Analyzing the Attitudes of Consumers to Electric Vehicles Using Bayesian Networks

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Abstract. Road transport, as 'a producer' of carbon dioxide (CO_2), causes high levels of air pollution, especially in cities. A suggested solution to this situation is the effective diffusion of electric vehicles (EVs). Regulations in the European Union aim to encourage consumers to buy electric cars. In addition, car manufacturers are constantly expanding their range of hybrid vehicles (HEVs) and EVs. Nonetheless, consumers have still many doubts regarding adopting an EV. Our survey among social media users investigates the attitudes and readiness of consumers to adopt HEVs and EVs. To investigate the factors underlying consumers' attitudes to such vehicles, Bayesian networks were used as an exploratory tool. This paper presents results of this analysis.

Keywords: electric vehicle, hybrid electric vehicle, innovation diffusion, consumers, willingness to pay, survey, Bayesian network

1 Introduction

The European Union aims to reduce greenhouse gas emissions, produce more energy from renewable sources and improve energy efficiency. The EU has proposed various tools, such as: financial incentives, infrastructure developments, and strategies to encourage people to purchase EVs (Hawkins, 2013, Sierzchula, 2014, Pasaoglu, 2012). Similar strategies have already been introduced in Poland to encourage consumers to buy or rent an EV. However, the current share of EVs in the Polish market is not sufficient to claim the successful diffusion of EVs.

This paper presents results from an online survey conducted among social media users in 2020. The aim of the study is to obtain better knowledge about consumers' opinions regarding EVs and HEVs.

2 Data collection, the sample and methods

The dissemination of innovation through social media channels can bring effective results (Hanna, 2011). People who have self-perception as leaders of opinion formation,

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build strong online networks and have significant effect on users' news sharing intention in social media (Ma, 2014). Studies show that social media campaigns can easily reach out to consumers in fast and cost efficient way (Chawla, 2018, Reid, 2014). Also, consumers are willing to search for information and exchange opinions with other users through social media channels.

To the best of our knowledge, the awareness and acceptance of EVs/HEVs among social media users have not been checked yet. Our study aims to fill this gap.

The respondents targeted were residents of Poland above the age of 18. Hence, the questionnaire was only conducted in the Polish language. The survey was disseminated on the Facebook platform. Answers from 858 questionnaires were analyzed.

The on-line survey was split into six parts, including a section checking respondents' knowledge and opinion about electric and hybrid vehicles. The definitions of the variables and their coding are presented in Table 1. The sections of the survey cover demographics (M1-M6), information about cars in the households of respondents (H1-H11), questions regarding the evaluation of electric and hybrid cars (OH1–OH8 and OE1–OE10) and further questions about respondents' opinion on electric and hybrid vehicles (F1–F7). Furthermore, respondents were asked about hypothetical situations in which they could use electric vehicles in everyday life (S1–S2), (D1–D8) including their opinion about the prices of electric and hybrid cars, as well as the possibility of enjoying the benefits of EVs (P1–P11). Respondents indicated their degree of acceptance of hybrid and electric vehicles on the basis of a standard five-point Likert scale.

Table 1. Definitions of the variables and coding (N = 858).

Variable	Code	Description
Gender	M1	nominal variable
Age	M2	ordinal variable
Level of education	M3	ordinal variable
Size of home town/city	M4	ordinal variable
Voivodeship (region)	M5	nominal variable
Number of people in the household	M6	ordinal variable
Number of cars in the household	H1	ordinal variable
Number of cars possessed	H2	ordinal variable
Source of the cars used in the household	H3	nominal variable
Price of the most expensive car purchased	H4	ordinal variable
Type of engine	H7 -H10	nominal variable
Type of hybrid vehicle (type of engine)	H11	nominal variable
Evaluation of hybrid cars	OH1 - OH8	(1) No/ (2) Rather no/ (3) Hard to say/ (4) Rather yes/ (5) Yes
Evaluation of electric cars	OE1 - OE11	(1) No/ (2) Rather no/ (3) Hard to say/ (4) Rather yes/ (5) Yes
Previous rental of vehicle or electric vehicle	S1 – S2	(1) No/ (2) I don't remember/ (3) Yes

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General opinion of electric and hybrid vehicles	F1 – F2, F6 - F7	(1) Negative (2) Rather negative (3) Hart to say (4) Rather positive (5) Positive
Family/friends' ownership of a hybrid/ electric vehicle	F3 - F4	(1) No/ (2) Rather no/ (3) Hard to say/ (4) Rather yes/ (5) Yes
Occurrence of conversations about hybrid/ electric vehicle	F5	(1) No/ (2) I don't remember/ (3) Yes
Convenience of electric vehicle in everyday life	D1 – D7	(1) No/ (2) Rather no/ (3) Hard to say/ (4) Rather yes/ (5) Yes
Usefulness of electric car in the household	D8	nominal variable
Willingness to pay for electric/ hybrid vehicle	P1 - P2	ordinal variable
Attractiveness of subsidies for purchasing electric and hybrid cars	P3 – P4	(1) No/ (2) Rather no/ (3) Hard to say/ (4) Rather yes/ (5) Yes
Obstacles for buying/using an electric car	P5 - P11	(1) No/ (2) Rather no/ (3) Hard to say/ (4) Rather yes/ (5) Yes

3 Analysis using a Bayesian network

Bayesian network analysis aims to infer the underlying network of relationships between a set of categorical variables. We used Kendall's test of correlation to analyze the strength and direction of association between pairs of ordinal variables (variables that are ordered with respect to a scale - for testing purposes, all the scales were orientated from the worst to the best condition from the point of view of HEV/EV propagation). When at least one of the variables in a pair was nominal (no natural ordering), then we analyzed the relationship between them using the chi-square test of association. To interpret interesting relations indicated by the Bayesian network, we analysed cross tables for the appropriate pair of variables.

A Bayesian network presents the relationships between variables in graphical form. Variables that are directly linked in such a network are strongly associated with other. Typically, the variable in a pair which influences the other is called the parent variable (Markowska- Przybyła, 2015, Borgelt, 2009). However, in our data the direction of influence is often unclear, and so we avoid indicating which variable is the parent variable and interpret links as direct relations between variables. The choice of an appropriate network is based on the likelihood of the data under a given model and a penalty function that penalizes the complexity of the model. The most commonly used criteria for choosing such a network are the Bayesian Information Criterion (BIC) and the Akaike Information Criterion (AIC), which uses a weaker penalty on the complexity of a model than the BIC and thus tends to select more complex models. We used the catnet

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package in the R environment to derive Bayesian networks describing the underlying structure of the data (Balov and Salzman, 2017).

The model obtained on the basis of the AIC criterion, under the assumption that any variable can have only one parent (due to the complexity of the networks derived), is illustrated in Figure 1. Three separate networks of variables were found. In total, the network contains 60 nodes.

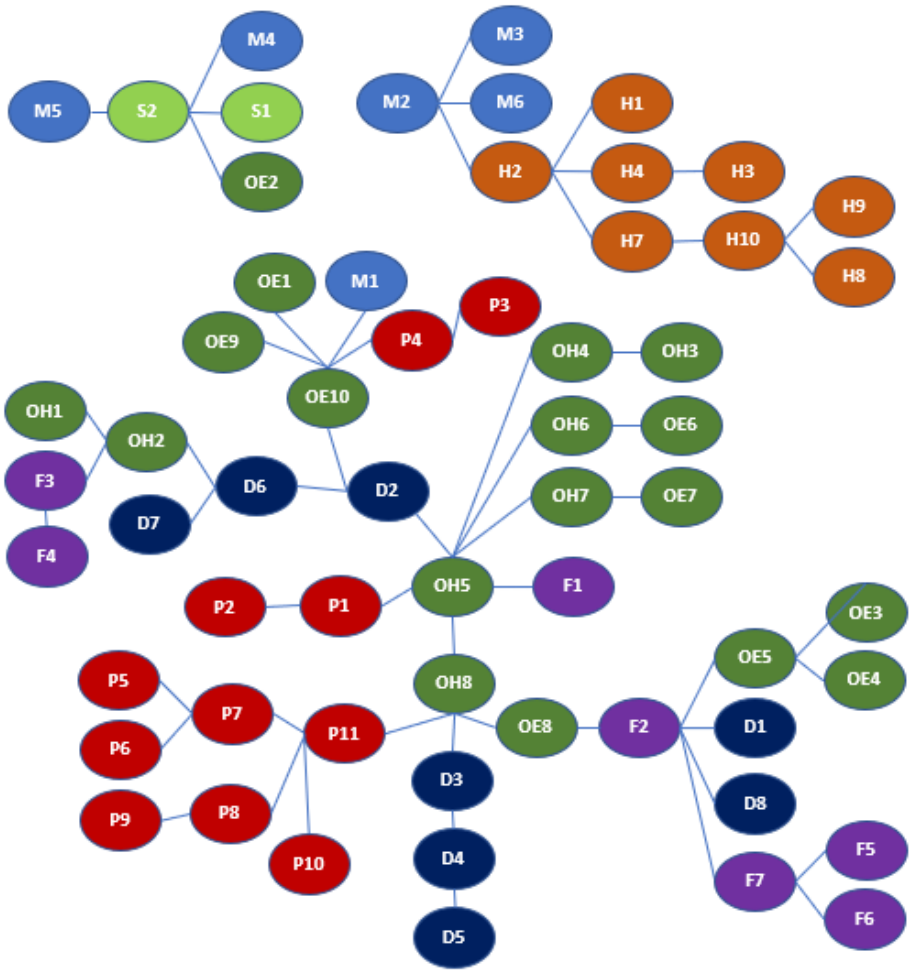

Fig. 1. Bayesian network created on the basis of the AIC criterion.

4 Results and Discussion

The size of a respondent's hometown is positively associated with experience of renting an EV (Kendall's correlation coefficient for M4 and S2 is 0.241, $p<0.001$). The age of

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respondents (M2) and the purpose for which cars are used in a household (H2) are clearly associated. As age increases, cars are increasingly used for professional purposes instead of just private ($p<0.001$).

The relationship between the price of the most expensive car in a household (H4) and whether a household bought new, second hand or both types of car (H3) shows that those who have only bought second hand cars tend to spend less ($p<0,001$). Almost half of such respondents (48.2% of 525 cases) have always paid less than 25 thousand PLN (just over €5000), while the majority of households that have bought a new car in the past have spent at least 100 thousand PLN (more than €20000). The present cost of EVs is in this range.

The opinion that HEVs should be introduced to the market on a larger scale (OH5) is strongly associated with one's personal opinion about HEVs (F1) (similar relation with EVs), as well with the willingness to pay extra for HEVs (P1) and EVs (P2) compared to petrol-engine cars. Positive opinions about EVs (F2) are associated with respondents having used an EV as a replacement car (D1), as well as with positive opinions among their relatives and friends about both HEVs (F6) and EVs (F7).

Respondents with positive or rather positive opinion about EVs (F2) declare that they could accept an EV as a second car in their household (64.4% of 306 cases and 74.4% of 227 cases accordingly).

The gender of respondents (M1) is associated with knowledge regarding EVs, especially with regard to the possibility of charging an EV at home (OE10). Male respondents mostly agree with statement that an EV can be charged using a household outlet (68,4% of male respondents), while just 22,5% of female respondents gave the same answer.

Opinions regarding possible obstacles to buying/ using an EV (P5 – P11) formed one branch of the Bayesian network and are closely related to opinions regarding the relative cost of running a HEV/ EV compared to a vehicle with a combustion engine (OH8/ OE8). The relation between OH8 and P11 shows that, even if respondents have difficulties with estimating the operating costs for a HEV (37.1% of respondents/ 318 cases chose the answer 'Hard to say', a similar proportion of answers to OE8), 53.8% of these respondents (171 cases) think that such difficulty in cost estimation is not or rather not an obstacle to buying/ using an EV.

The general opinion of respondents about electric vehicles (F2) is in strong relation with the general opinion of respondents' family/ friends about electric vehicles (F7) (Kendall's correlation coefficient is 0.573, $p<0.001$). The survey confirms that respondents' opinion of innovation (like EV in this case) is strongly influenced by the opinion of their environment (Edwards, 1953, Podsakoff et all., 2003).

The knowledge of whether any family members/friends have a HEV (F3) is strongly correlated with information of whether any family members/friends have an EV (F4) (Kendall's correlation coefficient is 0.401, $p<0.001$). 36.7% of respondents (315 cases) do not know anyone with a HEV/EV. 14.9% of respondents (128 cases) know owners of both HEV and EV vehicles. 21.7% of respondents (186 cases) know someone with a HEV, but no-one with an EV. Just 11 respondents (1.3%) know someone with an EV but no-one with an HEV.

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Table 2 presents how many respondents own a hybrid or electric vehicle. Table 3 presents the structure of vehicle types in the households of respondents.

Table 2. Types of engine in the cars owned by a household (N=858).

Type of engine	Yes		No	
Internal combustion engine	786	91,6%	72	8,4%
Hybrid engine	40	4,7%	818	95,3%
Electric motor	35	4,1%	823	95,9%

Table 3. Composition of car engines in a household (N=858).

All types of engines in a household	Share	
No car in the household	41	4,8%
ONLY internal combustion engine	745	86,8%
Internal combustion engine AND hybrid engine	19	2,2%
Internal combustion engine AND electric motor	22	2,6%
ONLY hybrid engine	18	2,1%
Hybrid engine AND electric motor	3	0,3%
ONLY electric motor	10	1,2%

Table 4 presents share of passenger cars by fuel type in Poland in 2020 according to the report of the European Automobile Manufacturers' Association (ACEA).

The Bayesian network confirms that the following factors have the highest influence on ownership of a HEV/EV and willingness to pay for HEV/ EV: the price of hybrid/electric cars, the positive opinion of consumers about HEVs/Evs, as well as the positive opinion of friends and relatives about HEVs/EVs, the possibility to enjoy such privileges as free parking in paid parking zones and the assumption that an electric vehicle would work well in the household as the only car or second/additional car.

Table 4. Share of passenger cars by fuel type in Poland and EU in 2020 (ACEA,2022).

	Petrol	Diesel	Battery electric	Plug-in hybrid	Hybrid electric	LPG
Poland	44,80%	40,2%	0,01%	0,0%	1,0%	13,8%
EU	51,7%	42,8%	0,5%	0,6%	1,2%	2,5%

The factors considered to be most important for the diffusion of EVs on the Polish market will be included in an agent-based model (ABM). This ABM will aid us in checking whether methods that are effective in other countries can also be successfully implemented in Poland. The results of comparative analysis with chosen countries, together with the results from simulations will indicate policies that should be implemented on the Polish market in the near future. Implementing the most efficient policies could lead to a more effective introduction of EVs.

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5 Limitations of the Study

The study conducted has some limitations. Firstly, the survey was limited linguistically, as it was only conducted in Polish to investigate the opinion of Polish social media users. In addition, the study was also limited by the way the online survey was disseminated, focusing only on social media users. Hence, consumers who are not active on social media were not included in the sample. Subsequent research could target a more diverse demographic and a wider audience to make the survey group more representative of the Polish population.

6 Conclusions and Future Work

The factors considered to be most important for the diffusion of EVs on the Polish market will be included in an agent-based model (ABM). This ABM will aid us in checking whether methods that are effective in other countries can also be successfully implemented in Poland. The results of comparative analysis with chosen countries, together with the results from simulations will indicate policies that should be implemented on the Polish market in the near future. Implementing the most efficient policies could lead to a more effective introduction of EVs.

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