0.379	0.73
Qn 31.7. Vehicle make ***	Age + gender	1.07	0.584	0.80
	Education + gender	3.56	0.168	0.67
	Location + gender	5.47	0.065	0.73
Qn 31.8. Segment/class of car	Age + gender	1.60	0.448	0.80
	Education + gender	0.19	0.910	0.73
	Location + gender	2.96	0.228	0.80
Qn. 31.9 Possibility to take advantage of government subsidies	Age + gender	0.29	0.867	0.60
	Education + gender	4.26	0.119	0.73
	Location + gender	1.17	0.556	0.67

* Abatements and privileges (free parking, ability to drive in bus lanes, purchase subsidies, etc.). ** Advantages of electric drive (quietness, acceleration, etc.). *** Vehicle brand (prestige, guarantee of quality).

Responses to questions 30 were responses assigned according to a scale from 1–4. The results are presented in Table 9.

Table 9. Factors adversely affecting EV purchase decisions.

Dependent Variable	Which Factor Argues Most Strongly against an Electric Car Purchase Decision?							
	Rating Scale							
	1		2		3		4	
	N	%	N	%	N	%	N	%
Qn. 30.1. Price	152	77%	41	21%	4	2%	1	1%
Qn 30.2. Lack of a sufficiently developed charging infrastructure	29	15%	50	25%	34	17%	85	43%
Qn 30.3. Too short-range	52	26%	89	45%	39	20%	18	9%
Qn 30.4. Charging time too long	34	17%	3	2%	34	17%	127	64%
Qn 30.5. No suitable car offer	4	2%	9	5%	51	26%	134	68%

where: 1—the biggest disadvantage, the 4—the least important disadvantage.

In the Ecology domain (Qn 29.2), independent variables such as education + gender or location + gender do influence the decision to purchase an electric car. In the area of Cost-offeset and benefits (Qn 29.3), independent variables such as age + gender, education + gender, and location + gender do influence the decision to purchase an electric car. In the Prestige/fashion area (Qn 29.5), independent variables such as age + gender, education + gender, and location + gender do influence the decision to purchase an electric car. In the area of Battery range/capacity (Qn 31.2), independent variables such as age + gender, education + gender, and location + gender do influence the decision to purchase an electric car.

The logistic regression model for question Q 29.5 and Qn 31.2 demonstrates 100% explanation of the effect of the independent variables by the explained nominal variable. For the other variables (Qn 29.2 and Qn 29.3), the accuracy of the model was between 0.80 and 0.87.

In other areas (Qn. 29.1, partly Qn.29.2, Qn. 29.4, Qn 31.1, Qn 31.3–Qn. 31.9) independent variables such as age + gender, education + gender and location + gender do not influence the decision to purchase an electric car. Linear regression models showed a lack of statistical significance.

In response to the question Qn 31 (Table 9: Which factor argues most strongly against an electric car purchase decision?), as many as 77% of respondents indicate price and too short a range (26%). On the other hand, the least important factors influencing the decision against EV purchase are: “lack of suitable car offer” (68%) and “charging time too long” (64%).

In contrast, the linear regression results indicate that the independent variables: (1) age + gender, (2) education + gender, and (3) location + gender are not statistically significant in explaining discouraging effects on electric vehicle purchase decisions. None of the models tested showed statistical significance (Table 10).

Table 10. Linear regression results for factors that least influence electric vehicle purchase abandonment (for question 30).

Dependent Variable	Independent Variables	F *	P *	$R^2_{adj.}$ *
Qn. 30.1. price	Age + gender	0.45	0.649	−0.09
	Education + gender	0.45	0.649	−0.09
	Location + gender	2.37	0.136	0.16
Qn 30.2. Lack of a sufficiently developed charging infrastructure	Age + gender	0.24	0.787	−0.12
	Education + gender	0.40	0.680	−0.09
	Location + gender	0.15	0.862	−0.14
Qn 30.2. Too short-range	Age + gender	2.02	0.175	0.13
	Education + gender	1.24	0.324	0.03
	Location + gender	2.94	0.092	0.22
Qn 30.3 Charging time too long	Age + gender	0.10	0.905	−0.15
	Education + gender	0.15	0.861	−0.14
	Location + gender	1.24	0.323	0.03
Qn 30.4 No suitable car offer	Age + gender	2.64	0.112	0.19
	Education + gender	0.08	0.923	−0.15
	Location + gender	0.18	0.838	−0.13

* F—value of the statistic, p—probability level, $R^2_{adj.}$—adjusted R-square. Ten linear models were shown to be statistically significant.

4.3. Car-Sharing Use and Willingness to Purchase an Electric Car

A χ^2 independence test was used to test whether there was a significant relationship between past car-sharing use and willingness to purchase an electric car, and the results are presented in Table 11.

Table 11. Car-sharing use according to willingness to purchase an electric car.

Have You Ever Used Car Sharing?	Parameter	Are You Planning to Purchase an Electric Car?	
		No	Yes
No	n	42	7
	%	85.71	14.29
Yes	n	13	10
	%	56.52	43.48
$\chi^2(1) = 1.21$; $p = 0.271$; $V = 0.16$			

The test was not statistically significant, which means that there is no relationship between the former usage of car-sharing services and the desire to purchase an EV.

5. Discussion

Based on the research conducted, it can be concluded that there are few socioeconomic factors that can be used to predict consumer behaviour in terms of willingness to purchase an electric car. These are: age, gender, place of residence and education. For this purpose, Random Forest proved to be the most accurate method (the other methods—cart, k-nearest neighbour, and support vector machine—were less accurate). This validated research Hypothesis H3: There are independent variables that, using machine learning methods such as Random Forest, will predict willingness to purchase an electric vehicle for personal use.

The research shows that the person who is the most likely to buy an EV by 2024 is characterised by the following qualities: female, aged 35–44, employed or self-employed and living in a city over 500 K. Conversely, the person least likely to plan to buy an EV by 2024 is: male, aged 18–34, working or self-employed and living in a city over 500 K. The study by Novotny et al. [42] also proved that masculinity has a significant negative impact on BEV sales. This is consistent with the results of the previously-cited German study [41], which found that residents of large cities who were more likely to be assigned a green identity (e.g., working men), were not as willing to switch to zero-emission cars. That observation is in accordance with Tindall et al. [67] who discerned that women, on average, are much more likely to be environmentally friendly in their private sphere—when it comes to purchasing decisions, separating waste at home, or limiting the use of a car for the sake of clean air [67]. According to the cited authors, this is due to existing societal beliefs that pro-environmental products and behaviours are considered feminine and men do not want to be associated with them because they are most likely afraid of losing their gender identity. They are more likely to take environmental action if it validates their masculinity. This may be an important clue for companies involved in creating and promoting environmental products and attitudes [67].

In the light of this finding, EV manufacturers should advocate environmental protection and green life issues to increase consumers' cognition and preference for EVs. Targeted information and education campaigns on the incentives for using EVs and introducing more attractive battery and charging systems are needed. This recommendation is in line with postulates of Schuitema et al. [39]. As Machová et al. stated [68], informing and educating consumers plays a crucial role in influencing them to purchase environmentally friendly products.

The findings of the "New Mobility Barometer" study [12] noted that considering an EV purchase while looking for a new car does not necessarily translate into a decision to buy one. In contrast, the authors did not confirm the findings of the UK study [40] that EV purchase intention increases among younger people who are students or unemployed.

The H2 hypothesis could not be confirmed: the study did not prove that previous experience with electric car sharing has a positive impact on EV purchase decision. These results are consistent with the earlier study by Jensen et al. [35], which found that individual preferences of consumers who experienced electric vehicle driving during a three-month trial period did not translate into a purchase decision.

It was found that the factors that stimulate the decision to purchase an electric car to the highest extent are: (1) Purchase cost/price, (2) Appearance and design (colour, aesthetics), (3) Car segment/class, (4) Equipment, (5) Electric drive advantages. In this case, these decisions are differentiated by factors such as age, gender, education, and place of residence. According to the latest "New Mobility Barometer" report, Poles will be willing to buy an EV if it is 22% cheaper [12]. Upfront cost of EV was confirmed to be a strongly influential factor in several studies [69–73]. This underscores that the price of EVs is a key factor in the choice of the average consumer and, consequently, that subsidy schemes will play an important role in strengthening the demand side in coming years.

The factors that are less influential in the decision not to purchase an electric vehicle were identified as (1) Operating costs, (2) Cost-offsets and benefits, (3) Advantages of electric propulsion. The impact of these factors is differentiated by factors such as age, gender, education and place of residence. This is particularly important from the point of view of shaping information policy both at the level of government administration and companies involved in promoting pro-environmental solutions. Conversely, regression models used by Brase [2] indicated that predictors of vehicle choices concerns were about the performance and range of EVs, EV prevalence in general, and beliefs about what message different car types brought about their owners and the owners' values.

On the other hand, the results of the study indicate that some factors regarding the purchase of an electric vehicle are statistically significant and may predict consumers' decision to purchase an electric vehicle. These are the following factors or beliefs/attitudes of the respondents: (1) positive green attitude, (2) cost-offsets and benefits (3) prestige/mode, and (4) range/battery capacity. In this case, independent variables such as age + gender, education + gender, location + gender were significant. Similar results on battery life were obtained by Gurudath and Rani [45] on a sample of 126 respondents from India.

Although the relationship between previous use of car-sharing services and willingness to purchase an electric car was not confirmed, factors such as age, education and financial situation will influence the decision to purchase an electric car. It is likely that the decision to purchase an electric car is also influenced by the general trend of using green modes of transportation and the need to care for the environment.

The research showed that as many as 77% of the respondents indicated that the price of an electric car is the factor that most strongly argues against the decision to purchase one. A similar result was obtained in the other studies (cf. [13,74]). This leads to a political recommendation that a suitable and efficient subsidy system, inclusive for the less well-off, is needed if governments expect to achieve a massive shift towards zero-emission individual mobility. This advice is consistent with the recommendations of other authors, previously cited in this article [57,61]. Evidence from Norway, a global forerunner in the field of electromobility and the BEV market share, shows that strong incentives for promoting purchase and ownership of BEVs are essential. Findings by Bjerkan et al. [75] clearly support the significance of incentives for reducing purchase costs (e.g.,: exemption from VAT and purchase taxes).

Too short EV range was second important obstacle for potential EV buyers (26% of respondents). On the other hand, "lack of suitable car offer" and "charging time too long" were considered the least important factors (68% of respondents).

The results obtained by the authors using the Random Forest model allow us to conclude that the most important consumer beliefs/claims supporting or discouraging plans to purchase an electric car by 2024 are the following:

(1) It makes no sense to choose an electric car because of the "dirty" energy sources in our country.
(2) In 10 years, electric cars will replace gasoline and diesel cars.
(3) It would be better if I travelled in a more environmentally friendly way.
(4) If my employer arranged rides for several people from home to work using electric vans (e.g., vanpooling), I would use this option regularly.

Therefore, using a Random Forest algorithm can help automate the identification of customers buying electric vehicles and tailor manufacturers' products to their customers' preferences and views on green solutions.

The results of this study regarding the belief in the environmental impact of EVs (3) as a determinant of purchase intention are in line with a study conducted in Norway [38].

Successful EV promulgation and making them truly zero-emission (not just locally) requires complex multidimensional public policy, including efficient support for future expansion of micro-installation of solar and wind systems. The photovoltaic boom that happened in Poland in the period of 2015–2021 (Poland then led the European Union in terms of the growth rate of photovoltaic power [76]) was possible because of (1) available grants decreasing investment costs within the "My Electricity" program (owners of single-family house were mostly targeted by the grants), (2) income tax reductions, and (3) favourable and "prosumer"-friendly billing mechanism (i.e., net-metering system).

As regards the latter: power grid operator serves as a virtual energy storage for individual producers at a cost of 20/30% of energy surplus added to the grid (20% for on-grid PV installation up to 10 kWp; 30% for the bigger ones). Net metering allows solar energy systems owners to export surplus power to the grid and reduce their future electric bills. As the authors already mentioned, the power installed in PV in Poland rocketed in last few years. Unfortunately, the backward power grid system appeared to be technologically inefficient—it could not storage the whole energy added by PV. Technical challenges surrounding on-grid energy storage resulted in a regulatory change (beginning in April 2022) shifting from net metering towards net-billing.

According to initial estimate, the new system will be less favourable for new on-grid solar energy system owners. Moreover, current grant system is addressed mainly to private owners of single-family houses, terraced houses or semi-detached houses. Taking into account that the majority of inhabitants in urban areas live in multi-family buildings, this group is excluded from this system. Therefore, lack of charging stations available for majority of city dwellers in their residences may be one of brakes for EV readiness in urban areas.

One promising direction linking "prosumer" energy storage and EVs is a solution based on the 'vehicle-to-grid' concept (V2G). This is a technology that makes good use of EVs to balance electricity demand in the power system [77]. To-date there are only a few cars with this feature available, but enhanced, collaborative efforts of the automotive industry, power grid companies, and regulators could be beneficial and effective in a relatively short term.

These changes, and many others needed to accelerate EV uptake, will require some support at the EU, national and regional levels, and local levels, particularly in terms of developing and implementing appropriate financial incentive policies and large investments in infrastructure. As Bobeth and Kastner pointed out, broader policy support programs are also needed for the uptake of electric vehicles [47].

This also requires amendment of the Fitfor55 package adopted by the European Union, which identifies electric mobility as a pillar of transport decarbonization. This amendment should concern more rapid implementation of legislative changes and an increase in financial outlays, which would have an enormous impact on the development of electromobility. At the same time, the authors point out that there is also a lack of extensive research on the impact and role of state and international regulatory bodies in the deployment of electric vehicles. Local policies to support EVs may also need to be explored.

Based on the findings, we the authors recommend authorities consider the following actions at the local level.

Future research is required in the field of developing efficient business models for housing cooperatives willing to equip their buildings in charging stations and PV systems. Since Polish law currently does not oblige the existing housing communities to invest in e-mobility, demonstrating their economic rationality would help to drive such legal policy changes. Transforming housing communities into lower- and greener-energy, and supporting e-mobility, requires the development of modern management tools (business models) and legal solutions in the field of the use of renewable energy sources, ensuring the profitability of this process.

6. Conclusions

This paper reviews and analyses the socio-economic dynamics of green revolution in private transportation and extends previous knowledge on sustainable mobility development in Poland. This article highlights a number of opportunities and challenges for successful promulgation of private EVs in urban areas.

In the presented research, an ensemble machine learning technique using Random Forest (RF) was applied, which is an innovative approach for this type of research. As confirmed by the results from the literature review, this type of advanced econometric modeling has not been used in the literature before.

The proposed Random Forest approach enables the prediction of consumer behaviour in terms of their propensity to purchase an electric car. It may be particularly helpful in detecting which customers are more likely to purchase an electric car. This algorithm will also help the automotive industry to operate effectively in the private electric car segment. It will help in recommending suitable products and services and predicting customer satisfaction.

The findings indicate that it is particularly important to carry out long-term information campaigns at the national and regional levels to demonstrate the advantages of electric automotive vehicles, e.g., in terms of their efficiency, technological awareness, and positive environmental impact. These conclusions are consistent with the results of the studies cited earlier [15,44,45].

In view of the research results presented herein and taking into account the current watershed moment (Russia's aggression against Ukraine driving renewed efforts for nations to become independent from fossil fuels imported from Russia, it may be expected that EV promulgation will accelerate. This will require more effective approaches on the part of EV manufacturers to more effectively move public opinion regarding the value of EV purchases for individuals as well as for society as a whole. This paper's findings demonstrate important potential target areas for those efforts.

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Abbreviations

BEV	Battery Electric Vehicle
HEV	Hybrid Electric Vehicles
ICEV	Internal Combustion Engine Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
EV	Electric vehicle
V2G	'Vehicle-to-grid' concept

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