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Future Challenges of the Electric Vehicle Market Perceived by Individual Drivers from Eastern Poland

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Abstract: In the past few years, it can be seen that the automotive market has been developing quite rapidly, especially when it comes to electric cars. This is because the development of sustainable cars seems to be an extremely important issue at the moment. Nowadays, cars with different propulsion systems (among others electric, hybrid, gas, or hydrogen) can be met on the roads. But, political action is mainly aimed at electric cars. Such an approach will certainly lead to fundamental changes in production processes in the near future via the emergence and development of new technologies in the field of electric passenger cars. Therefore, the manuscript discusses the concept of vehicles with different types of power supply, with the main emphasis on electric vehicles. The essence of electric vehicles, their genesis, rationale for development, and growth are indicated. The different markets around the world, through the prism of, on the one hand, programs supporting the purchase and use of this type of vehicle and, on the other hand, factors limiting and inhibiting their uptake, are also discussed. The research was conducted in a group of both current and potential drivers from Eastern Poland, with different categories of grouping variables used in the analyses. On the basis of the research carried out and the results obtained, it can be argued that due to various factors, the respondents' opinions are varied, and there are no unambiguous conclusions stating that such solutions will soon be available. Indeed, a number of doubts and barriers were noted among respondents. Driver preferences are therefore a key issue, but production capacity and the profitability of investments in the purchase of vehicles with an electric power supply should also be taken into account.

Keywords: sustainable transportation issues; automotive market; electric vehicles; sustainable development; hybrid vehicles; drivers' preferences and attitudes

Citation: Stoma, M.; Dudziak, A. Future Challenges of the Electric Vehicle Market Perceived by Individual Drivers from Eastern Poland. *Energies* **2023**, *16*, 7212. https://doi.org/10.3390/en16207212

Academic Editors: Byoung Kuk Lee, Paula Bajdor and Marta Starostka-Patyk

Received: 14 September 2023
Revised: 9 October 2023
Accepted: 19 October 2023
Published: 23 October 2023

1. Introduction

The automotive market has been growing rapidly in recent years. This is influenced by many different factors: economic, political, technological, environmental, and behavioral [1]. Among them, the following determinants seem to be important: the rapid development of new technologies, the introduction of many restrictive regulations in various areas of social life, changing customer preferences, as well as environmental aspects, including growing environmental awareness [2,3].

Especially the latter area is one of the key incentives for the introduction of new ideas into the automotive market, including the development of power sources [4,5]. Due to the dynamic development of the automotive market, apart from many advantages (such as fast and comfortable travel, improved road safety), it has also resulted in a massive increase in the level of air pollution, especially in highly urbanized environments, i.e., PM, nitrogen oxides (NOX), CO, sulfur dioxide (SO_2), etc. [6,7]. This information is also reflected in various indicators—according to many authors [8–10], the highest CO_2 productivity, based on production, occurs in the transport sector, which means that the highest value of GDP is generated per CO_2 emission unit.

Therefore, governments of many countries have started to take various actions in this area. An example is the COP21 conference (Paris, December 2015), where 195 countries signed an agreement to tackle climate change (especially related to global warming) in order to create a sustainable low-carbon future [2,11]. Furthermore, for the transport sector, the European Commission has set ambitious objectives for reducing CO_2 emissions by 2050—namely to achieve a reduction in greenhouse gas (GHG) emissions in the transport sector of at least 60% by 2050 compared to 1990 and the targets set out in the White Paper [12–14]. This is enshrined in two communications from the European Commission (holistic action plans): the Roadmap for moving to a competitive low-carbon economy in 2050 [15] and the Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system [14].

It should be added that in many countries around the world, a variety of additional restrictive regulations and legislation have been introduced to regulate the emission of pollutants. In the United States, for example, the "Clean Air Act" was issued in 1990—in order to achieve emission reductions, manufacturers must design and launch cleaner engines to the market, as well as provide cleaner fuel and adequate maintenance services [16,17]. In addition, in the US, each state also has its own emission control regulations. In turn, in Japan there is a law from 1992, revised in 2007, known as "NOx and PM law". To meet the NOx and PM standards set, new cars must be equipped with cleaner engines and old vehicles must be retrofitted with emission control devices [18–20]. As regards European countries, many of them have strict limits on emission factors due to the high use of diesel engines. There are also various programs that allow us to monitor the emission factor of each vehicle—an example is the "Low Emission Zone Program", created by Germany, the UK, and the Netherlands. This involved selecting cities where vehicles have to comply with the EU air quality standards [21,22].

As a result of the above regulations, and to meet market expectations, several types of cleaner technologies and power sources have been developed, including electric vehicles, hybrid electric vehicles, and hybrid fuel cell vehicles. The electrification of mobility is crucial in supporting the decarbonization of the transport sector, in particular the decarbonization of the fleet of light commercial vehicles and decoupling from oil [23]. It is worth adding that the growth of the electric vehicle market is noticeable in all sectors of the passenger car market [24].

Electric vehicles are already popular in many countries around the world; however, in Poland, especially in its eastern part, they have not yet been launched on a widespread scale, hence so few people have had any contact with all-electric drive sources so far. The concept itself also raises many doubts among current and potential drivers.

After an analysis of the relevant literature, it was noted that there are still few results of research conducted in this area of Poland, enabling the assessment of popularity, feasibility of implementation, as well as barriers to the dissemination of electric vehicles on Polish roads. It is important to note that the area of Eastern Poland, taken into account in this research and analysis, is a rather poorly urbanized, industrialized area—it is a typically agricultural region, dominated by smaller towns and rural areas, and their residents are frequently not up to date with the latest technologies.

Taking all this into consideration, the aim of the article is to examine and assess the attitudes and perception of the electric vehicles' concept by drivers from Eastern Poland in relation to their assessment of the prospects and opportunities for their development, as well as barriers and factors hindering the introduction of the analyzed concept to Polish roads.

The paper is structured as follows: Section 2 (Literature Review) provides the characteristics of the electric vehicle market. Attention has also been paid, on the one hand, to programs supporting the popularization of these types of vehicles on the roads, and on the other hand, to the factors inhibiting the development of this market. The research material and methods used during the research are included in Section 3. Then, Section 4 outlines and discusses the research results achieved. Ultimately, Section 5 provides the conclusions of the analyses and considerations undertaken.

2. Literature Review

Contrary to popular opinion, electric cars are not a new invention because they were one of the first vehicles used by people to move around. The history of the creation of electric cars dates back to the 19th century, when in the 1820s and 1830s, the first prototypes of electric vehicles were created. In 1828, Hungarian Ányos Jedlik invented a small model of a car driven with its own electric motor. Due to numerous disadvantages and imperfections (insufficient performance resulting from underdeveloped power technology), they did not gain widespread recognition and were replaced by cars with internal combustion engines in the early 20th century. Interest in the electric drive re-emerged only more than 100 years later, after World War II, thanks to the invention of the transistor. In the late 1950s, Exide battery manufacturers built a car in this technology, but it was not until the mid-1990s that they began to produce them on a larger scale [25,26], mainly in California, USA, owing to its Zero Emission Act [27]. HEV vehicles were put into limited production in 1997. PHEV vehicles were introduced into limited production in 2004 and into mass production in 2011. Electric vehicles were launched for public use in 2011 [28,29].

Among the electric vehicles, the following types can be distinguished: Battery Electric Vehicles (BEV); Hybrid Electric Vehicles—including: full hybrid (HEV), mild hybrid (MHEV), and Plug-in Hybrid Electric Vehicles (PHEV); Fuel Cell Electric Vehicles (FCEV); and Extended-Range EVs (ER-EV).

Battery Electric Vehicles (BEV) are 100% electrically powered vehicles; they do not have an internal combustion engine or fuel tank, and therefore do not rely on any type of liquid fuel [23,30]. They are powered via the current stored in the battery, so to recharge, they must be connected to a power source. A typical BEV has a range of 160 to 250 km, although some can go up to 500 km on a single charge [31,32]. The main benefit of the electric-powered engine is zero-emission gas—it does not emit any direct pollutants such as particulates, nitrogen oxides (NOx), carbon monoxide (CO), and unburnt hydrocarbons (UHC) at the tailpipe as well as over its entire life cycle [33,34]. It should be added, however, that BEVs are not completely safe for the environment because their impact on greenhouse gas (GHG) emissions is determined via the method of generating electricity used to power the vehicle [35–38].

Hybrid Electric Vehicles are another type of electric vehicles among which the following types can be distinguished: Full Hybrid (HEV), Mild Hybrid (MHEV), and Plug-in Hybrid Electric Vehicles (PHEV). A hybrid electric vehicle (HEV) is a vehicle with an alternative drive powered via a conventional internal combustion engine and an electric motor. Hybrid cars also have batteries that only recharge while driving, e.g., by recovering energy from braking. An HEV car can drive just a few kilometers on electricity. However, the interaction of the battery and the electric motor system helps to reduce emissions while allowing the vehicle to achieve greater fuel efficiency or performance compared to a conventional combustion engine vehicle [39,40]. Moreover, the addition of an electric motor allows the use of a smaller motor, which consequently results in less weight. The difference with PHEVs is that HEVs cannot be connected to the electricity grid. In turn, when comparing HEV and BEV, it seems that HEV is a better option for reducing greenhouse gas emissions than BEV.

In turn, the MHEV—Mild Hybrid Electric Vehicle—is a vehicle equipped with both an internal combustion engine and one electric motor/generator in a parallel mixture design. The electric motor cannot power the car itself as it only has a supporting function. It allows the engine to be turned off when the vehicle is stationary for more than 5 s and can restart the engine immediately when the clutch pedal is pressed again—this means that it supports the output power by quickly restarting the engine when the stop/start system is active. MHEVs have smaller batteries than regular full hybrid cars, which, on the one hand leads to their lower weight, but it does not allow for high fuel efficiency compared to a full hybrid vehicle [41–43].

In contrast, the Plug-in Hybrid Electric Vehicle (PHEV) is a combination of BEV and HEV vehicles. Like HEV, they have a hybrid drive using two engines: conventional (combustion engine) and electric. The difference between plug-in hybrids (PHEV) and hybrid cars (HEV) is that PHEV, after the battery is exhausted, can be recharged by connecting an external source of electricity [44]. It should be added that PHEVs have smaller batteries than BEVs. However, as they are equipped with a parallel hybrid drive system, they are able to accumulate enough electricity from the grid to considerably reduce fuel consumption under normal driving conditions. Plug-in hybrid electric vehicles (PHEV) ensure, on the one hand, fuel economy—compared to an internal combustion engine vehicle (ICEV)—and on the other hand, a competitive driving range in relation to a regular hybrid PHEV range in electric mode is much greater and, depending on the model as well as if it is in zero-emission mode, several dozen kilometers can be driven in a vehicle of this type [45].

As already mentioned, in addition to BEVs, PHEVs, or HEVs, in response to the requirements of the market, government, and non-governmental bodies, other solutions in the field of automotive technologies, especially power sources, have appeared. One such solution is Fuel Cell Electric Vehicles (FCEV), i.e., hydrogen-powered vehicles. These vehicles, like BEVs, are equipped with an electric motor, but they obtain energy in a totally different way. Instead of charging the battery, the FCEV stores hydrogen gas in a tank. The fuel cell in an FCEV (usually a polymer electrolyte membrane—PEM) combines compressed pure hydrogen with oxygen extracted from the air. The energy generated via this reaction (via reverse electrolysis) goes to the electric motor, which drives the vehicle, just like in the BEV. In fuel cell vehicles, as in electric cars, there are no exhaust gases as no gases are produced from the exhaust pipe. The only waste generated in the process of converting electricity is water, which is a product of hydrogen combustion [46–48].

It should be added that FCEV vehicles are more efficient than those with an internal combustion engine. In turn, referring FCEVs to other electric cars, it should be noted that hydrogen cars can be refueled in a short time because they are not charged from an energy source—it is enough to refuel hydrogen into the tank, as in combustion cars. It is also possible to charge the battery using the recuperative braking system. An additional advantage of these type of vehicles is the large range, up to several hundred kilometers. On the other hand, it is worth noting that although these types of vehicles are considered "zero emission" vehicles, most of the hydrogen is obtained from natural gas [49,50].

The ER-EV (extended-range EVs) should also be mentioned, which is often referred to as the reverse of a mild hybrid. These vehicles are very similar to BEV vehicles, as their main drive is the electric motor. However, they have an additional internal combustion engine that acts as a generator to charge the vehicle's battery, and consequently, allows us to increase the range—this solution allows the car's range to be extended to 500–600 km. It should be added that this type of motor is not attached to the wheels of the vehicle [51–54]. The biggest advantage of EREV cars is the fact that, despite the presence of a combustion engine, they are almost as ecological and energy-saving as BEVs; hence, they are considered low-emission vehicles.

Table 1 presents a brief comparison of the electric cars described above, indicating their type of drive, possible equipment with an internal combustion engine, the possibility of charging from the grid, as well as the typical, average range on an electric motor.

This article focuses on battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs).

When considering electric vehicles together, the following advantages should be pointed out, especially in comparison with traditional cars [3,55–57]: zero emissions; simpler and more compact engines, which results in cheaper maintenance; fewer breakdowns; more comfortable driving (no vibration and engine noise); and the ability to move in low emission zones (where other combustion vehicles are not allowed). Electric vehicles are not subject to the same traffic limitations and restrictions in big cities, particularly during periods of high pollution levels [58].

Table 1. Comparison of different types of electric cars.

Type of an Electric Car	Drive Source and Type	Internal Combustion Engine	Connection to the Electricity Grid	Typical Range on Electricity
BEV	100% electrically powered	No	Yes	160–250 km
HEV	powered via a conventional internal combustion engine and an electric motor	Yes	No	a few kilometers
MHEV	a vehicle equipped with both an internal combustion engine and one electric motor/generator—the electric motor has only a supporting function	Yes	No	-
PHEV	have a hybrid drive using two engines: conventional (combustion engine) and electric	Yes	Yes	about 50 km
FCEV	hydrogen-powered vehicles, equipped with an electric motor	No	No	up to several hundred kilometers
ER-EV	their main drive is the electric motor, but they have an additional internal combustion engine that acts as a generator to charge the vehicle's battery	Yes	No	500–600 km

Currently, the electric car market is developing quite dynamically in many economies around the world. However, the use of this type of vehicle varies across world economies. The popularity of electric vehicles is influenced by a variety of factors which undoubtedly include market prices, consumer demand, and accessibility of charging infrastructure, but also government policies, such as buying incentives and long-term regulatory actions (CO_2 emission regulations, fuel consumption standards, and phasing out internal combustion engine vehicles) [59].

Analyzing the global cumulative sales of electric vehicles (BEV) and plug-in hybrids (PHEV), it can be seen that in 2015–2020, there is over a 5.5-fold increase. In 2015, sales of these types of cars in the world amounted to approx. 548,000 units, and 5 years later in 2020, almost 3 million, of which 68% were only electric long-range BEVs and 32% were PHEVs' short range [24]. However, according to other authors, by the end of 2020, the number of plug-in electric cars accounted for only 1% of all passenger vehicles on the roads of the world, of which two-thirds were electric cars [60].

In turn, analyzing only European countries, it should be noted that in 2020 the cumulative sales of BEV and PHEV amounted to slightly more than 1.3 million units. At the end of 2021, there were around 5.5 million plug-in passenger cars in Europe, representing more than 32% of the global stock [59]. It should be added that according to long-term forecasts, in 2040, electric vehicles will constitute as much as 25% of all vehicles (500 million electric cars out of 2 billion cars in total) [61].

Most electric cars are sold in China [59]. In turn, the United States has the world's greatest amount of electric vehicles capable of speeds above 105 km/h (the so-called Highway capable). They are very popular especially in California, Georgia, and Hawaii. In Europe, as at the end of 2021, Germany has the largest number of plug-in cars registered since 2010, with 1.38 million units [62], followed by France, Great Britain, Norway, and The Netherlands.

Norway has the highest number of electric vehicles per capita (1 in 100 cars is an electric car) [63]. In addition, Norway has the world's largest market share of new car sales in the plug-in segment, with 86.2% in 2021 [64]. What is more, the fleet of electric cars in this country is one of the most ecological because almost 100% of electricity comes from hydropower plants. The Netherlands, on the other hand, had the highest density of electric vehicle charging stations in the world until 2019 [65].

In turn, Poland is one of the least electrified EU countries. Despite the dynamic increase in the popularity of electric vehicles in recent years, their sales have not achieved a considerable market share. The most popular drive is still "petrol" with a 41% market share. In Poland, by the end of January 2023, 67,097 fully or partially electric vehicles were registered, 63% more than a year earlier [66]. Of these, 51% are fully electric vehicles (BEV) and the rest are hybrid vehicles (PHEV). In turn, by the end of February 2023, a total of 70,263 passenger and commercial electric cars were registered in Poland—for the first two months of 2023, their number increased by 5056 units, i.e., 56% more than in the same period of 2022 [67] Thus, although the number of such vehicles is growing at an ever-increasing pace, it remains significantly below the government's objectives, which initially envisaged that approximately one million electric vehicles could be observed on Polish roads by the end of 2025 [68]. However, in 2019, the government reduced its target to 600,000 electric and hybrid vehicles until the end of 2030 [69].

Based on the available statistical data (Polish Automotive Industry Association (PZPM) and Polish Alternative Fuels Association (PSPA)), information on the number of newly registered electric cars (new and used) in the period of January–June 2021 and in the same period in 2022 has been provided. The data are presented in Figure 1. An increase in registered vehicles by 41% was observed here, from 8208 units (in 2021) to 11,595 units (in 2022).

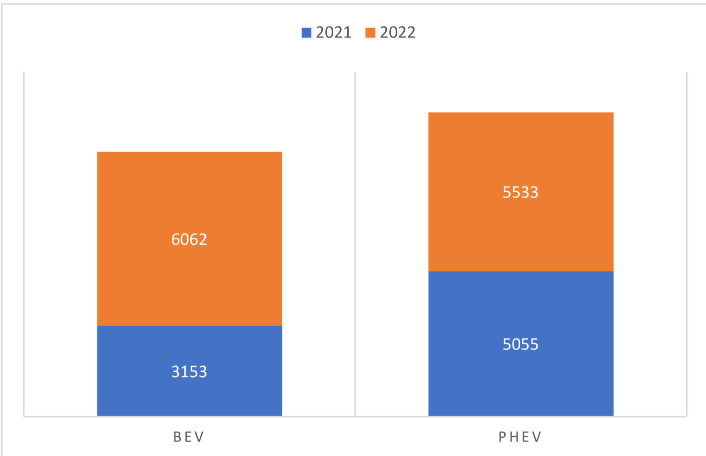

Figure 1. Number of newly registered electric passenger cars (new and used) in the period of January–June 2021 and January–June 2022 in Poland.

The data published in Poland also indicate that the infrastructure for charging electric vehicles in Poland has been expanded. At the end of January 2023, there were 2622 public charging stations in Poland with 5139 charging points (an increase of 36% and 32% compared to the previous year) [66].

As can be seen from the above data, the Polish e-mobility sector is now at an initial stage of development. However, due to the volume of the Polish automotive market, as well as its substantial electrification potential, it is expected that by the end of 2023, the share of electric cars may reach the level of 5–7% in total registrations, and in 2024, even over 10% [70]. It should be added that an additional stimulus for the increase in demand for electric vehicles in Poland may be an increase in the number of fleet orders due to the fact that the electrification of company fleets is a popular and relatively easy to implement (compared to other pro-climate measures) way of implementing the ESG strategy by corporations. It seems that a large number of orders for zero-emission vehicles will also appear from public administration and local governments due to the statutory obligation to electrify a large part of fleets by 2025 [71].

In Poland, the main factor hindering the electric car market development is their relatively high price—new electric cars cost much more than their counterparts with a petrol engine. The same applies to the insufficient road infrastructure in this area. In addition, not every electric car meets the statutory requirements for electric vehicles. According to the Polish Act on Electromobility and Alternative Fuels, a PHEV hybrid is not entitled to a green registration plate, driving on bus lanes, or exemption from fees in paid parking zones; it also does not have the right to enter clean transport zones, although this type of vehicle can drive around the city like a classic "electrician". Similar restrictions also apply to EREV vehicles, which, although they are electric vehicles, their batteries are not charged only from an external source because, in accordance with applicable regulations in Poland, only electric cars whose batteries are charged only from an external power source (charging station, wallbox, 230/380 V charger) can enjoy tax rights and facilitations, i.e., legally move on bus lanes and park free of charge in public paid parking zones (but not in commercial paid parking lots) [72].

It seems that the potential of the zero-emission car market in Poland is much greater than the current data on registrations indicate. However, to observe a considerable increase in the share of electric vehicles on the automotive market, it is necessary to implement programs supporting electromobility. According to the simulations of Carsmile experts, if Poland manages to implement an appropriate electromobility support program in a coherent and consistent manner, it will probably be possible to exceed the barrier of 1 million sold electric cars in the years 2030–2032. In the opposite situation, without appropriate regulatory support on the one hand, and on the other, determination on the part of car manufacturers, reaching one million zero-emission vehicles sold will be significantly longer in time [73].

As can be seen from the above analysis, the introduction of programs supporting the purchase and operation of electric vehicles seems to be extremely important for the increasing transition of individual world economies to electromobility. In many countries, especially economically developed ones, there are special solutions supporting the growth of the electric car market aimed at promoting the purchase of vehicles of this type and the electrification of the vehicle fleet, and thus, promoting sustainable and environmentally friendly mobility [5].

These solutions are both financial and non-financial [30,74,75], where all encourage a greater adoption of electric vehicles. In addition, innovative business models are emerging in the field of car marketing and the development of charging infrastructure [76–79].

As for financial tools, the preferential credit interest rates (for loans for the purchase of this type of vehicle) or tax reductions or exemptions should be mentioned [80,81]. An example of this is the United States, where reference tax policy was applied to electric vehicles due to the fact that they were considered zero-emission vehicles (ZEV). In addition, financial incentives in the form of shopping discounts are used in several states, for example, in California [82]. Governments of many European countries also promote electric cars by supporting their purchase (e.g., Belgium, France, Great Britain, Germany, Spain, Greece, and Serbia), tax incentives, e.g., lower road tax (Belgium, Great Britain, Spain, Norway, Greece, and Serbia), registration fee discount (France), and other activities and initiatives of this type, including free public parking as well as reduced or completely abolished tolls among others on highways.

In turn, non-financial incentives include, for example, the development of related infrastructure (charging stations) or the possibility of using specially separated high-traffic lanes [75,82].

It should be mentioned, however, that not all European countries still use support programs for the purchase of electric vehicles. An example is Italy, where the government stopped using financial incentives in 2014 because of limited public charging infrastructure and poor perception. Also in Portugal, at the end of 2011, all incentives to purchase new electric vehicles were withdrawn. However, the Swiss government does not offer any subsidies or incentives to buy electric vehicles, and individual cantons may offer special tax reductions.

As for Poland, the "My electrician" program has been operating since July 2021—in the offer for individual buyers, while in the most important segment from the market point of view, i.e., leasing and long-term rental, it was launched in the second quarter of 2022. This program provides the possibility to acquire government financing for the acquisition of BEVs (including cars and trucks up to 3.5 tons, mopeds, motorcycles, and quads) [68,83].

3. Materials and Methods

3.1. Study Design—The Selection of the Research Method

The research tool used in the research was the author's structured questionnaire; the diagnostic survey method was used to enable proper processing of the obtained primary data. This method, in line with the qualitative approach adopted, achieved the research objectives set by the authors. It is also worth adding that the chosen research method allows a variety of information on the scope of the research to be collected from many different perspectives, and this in turn allows for obtaining information on the subjective and objective opinions and declarations, as well as the attitudes of the respondents. The research was conducted in January–March 2023. A total 497 people were randomly selected for the study.

The primary objective of the study was to illustrate the phenomenon of preferences as to the type of vehicle due to the type of electric drive used, and above all, opinions on the prospects for their introduction to the market. A block diagram of the research procedure according to which the research was conducted is presented in Figure 2.

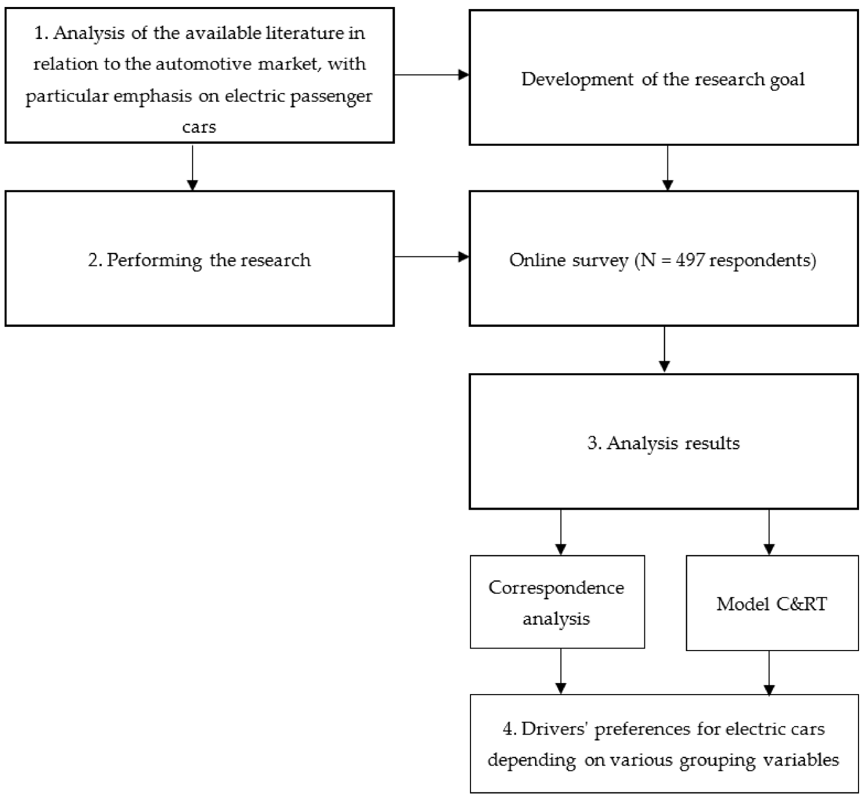

Figure 2. Flow chart of the research methodology.

3.2. Survey Questionnaire as a Research Tool

As mentioned earlier, a proprietary structured questionnaire was used in the study as a research tool. It was disseminated using the Google Forms tool (version 2023). It is worth mentioning that the survey was anonymous. Persons who took part in the study were informed in advance of its assumptions, as well as how to fill it out correctly, and they voluntarily decided to complete it.

The survey questionnaire that was used in the research had two parts, i.e., metric and substantive. It also contained an introduction in which the respondents were introduced to the purpose and objectives of the study. The first, metric part of the questionnaire provided information on the socio-demographic features of the respondents. The grouping variables analyzed were characteristics describing the respondent such as gender, age, or place of residence. The second, substantive part of the survey questionnaire related to the research objectives set in the study. It consisted mainly of closed, single-choice questions. Respondents were specifically asked which types of vehicles they preferred (the choices were standard, hybrid, electric, hydrogen, and autonomous). The next section focused only on electric vehicles and respondents were asked questions about when these type of vehicles would be popularized in Poland. An important issue was also the question of barriers perceived by the survey respondents that block or hinder the development of the electric car market in Poland.

3.3. Research Sample

As mentioned earlier, the research sample used in this study comprised 497 people, all inhabitants of Eastern Poland. They were both active and passive or potential drivers. Purposive sampling—which is one of the non-random sampling methods—was used to select the sample. The reason for using this sampling method in the research was that the respondents met the criteria defining the accepted categories of grouping variables—they were listed in the metric section of the survey questionnaire. No less important is also the fact that the use of this sampling method makes it possible to create a sample that is very close to a representative sample [84].

3.4. Research Methods

In this research, the correspondence analysis method was applied, which is one of many specialized data mining methods. It allows the exploration of pertinent data from a survey questionnaire, measured on a nominal and ordinal scale, by identifying the structure of associations between the variables under study and by presenting, without distortion in a two-dimensional space, the original combination of points representing the variables under study [85].

The method is characterized by its wide range of applications and the possibility of graphical presentation of the research results. The results obtained using it are transparent, which facilitates their interpretation. Moreover, it enables accurate identification of the coexistence of categories of variables or objects, as measured on a nominal and ordinal scale [86].

Another method used in the research is the method of C&RT interactive trees. Classification and Regression Trees (C&RT) are an extension of the classic CART algorithm that introduces the concept of interaction between variables. Unlike standard decision trees, where each feature is considered independently, interactive trees consider potential relationships between variables. C&RT interactive trees have the advantage of being able to detect more complex patterns and relationships in the data by considering interactions between variables. They can be especially useful in cases where single variables do not give a complete picture of the relationships in the data. The C&RT interactive tree construction algorithm differs from the traditional CART mainly in the step of selecting the feature and the cut-off point. Instead of evaluating each feature independently, the C&RT algorithm can examine interactions between two or more features. There are various methods for assessing interactions, such as the correlation coefficient between features, analysis of variance, or other statistical measures [87–89].

4. Results and Discussion

Implementing the first phase of the adopted research procedure, the perspective of passenger cars development was verified in relation to the moment when it will appear on the market (the dependent variable is the time perspective of introducing the car to the market—2 years, 2–5 years, 5–10 years, and over 10 years) and the type of drive used (i.e., PHEV—Plug-in Hybrid Electric Vehicle, BEV—Battery Electric Vehicle, HEV—Hybrid Electric Vehicle, AV—Autonomous Vehicle, FCEV—Fuel Cell Electric Vehicle, and SV—Standard Vehicle), as well as the place of residence (rural areas and cities: up to 100 thousand inhabitants, 100–300 thousand inhabitants, and over 300 thousand inhabitants) and the age of the driver (19–25, 26–40, 41–60, and over 60 years old). Figure 3 illustrates the relationships obtained as a result of the analyses carried out.

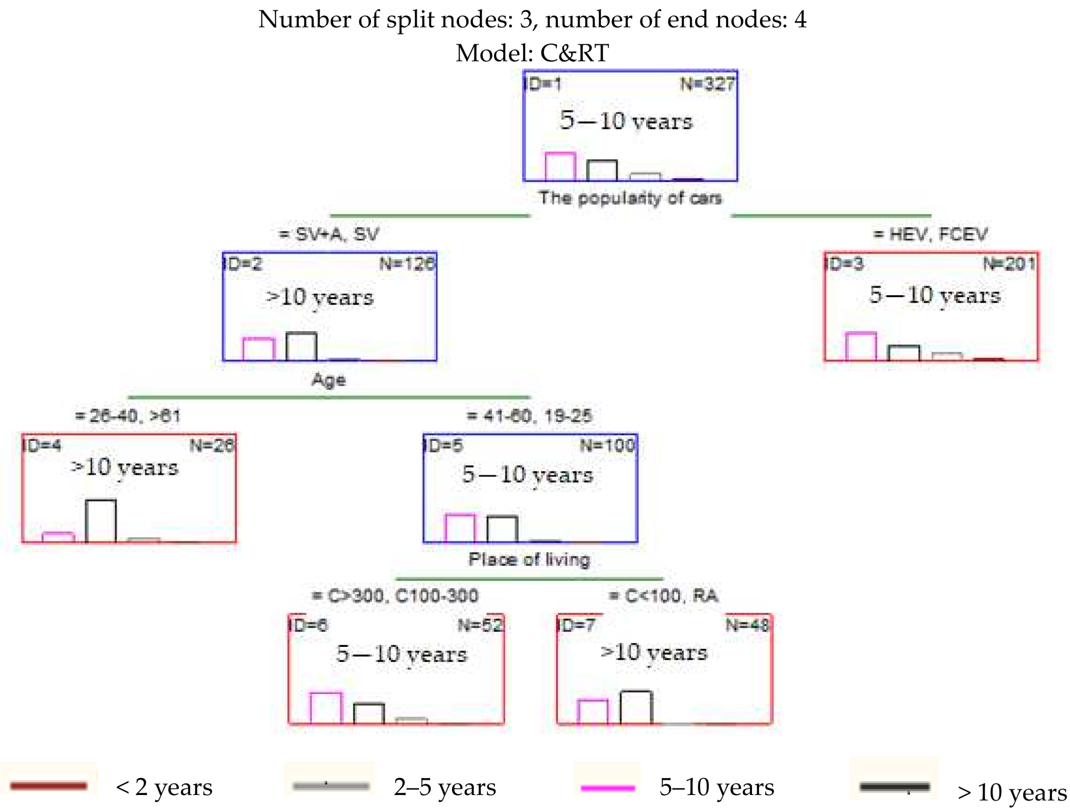

Figure 3. Time perspective for introducing various types of cars to the market in the opinion of respondents from Eastern Poland. Abbreviations: Place of living: RA—rural areas, C < 100—cities up to 100 thousand, C100–300—cities 100–300 thousand inhabitants, C > 300—cities over 300 thousand residents. The type of drive used in the car: PHEV—Plug-in Hybrid Electric Vehicle, BEV—Battery Electric Vehicle, HEV—Hybrid Electric Vehicle, AV—Autonomous Vehicle, FCEV—Fuel Cell Electric Vehicle, SV—Standard Vehicle. Driver's age: 19–25 years old, 26–40 years old, 41–60 years old, over 61 years old.

From the data presented in Figure 3, it is apparent that rules have been created indicating that a group of drivers who expressed their opinions on the prospects for different types of cars in the market have been singled out.

In the first node (ID = 1), N = 327 cases were extracted from the entire dataset. The bar for the 5–10 years category was slightly larger than the others, which means that our list was dominated by those cases for which the value of the dependent variable was "5–10 years". This further means that, according to respondents, the prospect of introducing innovative vehicles to the market is quite remote.

Therefore, the next phase of the research attempted to separate cases, i.e., to create rules that would reliably predict the phenomenon under analysis.

The first variable related to separation was "the type of drive used in the vehicle". Thus, if the respondent chose SV + A or SV, then for these type of vehicles, the perspective would cover a period of 5–10 years until the car was introduced to the market (node identifier = 2, where there were N = 126 cases). Analyzing this issue further, cars of this type, in the perspective of market development over 10 years, were more willingly indicated by people aged 26–40 and people over 61 years. On the other hand, these vehicles were perceived by people aged 19–25 and 41–60 (node ID = 5) in the perspective of 5–10 years of market development, but here it was also possible to indicate that people living in medium-sized cities (100–300 thousand inhabitants) and over 300 thousand inhabitants see the prospect of their more dynamic development for 5–10 years (ID = 6). In turn, drivers living in rural areas and small towns (up to 100,000 inhabitants) believed that cars of this type will appear only in at least 10 years (ID = 7).

With regard to HEV and FCEV cars, the perspective for these cars was indicated as 5–10 years (ID = 3). However, it was not possible to draw further information on the respondents' data from the analysis carried out.

Therefore, in the next stage of the research procedure, a concordance analysis of three groups of features was carried out, i.e., the type of car (six response groups), the gender of the respondents (two response groups), and the driver's activity (two response groups) using correspondence analysis. Respondents were asked what types of vehicles seem most likely to be introduced to the market in the near future in Poland.

A two-dimensional factor space was chosen for the presentation of the configuration of the points representing the input data (Table 2).

Table 2. Factors of information resources (vehicle type, gender, and driver activity).

Number of Dimensions	Eigenvalues and Inertia, Total Inertia = 0.08950 χ^2 = 44.480 df = 15 p = 0.00009				
	Singular Value	Eigenvalues	Percentage of Inertia	Cumulative Percentage	Chi^2
1	0.269253	0.072497	81.00561	81.0056	36.03123
2	0.120855	0.014606	16.31996	97.3256	7.25910
3	0.048924	0.002394	2.67442	100.0000	1.18958

The first factor allowed to reproduce as much as 81% of the variability in the input data (i.e., total inertia), while the second factor 16.32% (this relationship is presented in Table 1). The greatest contribution to the creation of a two-dimensional factor space, by vehicle type, was made by AV and FCEV, coordinate I, and PHEV and FCEV, coordinate II. In turn, active drivers, both women and men (dimension I) and men (this time active and passive drivers—dimension II) contributed the most to the two-dimensional factor space by gender and road activity as a driver (Figure 4).

When analyzing the information presented in Figure 4 in more detail, it is possible to identify three groups with similar indicator structures. The first group were women who actively use cars. According to them, in the coming years in Poland it will be possible to observe the development of HEV vehicles. The second group were men, also active drivers; in their opinion, however, standard vehicles will dominate the Polish market for the next few years. In contrast, the third group were people (both women and men) who believe that the future of the automotive market will be based on electric vehicles—they pointed to completely electric vehicles (BEVs), as well as for PHEVs.

At a later stage, the correspondence analysis was carried out again, but other dependent variables were taken into account, such as the compatibility analysis of other groups of features that had been conducted, i.e., the perception of the development prospects for electric cars (five categories of answers), the gender of the respondents (two categories of answers), and the activity of the driver (two categories). Respondents were asked about the type of vehicles they thought were most likely to be launched in Poland in the near future. The following types of vehicles have been included in this analysis: PHEV—Plug-in

Hybrid Electric Vehicle, BEV—Battery Electric Vehicle, HEV—Hybrid Electric Vehicle, AV—Autonomous Vehicle, FCEV—Fuel Cell Electric Vehicle, and SV—Standard Vehicle (Figure 5).

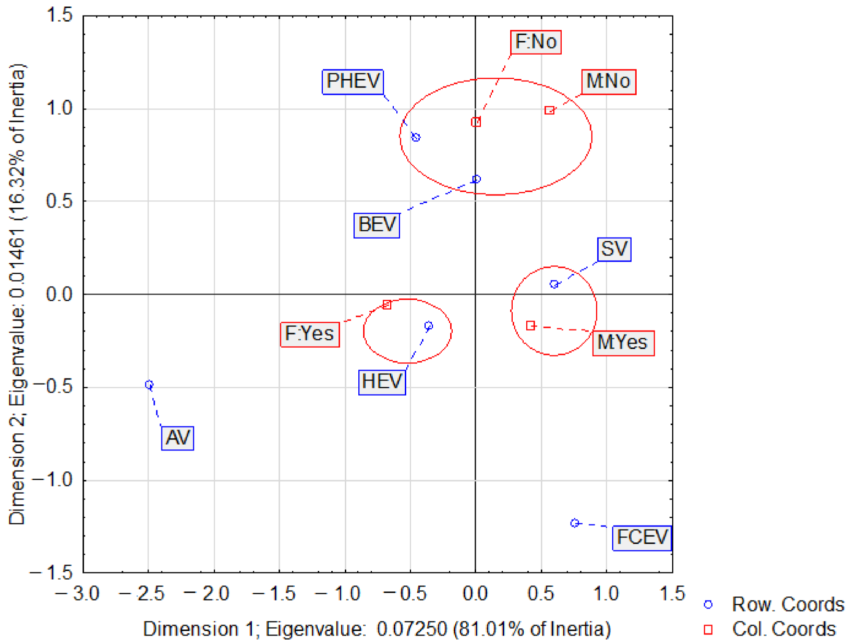

Figure 4. Correspondence analysis results between the three groups of characteristics—vehicle type, gender, and driver activity. Abbreviations: PHEV—Plug-in Hybrid Electric Vehicle, BEV—Battery Electric Vehicle, HEV—Hybrid Electric Vehicle, AV—Autonomous Vehicle, FCEV—Fuel Cell Electric Vehicle, SV—Standard Vehicle, F—female, M—male, Yes—active driver, No—passive driver.

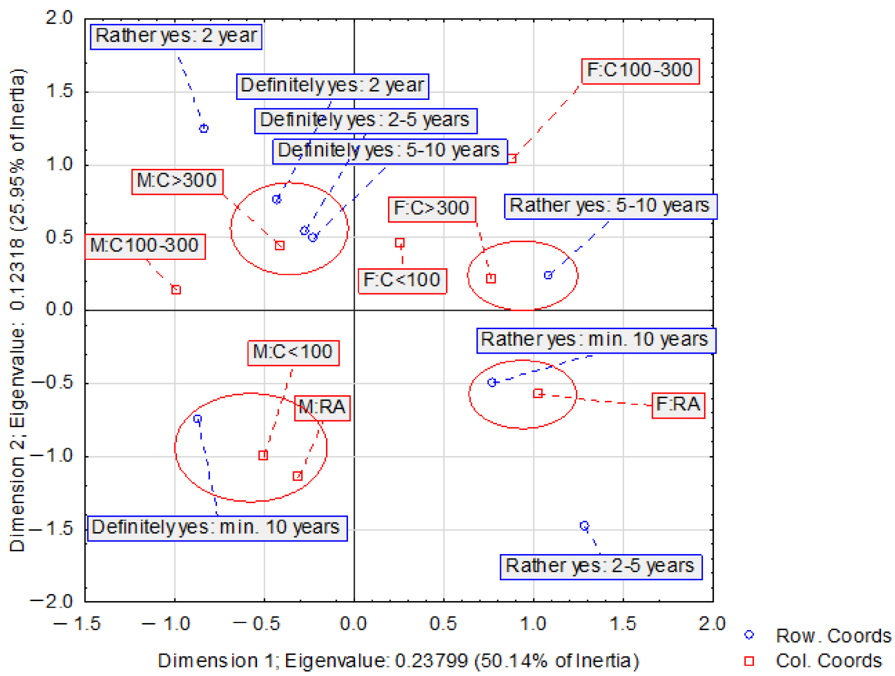

Figure 5. Correspondence analysis results between the four groups of characteristics—gender, place of residence, time perspective, and declaration/vision/opinion on the development of electric cars. Abbreviations: Place of living: RA—rural areas, C < 100—cities up to 100 thousand, C100–300—cities 100–300 thousand inhabitants, C > 300—cities over 300 thousand residents. Gender: M—male, F—female.

Again, the best result turned out to be the presentation of the correspondence analysis results for the input data, where a bidimensional factorial space was selected (Table 3). As can be seen from the information in Table 3, the first factor allowed 50.1% of the variability of the input data (i.e., total inertia) to be reproduced, and the second factor allowed 26%.

Table 3. Factors of information resources (gender, place of residence, time perspective, and declaration/vision/opinion on the development of electric cars).

Number of Dimensions	Eigenvalues and Inertia, Total Inertia = 0.47466 χ^2 = 155.21 df = 49 p = 0.0000				
	Singular Value	**Eigenvalues**	**Percentage of Inertia**	**Cumulative Percentage**	**Chi^2**
1	0.487844	0.237992	50.13940	50.1394	77.82339
2	0.350963	0.123175	25.95015	76.0896	40.27827
3	0.238411	0.056840	11.97481	88.0644	18.58659
4	0.177165	0.031387	6.61260	94.6770	10.26369
5	0.130685	0.017078	3.59804	98.2750	5.58466
6	0.090075	0.008114	1.70934	99.9843	2.65313
7	0.008622	0.000074	0.01566	100.0000	0.02431

As observed in Figure 5, the greatest contribution to the creation of a two-dimensional factor space by gender and place of residence was made by men from cities of 100–300 thousand inhabitants and women living in rural areas—coordinate I—and women from cities of 100–300 thousand inhabitants and men living in rural areas—coordinate II.

In turn, drivers who stated that electric cars will develop in the perspective of min. 10 years and those who claimed that it will happen in 5–10 years (dimension I) and those who claim that it will happen in 2 years and in 2–5 years (dimension II) had the greatest contribution to creating a two-dimensional space of factors according to people determined to show the future for electric cars.

In this case, the in-depth analysis of the data shown in Figure 4 has made it possible to identify four groups with a transparent structure of indicators. The first group were men from rural areas and small cities. They strongly declare that they see perspectives for the development of the electric vehicle market, but only in a minimum 10-year timeframe. Another group were also men, but this time also residents of large cities—they also definitely pointed to the possibility of dissemination on Polish EVs roads; however, giving different time perspectives from 2 up to 10 years. The third group were women who were also residents of large cities, but they were a bit more cautious about the topic under consideration, stating that it is rather possible to develop the electric vehicle market over the next 5–10 years. The fourth group were women from rural areas who were the least enthusiastic about the development prospects of electric vehicles, stating that this will probably be possible, but at the earliest in a minimum of 10 years.

In the further phase of the research procedure, the focus was exclusively on electric vehicles. Therefore, the development perspective of this type of vehicle has been verified in relation to the various variables (the dependent variable is the type of electric car—BEV or PHEV) as well as the frequency of vehicle use (occasionally, often, very often, and never), driver education (higher, secondary education), age of the driver (18–25, 26–40, and 41–60), and—as in the previous analysis—place of residence (rural areas and cities: up to 100 thousand inhabitants, 100–300 thousand inhabitants, and over 300 thousand inhabitants).

Figure 6 illustrates the relationships obtained as a result of the analyzes carried out.

According to the data provided in Figure 6, rules have been set up for identifying group of drivers who have expressed their views on the development prospects for BEV and PHEV electric vehicles on the market.

In the first node (ID = 1), N = 62 cases were extracted from the entire dataset. The bar for the PHEV category was larger than for the BEV category, which means that our comparison was dominated by those cases for which the value of the dependent variable was "PHEV". This further means that respondents believed that the prospect of introducing PHEV vehicles to the market was more likely.

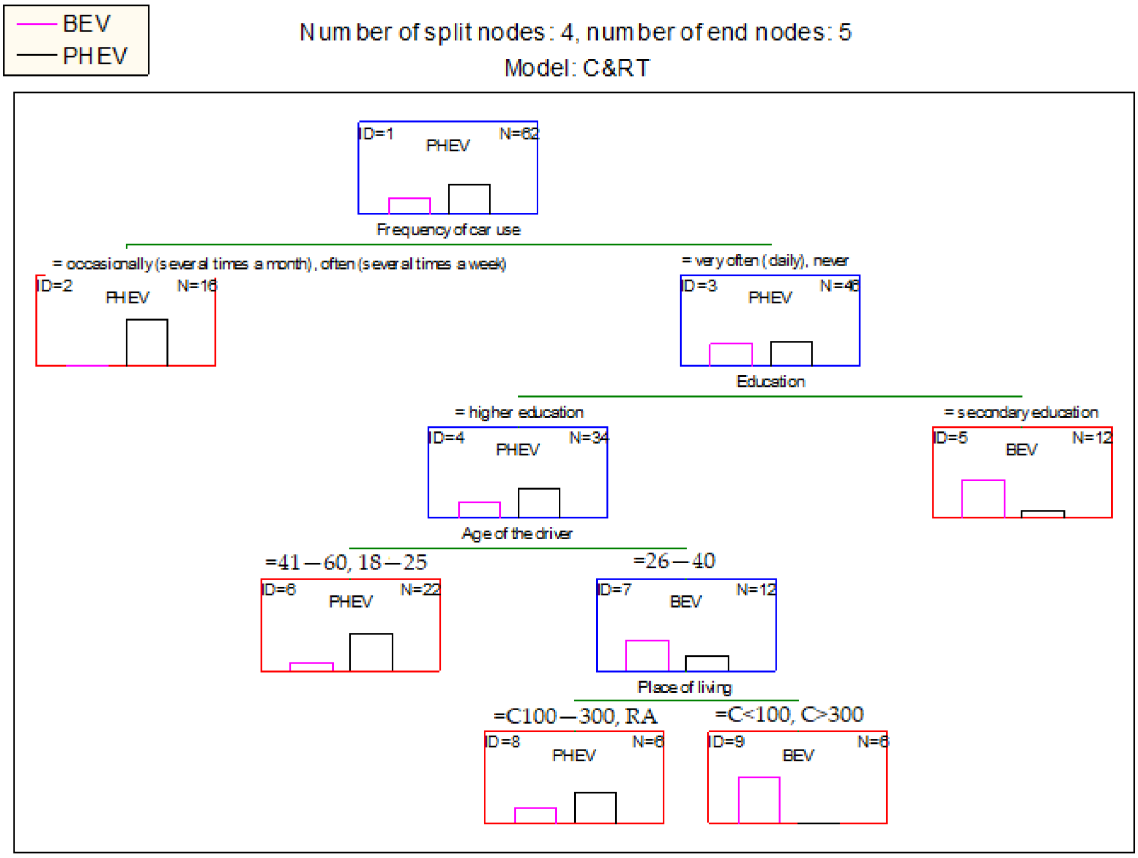

Figure 6. Popularity of electric cars (BEV and PHEV) depending on various variables—in the opinion of respondents from Eastern Poland. Abbreviations: The type of drive used in the car: PHEV—Plug-in Hybrid Electric Vehicle, BEV—Battery Electric Vehicle, HEV—Hybrid Electric Vehicle, AV—Autonomous Vehicle, FCEV—Fuel Cell Electric Vehicle, SV—Standard Vehicle. Place of living: RA—rural areas, C < 100—cities up to 100 thousand, C100–300—cities 100–300 thousand inhabitants, C > 300—cities over 300 thousand residents. Driver's age: 19–25 years old, 26–40 years old, 41–60 years old, over 61 years old.

Therefore, in the subsequent step, an attempt was made to isolate cases, that is to create rules that would predict it in a reliable way. The first variable involved in the separation is "frequency of car use". So, if the respondent chose "occasionally" and "often", he saw a greater perspective for PHEV cars (node ID = 2).

For people who often drive a car or do not drive a car at all, the number of answers in favor of the PHEV solution was not large. However, the respondents were further distinguished by education—people with a higher education believed in PHEV, while people with secondary education chose BEV vehicles.

In addition, people with a higher education chose PHEV, and these were people aged 18–25 and 41–60. Drivers aged 26–40 chose BEV cars and, moreover, they were mainly people living in small towns (up to 100 thousand inhabitants) and large cities (over 300 thousand inhabitants).

In this study, to assess the level and time of adoption of BEV and PHEV, correspondence analysis and one of the data mining methods—CART (Classification and Regression Trees), which is a method of non-parametric discrimination—were mainly used. There are many alternative methods available in the literature, e.g., McManus and Senter [90] used the Bass, Generalized Bass, Logistic, and Gompertz market models. Jeon [91], Becker [92] or Won et al. [93] studied the penetration rate of HEV, PHEV, and EV vehicles by 2030 using the

Bass diffusion model. Still, other methods were used by Balducci [94], who used existing forecasts, survey data, and supplier capabilities to study the penetration rate of electric vehicles. Tran et al. [74], to test various conditions that may affect the adoption of HEV, PHEV, and BEV technologies by 2030 in the EU, used a Monte Carlo simulation, whereas Eggers and Eggers [95] conducted their research by modeling consumer preferences.

In the last phase of the research, the focus was on identifying the main barriers—the factors that inhibit or even prevent the introduction of electric vehicles on a large scale in Poland. The results obtained are presented in Figure 7 (it should be mentioned that the respondents could indicate up to three factors that in their opinion, slow down the spread of electric vehicles to the greatest extent).

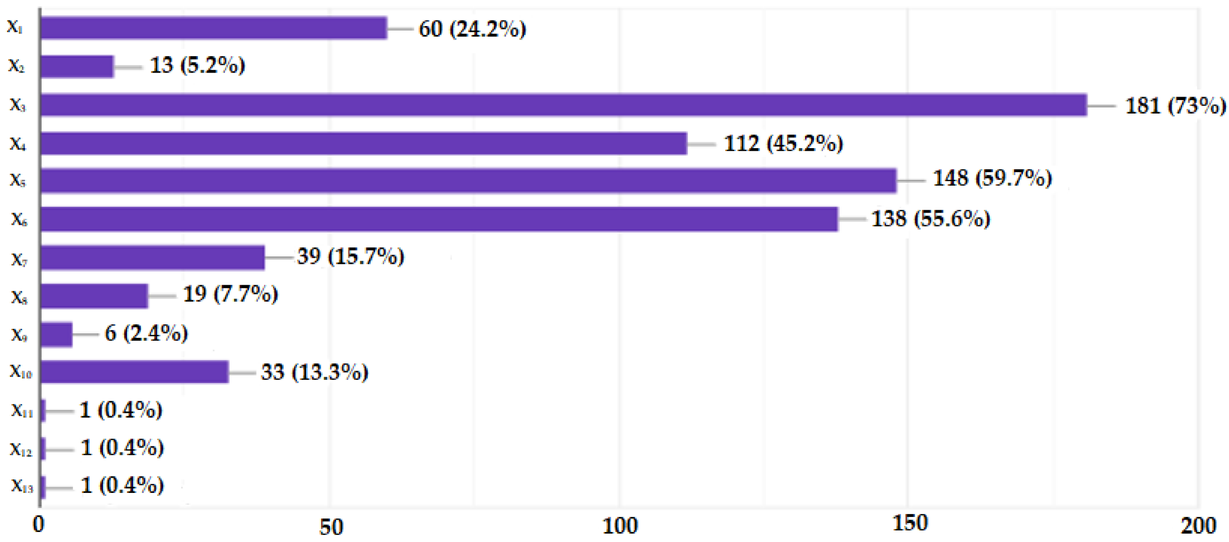

Figure 7. Barriers to widespread market introduction of electric cars in the opinion of respondents from Eastern Poland. Variables: X_1—Mentality of society (fear of novelties, changes), X_2—Concern about driving safety, X_3—Lack of infrastructure (e.g., charging stations), X_4—Long battery charging time, X_5—Too high prices, X_6—Too little range on one charging the battery, X_7—Insufficient support from the authorities in the field of co-financing the purchase of electric cars, X_8—Too limited information in the media about these types of vehicles, X_9—Problems with payments at charging stations, X_{10}—Higher repair costs, X_{11}—High the price of cars, X_{12}—The problem of charging cars in winter, and X_{13}—The problematic issue of battery disposal.

As it results from the information presented in Figure 6, the main barriers to the introduction of electric cars in Poland, according to the answers of the respondents participating in the research, should be indicated primarily by the lack of appropriate infrastructure (e.g., charging stations) (variable X_3), too high prices of (X_5), and short range on one battery charge (X_6). The fact that one of the key determinants of the minor adoption of electric vehicles in Poland is their very high price in comparison with conventional vehicles is also indicated by other researchers [68,96]. The high cost of electric vehicles has also been indicated in studies by Bienias et al., which results in a limited diffusion potential of BEV and HEV—this is because most Polish consumers buy cars on the secondary market [97]. In turn, Sendek-Matysiak and Pyza point to the limited access to appropriate charging points for electric vehicles, especially during longer journeys, which in turn discourages potential buyers from purchasing electric vehicles [98]. Kowalska-Pyzalska et al. [99] came to a similar conclusion; they stated that—apart from the high price of electric vehicles—the limited network of charging stations is the main barrier to their adoption.

Perspectives for the development of the automotive market, including the electric vehicle market, largely depend on the needs, preferences, and consumer behavior. The demand of customers in different countries and in different regions of the world may differ significantly. For example, American clients require vehicles with powerful engines [100]. In turn, Japanese customers pay most attention to fuel consumption issues; hence, hybrid, electric, and other compact cars (with small, light engines) are popular in Japan [101]. By contrast, in Europe, diesel vehicles are still in greatest demand; however, European customers are also interested in purchasing mainly compact cars due to road conditions [102].

On the other hand, in Poland, and especially in its eastern part, which is a rather poorly urbanized and industrialized area and consequently not very rich, electric vehicles are not yet very popular. This may result—as indicated by the respondents participating in the study—on the one hand, from too high purchase prices of such a vehicle, and on the other hand, from the still not very developed infrastructure.

Nevertheless, it seems that electric vehicles will play an increasingly important role over the coming years, especially when it comes to smart cities [3]. This should be more evident in some countries, especially those that intend to ban internal combustion engine vehicles to a greater or lesser extent in the near future. An example is Norway, where it is planned that from 2025, all cars and vans sold should be zero emission. Other countries, however, have proposed a more realistic date—India, Israel, and the Netherlands have declared that all vehicles sold in 2030 will already be electric vehicles. In turn, Germany and Great Britain moved this date even further to 2040.

When analyzing the results obtained, as well as the available data on EV sales, it should also be borne in mind that more than 90% of electric vehicles were sold in only 10 countries (i.e., China, USA, Japan, Canada, Norway, Great Britain, France, Germany, The Netherlands, and Sweden).

Considering the above, it should be noted that the national governments should take further actions and efforts to allow for the wider dissemination of these types of vehicles. They should focus primarily on support programs as well as scientific research, which in turn will facilitate the process of charging and improving the batteries. One of the significant barriers to the rapid development of the electric vehicle market, as also indicated by respondents from Eastern Poland, is, on the one hand, too long charging time, and on the other, too short driving range on a single charge.

In order to encourage Poles to purchase EVs, other privileges should also be introduced, such as exemption from charges in paid parking zones, free entry to so-called clean transport zones (which are practically non-existent in Poland at present), and the opportunity of using bus lanes.

5. Conclusions

The article presents the results obtained from our own research on the future and development prospects of the electric vehicle market in Poland according to respondents from Eastern Poland. It also identified the most significant barriers slowing down the dynamic development and widespread use of EVs.

The research shows that the majority of respondents believe that innovative technologies used in modern vehicles, especially in relation to its drive (e.g., BEV, PHEV, FCEV), as well as functions (AV) are not yet very popular in Poland, especially in Eastern Poland, where the prospect of their widespread introduction to the market is still quite distant and amounts to—in the opinion of the largest number of respondents—about 5–10 years.

The following observations and conclusions have been drawn from the conducted research and analysis of the obtained results, mainly concerning electric cars.

Firstly, the analysis of correspondence showed that active drivers, when asked about the type of vehicles in Poland they thought would be the most popular on the market in the near future, indicated men for standard vehicles (with conventional engines), and women for hybrid vehicles (HEVs). On the other hand, only less active or currently inactive drivers pointed to BEV and PHEV vehicles, which confirms the low popularity of this type of vehicle in Eastern Poland.

In addition, by further analyzing the prospects for the development of electric vehicles in the opinion of respondents from Eastern Poland, it was shown that mainly men from large cities declare a positive attitude in this area (however, pointing to different time perspectives). In turn, the most skeptical are women and men from rural areas, as well as men from small towns (less than 100 thousand inhabitants). They claim that the time perspective for the popularization of electric vehicles in Poland is at least 10 years.

Based on the C&RT model, it was also found that the prospect of introducing PHEVs to the market is more likely than BEVs—especially in the opinion of respondents with higher education, young (18–25 years old) or middle-aged (41–60 years old), living in mostly big cities. Only respondents with secondary education pointed rather to BEV vehicles—these were drivers aged 26–40, living in small towns (up to 100 thousand inhabitants) and large cities (over 300 thousand inhabitants).

Conducting our own research also allowed us to identify the main barriers to the introduction of electric cars—these are the lack of appropriate infrastructure (e.g., charging stations), too high purchase prices of these types of vehicles, as well as a small range on a single battery charge.

As it results from the conducted analyses, the opinions and ratings of drivers from Eastern Poland are divided and varied, which may result from various reasons, but also from the selection of variables used for the analyses. Therefore, there is a need to continue research into the issues under consideration in the future, as well as to carry out in-depth studies.

Author Contributions: Conceptualization, M.S. and A.D.; methodology, M.S. and A.D.; software, A.D.; validation, M.S. and A.D.; formal analysis, M.S. and A.D.; investigation, M.S. and A.D.; resources, M.S. and A.D.; data curation, M.S. and A.D.; writing—original draft preparation, M.S. and A.D.; writing—review and editing, M.S. and A.D.; visualization, A.D.; supervision, M.S.; project administration, M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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