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Article

Selection of the Family Electric Car Based on Objective and Subjective Criteria—Analysis of a Case Study of Polish Consumers

Paweł Ziemba [1,*], Marek Kannchen [2] and Mariusz Borawski [3]

[1] Institute of Management, University of Szczecin, 70-453 Szczecin, Poland
[2] Faculty of Technology, The Jacob of Paradies University, 66-400 Gorzów Wielkopolski, Poland; mkannchen@ajp.edu.pl
[3] Faculty of Computer Science and Telecommunications, Maritime University of Szczecin, 70-500 Szczecin, Poland; m.borawski@pm.szczecin.pl
* Correspondence: pawel.ziemba@usz.edu.pl

Abstract: In accordance with the policies of European Union countries, including Poland, users of combustion vehicles are and will be encouraged in the coming years to purchase BEVs (battery electric vehicles) through various restrictions, burdens, and incentives. In this context, it is important to choose a BEV that meets consumer needs. The practical aim of the article was to analyse BEVs used in households and to select a car with the highest utility for such a household located in a specific city in Poland. The scientific goal was to analyse the impact of subjective criteria and the imprecision of judgements on the results of the multi-criteria assessment of BEVs. The research used the PVM-VSI (Preference Vector Method—Vector Space of Increments) method, which allows for examining the impact of subjective criteria on the assessment results. Moreover, by examining the deviations of the assessments, the PVM-VSI method also allows for measuring the imprecision of subjective judgements. The study showed that including subjective criteria in the decision-making model may have a decisive impact on the obtained ranking of alternatives. In the study using objective and subjective criteria, Nissan Ariya ranked first. However, in the ranking based solely on objective criteria, Kia Niro EV won, and the winner of the first ranking took the last place. In the study, the imprecision of judgements did not have a significant impact on the order of vehicles in the ranking. Based on utilities and standard deviations, it was found that only if the decision-maker was prone to gambling would there be a slight switch between alternatives.

Keywords: electric vehicles; transport policy; multi-criteria decision analysis; subjective criteria; uncertainty; imprecise judgements; PVM-VSI

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1. Introduction

Over recent years, there has been an increasing emphasis on energy transformation and the transition from fossil fuels to renewable energy sources throughout the European Union (EU). The 'Green Deal' (adopted by the EU in 2019) and 'Fit for 55' (adopted in 2021) programs are of particular importance in this respect. The first one is a plan to achieve 'zero-emissions' and energy independence by the EU economy by 2050 [1]. In turn, the second program requires EU countries to reduce greenhouse gas emissions by 55% by 2030 [2]. One of the effects associated with these programs is a strong push to replace combustion cars with BEVs (battery electric vehicles). This program includes not only BEVs, but also hydrogen vehicles and the use of zero-emission fuel [3]. Hydrogen vehicles are characterized by faster charging, a longer range, and, above all, a cleaner value chain than BEV vehicles [4,5]. Emphasis on replacing combustion cars with electric ones is also visible in Poland, where approximately 73% of passenger cars are more than 10 years old [6], and only 13% of surveyed Poles declare their willingness to buy an EV (electric vehicle) in the future, including 2.7% who declare the purchase of a BEV [7].

Polish consumers are encouraged to purchase BEVs through both incentive and restriction programs. Such incentives include government programs for partial co-financing of the purchase of BEVs: 'Green car', 'Hummingbird', 'e-Van', and 'My electrician' introduced in 2021 [8,9]. The latter program allows citizens to obtain funding for the purchase of a passenger BEV in the maximum amount of PLN 27,000. Moreover, BEVs in Poland are legally guaranteed certain facilities in urban traffic: they are exempt from fees in paid parking zones and can use the so-called 'bus lanes' [10]. These privileges allow for financial savings related to not having to pay parking fees in city centres, as well as time savings resulting from avoiding city traffic jams by using bus lanes.

On the other hand, in the coming years, restrictions and burdens are planned to be imposed on users of combustion vehicles, both financial and making it difficult to drive combustion cars. According to the annex to the 'Proposal for a Council Implementing Decision on the approval of the assessment of the recovery and resilience plan for Poland', an increased registration fee for combustion vehicles is to be introduced in Poland in 2024, and a tax on the ownership of combustion vehicles will be introduced in 2026. Both fees are to be linked to CO2 and NOx emissions, and their aim will be to stimulate demand for BEVs [11]. Moreover, in large cities in Poland, 'zero and low-emission transport zones' are beginning to be established, to which only BEVs and internal combustion vehicles with sufficiently low pollutant emissions can enter (depending on the Euro exhaust emission standard). The obligation to create such zones from 2025 is also to be regulated by law, in accordance with the 'Proposal for a Council Implementing Decision on the approval of the assessment of the recovery and resilience plan for Poland' [11]. It should also be noted that from 2035, all new cars sold in EU countries will have to have zero CO2 emissions, and earlier from 2030 they will have to emit 55% less CO2 than in 2021 [12].

According to PAFA (Polish Alternative Fuels Association), at the end of 2022, there were 31,249 BEVs registered in Poland [13]. In the 'Polish EV Outlook 2023' report, PAFA assumes that by the end of 2025 there will be over 226,000 BEVs on Polish roads [14]. These assumptions seem to be greatly exaggerated when the number of BEVs forecast in the report at the end of 2023 is analysed in relation to the actual number of BEVs registered in Poland by the end of October 2023. The forecast assumes that at the end of 2023 there will be approximately 75,000 registered BEVs in Poland, while the number of BEVs registered by the end of October 2023 is 46,888 [13]. Therefore, in order to meet the forecast, almost 30,000 BEVs would have to be registered in the last two months of 2023, which is completely unlikely. However, even apart from PAFA's unreliable forecast, it can be expected that, among others, due to the incentives and restrictions mentioned above, the share of BEVs in the passenger vehicle market in Poland will systematically increase in the coming years.

The share of electric car sales in the total number of cars sold will increase, as indicated by research conducted in Norway. Norway is the leading country in terms of the distribution of electric cars. Sales of new electric cars increased there from 0.07% in 2013 to 86.2% in 2021, of which 64.5% of BEVs and 21.7% of PHEVs (plug-hybrid electric vehicles) were registered in 2021 [15]. Consumers' willingness to purchase BEVs is the result of demographic, situational, and psychological factors [16]. In the most developed countries, there has been a sharp increase in the number of new electric cars in recent years. Eurostat reports that in Germany the number of new electric cars increased from 194,163 in 2020 to 470,559 in 2022, in France it increased from 112,499 to 207,171 in the same years, and in the UK it increased from 15,579 in 2018 to 263,197 in 2022 (no data for 2019–2020) [17]. In less developed countries, this increase is not so significant. In Poland, the number of new electric cars increased from 8100 to 11,293 in 2020–2022. It should be noted that the sale of hydrogen-powered cars is currently of marginal importance. In Germany, only 466 such cars were sold in 2021, but this may change in the future with the increasing availability of stations offering hydrogen fuel. Everything indicates that currently the issue of BEV purchases is becoming more and more important from the consumer's point of view.

In the context of the transport and environmental policy of the EU and Poland, related to imposing restrictions on combustion cars and promoting BEVs, an important issue is the selection of a BEV that meets the needs of individual users. The research presented in this article is intended to help make a consumer decision related to the purchase of a specific BEV for household needs in Poland. The study considered a case study for a specific city located in the western part of Poland—Gorzów Wielkopolski. The undertaken practical research problem is important in socio-economic research because the purchase of a BEV by a consumer is a long-term decision that affects other members of the consumer's family and requires the investment of very large financial resources for Polish conditions. Therefore, this is a critical decision for the consumer, having a significant and long-term impact both on the budget and on all household members. Polish consumers, despite their disadvantages, evaluate electric cars positively. The tendency of Polish consumers to purchase such a car increases, among other things, with the number of household members, the size of the hometown, and positive opinions about the impact of vehicles on the environment [18].

Considering the presented research problem, it should be noted that BEVs can be described by various attributes reflecting, among others, the technical parameters of vehicles. These are measurable, quantitative criteria (e.g., engine power), as well as non-measurable, qualitative ones (e.g., comfort). The former are objective by nature because the decision-maker has no influence on the values of these criteria/attributes (apart from issues such as measurement errors and inaccuracies) [19]. In turn, qualitative criteria (non-measurable) usually have the nature of subjective judgements expressed by the decision-maker [20]. MCDA (multi-criteria decision analysis) methods have the ability to combine quantitative and qualitative data, as well as subjective assessments with more traditional scientific evidence [21]. Therefore, these methods are applicable to research problems related to the assessment of BEVs. However, the subjectivity of assessments may obscure the decision-maker's understanding of alternatives and preferences [19]. Additionally, the subjectivity of assessments may introduce additional burden (bias) to the results of multi-criteria assessment [22]. It should also be noted that the subjective assessment process is inherently imprecise, including due to unclearly defined quality assessment criteria [23]. All these aspects make it necessary to separate objective and subjective criteria in the decision-making process [19]. In turn, an important scientific problem is the study of the impact of subjective criteria on the results of multi-criteria assessment. The MCDA method that allows the separation of subjective and objective criteria is PVM-VSI (Preference Vector Method—Vector Space of Increments) [24]. The use of this method in the problem of BEVs assessment will allow for examining the impact of subjective criteria on the assessment results. Moreover, by examining assessment deviations, the PVM–VSI method also allows for capturing and measuring the imprecision of subjective judgements.

Taking into account the research problems described above, the following research questions were asked:

1. Which BEV car(s) are most suitable for a Polish household in a selected medium-sized city?
2. How do subjective criteria and imprecision of judgements affect the results of the multi-criteria assessment of BEVs?

Two objectives of the article were formulated. The practical goal is to analyse BEVs used in households and select the vehicle with the highest utility for such a household located in a specific city in Poland (Gorzów Wielkopolski). In turn, the scientific goal is to analyse the impact of subjective criteria and the imprecision of judgements on the results of the multi-criteria assessment of BEVs. The tool used in the assessment, enabling such analyses, is the PVM-VSI method. The following research hypothesis was formulated: Subjective criteria and imprecision of judgements have a significant impact on the results of the multi-criteria assessment of BEVs.

Subjective criteria are generally not taken into account in research, but from the point of view of many consumers they are very important. For example, the comfort of driving a car is a very important issue for the passenger. When observing customers of car showrooms, you can notice how consumers try on the seats in the car. Therefore, this is an important element of choosing a car. On the other hand, the issues of the car's comfort, its appearance, etc., are subjective impressions difficult to express in words or numbers, and therefore difficult to precisely compare. The imprecision of the comparison may have a significant impact on the comparison result. Hence, the main problem considered in the article is the impact of subjective criteria and imprecision on the results of comparing alternatives.

The article is a continuation and significant development of the research presented in the conference proceedings [25]. This article is based on the same methodology (PVM-VSI) and considers a similar decision-making problem (choosing an electric car for the family). However, compared to the conference paper [25], in this study we focused on a different research problem. In [25], the aim was simply to provide recommendations for an electric car tailored to the needs of a specific group of consumers. In this work, the above-mentioned practical goal was supplemented by an additional (but more important) scientific goal, which is to study the impact of subjective criteria and the imprecision of judgements on the obtained decision recommendation. In turn, in the practical aspect, this study considers a new set of decision alternatives (electric cars). In this article, we rely on new and updated car data because the electric vehicle market is changing rapidly. Not all vehicles available on the market 2 years ago and included in conference paper [25] are currently available for sale. The specifications of several vehicles have changed to some extent and there are new electric cars available, which we have included in this article. Moreover, over this time, the preferences of decision-makers, expressed by the weights of the evaluation criteria, have also changed. Taking into account that in this study we used a new set of alternatives and based our results on the new preferences of the decision-maker, the considered decision model is completely different than in the conference paper [25]. Moreover, in this study, we improved the PVM-VSI method by eliminating the errors detected in it (e.g., multiple normalization of the same data). These errors could have distorted the assessment results and decision recommendations obtained. Compared to the conference paper [25], this article was prepared completely from scratch. We set a broader research problem and goal, prepared a literature review from scratch, collected data for the study anew, and formulated a decision-making model. Additionally, we re-described the PVM-VSI method, ensuring the consistency of the description of the methodology and the presentation of the obtained results. Finally, as part of the extended research goal, we analysed the impact of subjective criteria and the imprecision of judgements on the obtained results.

The second section of the article presents a literature review on the use of MCDA methods in problems related to the selection of electric cars. Section three presents the methodological details of the PVM-VSI method used in the study. The results of the research on the selection of BEVs for a household using objective and subjective criteria are presented in the fourth section. The fifth section compares the results obtained using objective and subjective criteria with those obtained using only objective criteria. The article ends with the sixth section, presenting conclusions on the choice of a BEV for a household and on the impact of subjective criteria on the obtained solution.

2. Literature Review

The literature contains examples of research on the choice of an electric car using MCDA methods. Current research on this topic is listed in Table 1. Of the presented works, eight were generally concerned with the choice of an electric car [26–33], four with the choice of an electric city car [34–37], and two with electric vans [38,39]. One example concerned the selection of a vehicle for local authorities and administrations [40].

In the multi-criteria decision-making problems mentioned above, methods from the PROMETHEE family were most often used to support decisions—being used five times [26,34,35,37,38]. Methods from the TOPSIS family [26,32,38] and Monte Carlo simulations [34,37,40] were used three times to solve the decision-making problem. The COMET [36,39], VIKOR [27,32], SAW [26,32], and AHP-MABAC [28,31] methods were used twice each. One example concerns the use of PROSA [40], ORESTE [33], COCOSO [30], ARAS [30], SECA [30], COPRAS [30], MAIRCA [30], MARCOS [30], and the author's method, which has not been named [32]. Moreover, many works use hybrid solutions or several methods to compare the created rankings. This is what the authors of the articles [26,30,32,34,37,38,40] did. In the remaining examples, only one of the previously mentioned methods was used to support the decision-maker.

Table 1. Application of MCDA methods in decision-making problems regarding the selection of EVs.

Decision-Making Problem	Applied Method(s)	No. of Criteria (Sub-Criteria)	No. of Objective Criteria	No. of Alternatives	Reference
Evaluation of a selected EV	VIKOR-SMAA-2	11	11	12	[27]
Choosing an EV in the mobility sector to reduce green-house gas (GHG) emission and its impact on environment	FAHP-MABAC	5	5	7	[28]
Consumer preference disaggregation to support new energy automobile purchase decision	Preference disaggregation analysis method	12	5	18	[29]
Selecting the best BEV car	COCOSO, ARAS, SECA, COPRAS, MAIRCA, MARCOS	11	11	10	[30]
Selection and ranking of the best alternative of the electric vehicle in India	AHP-MABAC	6	6	6	[31]
The process of supporting the decision to purchase an electric car taking into account consumer behaviour	New model, TOPSIS, VIKOR, SAW	11	5	9	[32]
Ranked EV cars with A-class cars and A-class SUVs relatively popular on the Chinese market	ORESTE	8	0	8	[33]
Selection of EV for the needs of sustainable transport under conditions of uncertainty	Fuzzy TOPSIS, Fuzzy SAW, NEAT F-PROMETHEE II	14	14	14	[26]
Choosing an EV in the context of suitability for urban delivery	PROMETHEE II	9	9	36	[35]
Selection of the best model of car for sustainable city transport	COMET	6	6	9	[36]
Ranking of city and compact EVs available on the Polish market	NEAT F-PROMETHEE, Monte Carlo	13	13	14	[37]
Choosing electric urban cars available in Poland	NEAT F-PROMETHEE, Monte Carlo	14	13	9	[34]
Choosing e-vans for city logistics	COMET	9	9	10	[39]
Choosing e-vans for city logistics	PROMETHEE II and Fuzzy TOPSIS	9	9	36	[38]
Selection of EVs for the sustainable development of local government and state administration units in Poland	PROSA-C, Monte Carlo	14	14	12	[40]

VIKOR—Višekriterijumsko Kompromisno Rangiranje; SMAA—Stochastic Multi-Criteria Acceptability Analysis; FAHP—Fuzzy Analytic Hierarchy Process; MABAC—Multi-Attributive Border Approximation Area Comparison; COCOSO—Combined Compromise Solution; ARAS—Additive Ratio Assessment; SECA—Simultaneous Evaluation of Criteria and Alternatives; COPRAS—Complex Proportional Assessment; MAIRCA—Multi-Attributive Ideal–Real Comparative Analysis; MARCOS—Measurement of Alternatives and Ranking according to Compromise Solution; TOPSIS—Technique for Order of Preference by Similarity to Ideal Solution; SAW—Simple Additive Weighting; ORESTE—Organisation, Rangement et Synthese de Donnees Relationnelles; NEAT F-PROMETHEE—New Easy Approach To Fuzzy Preference Ranking Organization Method for Enrichment Evaluation; COMET—Characteristic Objects Method; PROSA-C—PROMETHEE for Sustainability Assessment—Criteria.

Of the studies presented in Table 1, only in three cases, in addition to objective criteria, were subjective criteria also used. Chen et al. [29] used five objective and seven subjective criteria. Subjective ratings were obtained from online reviews of specific cars using sentiment analysis. Similarly, Song et al. [32] obtained subjective ratings from reviews of BEVs posted on the Internet by users. In this study, five quantitative (objective) and six qualitative (subjective) criteria were used to build the vehicle ranking. Also, Tian et al. [33] in their study used online reviews and sentiment analysis as a source of qualitative assessments for subjective criteria, and in the study they used only subjective criteria. Unfortunately, in none of the studies cited did the authors compare the results obtained using subjective criteria with those based solely on objective criteria. Therefore, the influence of subjective criteria on the results obtained when comparing different BEVs is in no way explained.

Based on Table 1, it can be seen that very few studies on BEVs use subjective criteria. Moreover, even if subjective criteria are taken into account in the evaluation of BEVs, there is no study of the impact of these criteria on the obtained vehicle rankings. Similarly, none of the cited publications analysed the imprecision of subjective ratings and the potential impact of the imprecision of judgements on the final rankings. This research gap was addressed in this article, using the PVM-VSI method in the research.

3. Materials and Methods

The PVM-VSI (preference vector method computed in the vector space of increments) method is a modification of the PVM method [41]. PVM and PVM-VSI solve the problem of ranking decision alternatives based on multi-criteria assessment. Both methods distinguish between subjective and objective evaluation criteria. PVM-VSI does not change the results of PVM calculations. The obtained measure values, and therefore the positions in the ranking, are the same. The PVM-VSI method introduces the possibility of calculations using standard deviations to the PVM method. Standard deviations may represent imprecision in the data or imprecision in the decision-maker's response. Due to the need to determine not only the standard deviation but also the covariance, the use of the PVM-VSI method for calculations with imprecise data is very difficult. When data come from different sources, determining covariance becomes very problematic. The article uses a variant of the PVM-VSI method that uses standard deviation to determine the imprecision of the decision-maker's preferences. This allows PVM-VSI to capture the uncertainty and inconsistency in assessments. It adds information about the imprecision of this ranking to the ranking of alternatives. This allows us to determine whether the ranking order of two or more alternatives having similar measure values is significant or not. If the imprecision of the decision-maker's answer is too high, this will translate into the imprecision of the measured value, and therefore the order of these alternatives may not be important and these alternatives should be treated as equivalent. In extreme cases, this may lead to negating the order of alternatives in the entire ranking. The PVM method does not calculate information about the imprecision of the measured value, which, given its small differences for the analysed alternatives, leads to the need for the researcher to intuitively define equivalent alternatives. The steps of the PVM-VSI method are shown in Figure 1.

In Step 1 of the research procedure, the decision-making problem should be formulated, and the evaluated alternatives and evaluation criteria should be established. Criteria should be divided into objective ones, i.e., those that numerically describe the performance of alternatives to the criterion, and subjective criteria, i.e., those for which there are no numerical values describing the performance of alternatives to the criterion. Objective criteria are included in the performance table E, described by Formula (1):

$$E = \begin{bmatrix} c_1(A_1) & c_2(A_1) & \cdots & c_n(A_1) \\ c_1(A_2) & c_2(A_2) & \cdots & c_n(A_2) \\ \vdots & \vdots & \ddots & \vdots \\ c_1(A_m) & c_2(A_m) & \cdots & c_n(A_m) \end{bmatrix} \quad (1)$$

where $c_l(A_i)$ is the performance of alternative A_i on the l-th criterion, m is the number of alternatives, and n is the number of objective criteria.

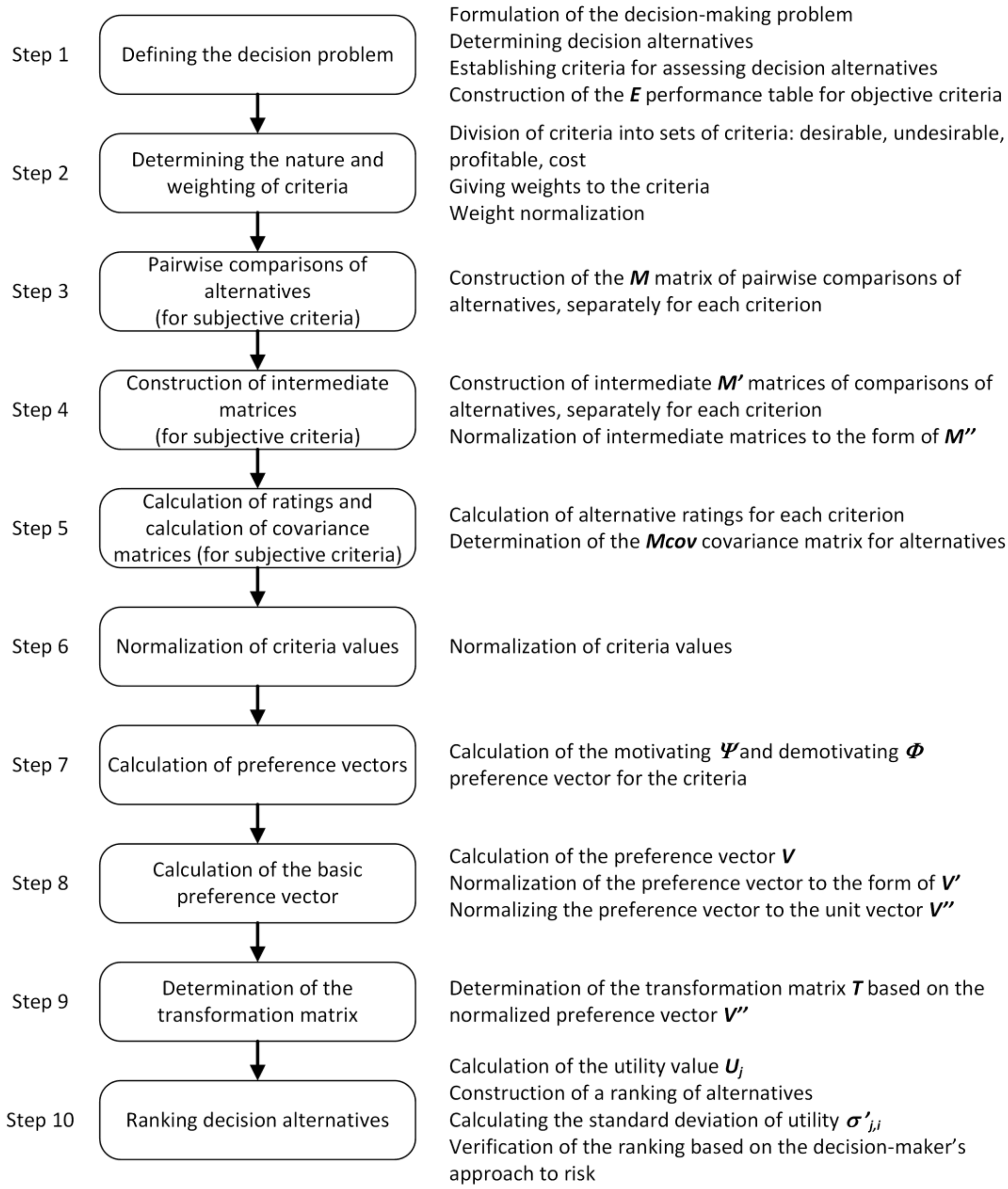

Figure 1. Flow diagram of the PVM-VSI method.

In Step 2, the nature of individual criteria should be determined (criteria such as profit and cost, as well as desirable and undesirable criteria). For profit criteria, the highest values are expected, and for cost criteria, the values are expected to be as low as possible. In turn, desirable criteria are those for which a specific value or range of values is expected. In the case of undesirable criteria, the most unfavourable values that the decision-maker does not want to obtain are defined. Additionally, in Step 2, the weights of individual criteria should be determined. After providing the weights, they are normalized according to Formula (2):

$$w'_l = \frac{w_l}{\sum_{i=1}^{n+N} w_i} \tag{2}$$

where w_l means the weight of the l-th criterion before normalization, w'_l is the weight of the same criterion after normalization, and N means the number of subjective criteria.

Steps 3, 4, and 5 are only performed when there are subjective criteria in the decision-making problem. In Step 3, the decision-maker's preferences (judgements) towards alternatives are examined based on subsequent subjective criteria. Preferences are determined by the decision-maker based on pairwise comparisons according to the rating scale adopted in the study. In Step 3, the pairwise comparison matrices M_l are obtained, described by Formula (3):

$$M_l = \begin{bmatrix} m_l(A_1, A_1) & m_l(A_1, A_2) & \cdots & m_l(A_1, A_m) \\ m_l(A_2, A_1) & m_l(A_2, A_2) & \cdots & m_l(A_2, A_m) \\ \vdots & \vdots & \ddots & \vdots \\ m_l(A_m, A_1) & m_l(A_m, A_2) & \cdots & m_l(A_m, A_m) \end{bmatrix} \tag{3}$$

where l is the index of the criterion and m is the number of alternatives. The elements of the comparison matrix are the values $m_l(A_i, A_j)$ defining the result of the comparison of the i-th and j-th alternatives. It should be pointed out that the information in the pairwise comparison matrices is often inconsistent. This results from the imprecise and often internally contradictory views of the decision-maker. For example, if the alternative A_i is twice as good as A_j and A_j is three times better than A_k, then the alternative A_i should be six times better than A_k. However, decision-makers' assessments often do not maintain such transitivity of preferences, which is manifested by inconsistencies. These inconsistencies are taken into account later in the PVM-VSI calculation procedure.

In Step 4, matrices $M'_l(A_k)$ are determined based on the M_l matrix. The $M'_l(A_k)$ matrix is the intermediate comparison matrix for the A_k alternative. The rows of the $M'_l(A_k)$ matrix contain comparisons of the i-th alternative with respect to the A_k alternative. The columns contain the next k-th decision alternatives. Each element of the $M'_l(A_k)$ matrix is determined based on Formula (4):

$$m'_{l,i,j}(A_k) = m_l(A_k, A_i)\, m_l(A_i, A_j) \tag{4}$$

The values in $M'_l(A_k)$ matrices are normalized to allow comparisons between individual matrices. Normalization leads to obtaining the $M''_l(A_k)$ matrices, the elements of which are described by Formula (5):

$$m''_{l,i,j}(A_k) = m_l(A_k, A_o)\, m'_{l,i,j}(A_k) \tag{5}$$

where o is the index of the alternative to which all $M'_l(A_k)$ matrices are reduced.

The $M''_l(A_k)$ matrices are the basis for performing Step 5, in which the performance of the alternative A_j is determined on the l-th subjective criterion $c_l(A_j)$ according to Formula (6):

$$c_l(A_j) = \frac{\sum_i \sum_{k,\, i \neq k} m''_{l,i,j}(A_k)}{m\,(m-1)} \tag{6}$$

Moreover, in Step 5, the covariance matrices $Mcov_j$ are calculated for all alternatives. The elements of these matrices are defined by Formula (7):

$$mcov_{j,o,p} = \frac{\sum_i \sum_{k,\, i \neq k} \left(m''_{o,i,j}(A_k) - c_l(A_j)\right)\left(m''_{p,i,j}(A_k) - c_l(A_j)\right)}{m\,(m-1)} \tag{7}$$

In Step 6, the performance normalization of the alternatives is performed on the criteria. Vector normalization is used based on Formula (8):

$$\overline{x_{j,l}} = \frac{c_l(A_j)}{\sqrt{\sum_{i=1}^{m} c_l(A_i)^2}} \tag{8}$$

Step 7 involves calculating the motivating $\vec{\Psi}$ and demotivating $\vec{\Phi}$ preference vector for the criteria. In the case of profit criteria, the elements of the motivating preference vector are calculated based on the third quartile, according to Formula (9):

$$\overline{\psi_l} = \text{quart}_{\text{IIIj}}(c_l(A_j)) \tag{9}$$

where l denotes the criterion index, $\overline{\psi}_l$ is an element of the $\vec{\Psi}$ vector, and $\text{quart}_{\text{IIIj}}$ denotes the third quartile calculated on the alternatives. In the case of profit criteria, the elements of the demotivating preference vector are calculated based on the first quartile, according to Formula (10):

$$\overline{\phi_l} = \text{quart}_{\text{Ij}}(c_l(A_j)) \tag{10}$$

It should be noted that for cost criteria, the quartiles are used in reverse, so for the $\vec{\Psi}$ vector, the first quartile is used, and for the $\vec{\Phi}$ vector, the third quartile is used.

In Step 8, the preference vector $\vec{V}$ is calculated. It is simply the difference between the motivating vector $\vec{\Psi}$ and the demotivating vector $\vec{\Phi}$. The elements of vector $\vec{V}$ are calculated according to Formula (11):

$$\overline{v_l} = \overline{\psi_l} - \overline{\phi_l} \tag{11}$$

The $\vec{V}$ vector is normalized to the form $\vec{V}'$ using vector normalization. The normalization of individual elements of the vector is presented in Formula (12):

$$\overline{v_l}' = \frac{\overline{v_l}}{\sqrt{\sum_{i=1}^{m} c_l(A_i)^2}} \tag{12}$$

Then, the $\vec{V}'$ vector is reduced to the form of a unit vector $\vec{V}''$ and weighted with the criteria weights, according to Formula (13):

$$\overline{v_l}'' = \frac{\overline{v_l}\prime w'_l}{\sqrt{\sum_{i=1}^{(n+N)} \overline{v_i}'^2}} \tag{13}$$

In Step 9, the transformation matrix T is determined based on the unit preference vector $\vec{V}''$, according to Formula (14):

$$T = \begin{bmatrix} \overline{v_1}'' & \overline{v_2}'' & \cdots & \overline{v_{n+N}}'' \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 0 \end{bmatrix} \tag{14}$$

The T matrix is always a square matrix. It is used to calculate the utility vectors of the alternatives $\vec{U_j}$.

The $\vec{U_j}$ vectors are calculated in the last 10th step of the PVM-VSI method. The vector $\vec{U_j}$ is the product of the $\vec{X_j}$ vector and the transformation matrix T, which is described by Formula (15):

$$\vec{U_j} = T \times \vec{X_j} \tag{15}$$

All elements of the vector $\vec{U_j}$ except the first one $\left(\overline{u_{j,1}}\right)$ have the value 0. $\overline{u_{j,1}}$ contains the utility (evaluation) of the j-th decision alternative.

If there are subjective criteria in a decision-making problem, in addition to the vector $\vec{U_j}$, the standard deviations of the alternatives are also calculated in the last step. The standard deviations are obtained by transforming the covariance matrices $Mcov_j$ to $Mcov'_j$. The transformation of individual matrix elements is described by Formula (16):

$$mcov'_{j,i,k} = \sum_{o=1}^{L} \sum_{p=1}^{L} t_{i,o} t_{k,p} mcov_{j,o,p} \quad (16)$$

where $t_{i,o}$, $t_{k,p}$ are the elements of the transformation matrix T. The elements of $mcov'_{j,i,k}$ for which $i = k$ are variances. They are the basis for calculating the standard deviations of the utility of alternatives according to Formula (17):

$$\sigma'_{j,i} = \sqrt{mcov'_{j,i,i}} \quad (17)$$

All elements of $\sigma'_{j,i}$ except the first $\left(\sigma'_{j,1}\right)$ are equal to zero. The element $\sigma'_{j,1}$ is the standard deviation of the utility of the j-th alternative. In this case, the standard deviation is a measure of the dispersion of a given alternative depending on the subjective and inconsistent assessments of the decision-maker. In other words, the standard deviation provides information about possible variations in the utility of a given alternative based on the decision-maker's inconsistent and subjective assessments.

In the constructed ranking, the standard deviation can be interpreted as a measure of the uncertainty of the alternative's position on the utility axis. This means that when two decision alternatives lie close to each other on the utility axis, in addition to the utility $(\overline{u_{j,1}})$ you can also compare their standard deviation $\left(\sigma'_{j,1}\right)$. An alternative with a large standard deviation is less stable in ranking and may significantly increase or significantly decrease its utility. The standard deviation in this case may influence the decision-maker's choice of the preferred alternative resulting from the utility value itself. This impact is due to the fact that the standard deviation is strongly related to the decision-maker's approach to risk. In the PVM-VSI method, we distinguished a three-stage approach to risk: (1) risk aversion, (2) risk tendency, (3) tendency to gamble.

1. If a decision-maker is highly risk averse, he will prefer stable alternatives with a small standard deviation (those that maximize the value of $\overline{u_{j,1}} - \sigma'_{j,1}$);
2. A decision-maker with a high propensity to risk will prefer alternatives that, thanks to a high deviation, can take a high position in the ranking (those that maximize the value of $\overline{u_{j,1}} + \sigma'_{j,1}$);
3. In an extreme case (tendency to gamble), the decision-maker may also prefer the j-th alternative, for which the value of $\overline{u_{j,1}} + \sigma'_{j,1}$ is greater than the value of $\overline{u_{k,1}} - \sigma'_{k,1}$ of another k-th alternative.

For a particular decision-maker, risk aversion can be measured. An example of a risk aversion measure defined within the expected utility theory is the Arrow–Pratt measure of absolute risk aversion (ARA) [42]. Based on the calculated value of the risk aversion measure, one of three levels of approach to risk can be selected.

4. Results

The practical aspect of the conducted research consisted in building a ranking of electric cars and identifying the vehicle best suited to the needs of a typical household in Poland. The cars included in the study were selected from among the vehicles currently available on the Polish market. The study took into account the perspective of a hypothetical decision-maker living in a specific medium-sized city in western Poland (Gorzów Wielkopolski). Family cars that can be used for everyday activities, such as transporting family members to school, commuting to work, and transporting shopping and small items, were considered. The car was also supposed to allow family trips farther from home and take an appropriate amount of luggage with them during the trip. Therefore, five-seat vehicles were considered, with a trunk capacity greater than 450 litres and a range of no less than 350 kilometres. Another important factor was the distance to an authorized service centre for a given car brand, no more than 100 kilometres from the decision-maker's place of residence. The budget for the purchase of the vehicle was PLN 200,000, which after increasing the additional payment of PLN 27,000 available in the 'My electrician' government program gives the maximum vehicle price of PLN 227,000.

4.1. Assessment Based on Objective and Subjective Criteria

The evaluation of electric cars was carried out using ten criteria, seven of which were objective. These were quantitative criteria describing the basic parameters of vehicles and their service. The next three criteria reflected the decision-maker's subjective judgements regarding visual aspects and driving comfort. In particular, the following objective criteria were taken into account in the study:

- C1—range on one charge [km]—tested using the WLTP method;
- C2—maximum speed [km/h];
- C3—time to fully charge the batteries with electricity from the wall plug [h];
- C4—engine power [PS];
- C5—minimum trunk capacity [L];
- C6—car price [PLN]—the study took into account the price of the base version of a given car model;
- C7—distance of the authorized service centres from the decision-maker's place of residence [km].

The subjective criteria taken into account were as follows:

- C8—external appearance;
- C9—appearance and functionality of the interior;
- C10—driving comfort.

Objective and subjective criteria were selected taking into account the perspective of a potential user. They include most of the information that is important from the consumer's point of view. Of course, you can also indicate important criteria that are missing, e.g., failure-free performance of the car. However, these types of criteria are difficult to measure due to the lack of reliable information for most cars. Typically, consumers must make purchasing decisions without this type of information.

The above-mentioned criteria allow for the assessment of vehicles taking into account the utility value of the car expected by the consumer (decision-maker) and taking into account preferences regarding the external appearance, interior, and comfort. Six alternatives—BEVs—were assessed:

- A1—Hyundai IONIQ 5 170 KM/58 kWh 2WD;
- A2—Kia EV6 170 KM/58 kWh/RWD;
- A3—Kia Niro EV 204 KM/65 kWh;
- A4—Nissan Ariya 214 KM/63 kWh;
- A5—Škoda ENYAQ iV 60;
- A6—Volkswagen ID.4 Pro/174 KM/77 kWh.

The parameters of individual BEVs were taken from the website elektromobilni.pl [43] and the online database of electric cars, the Electric Vehicle Database [44]. The data come from 2023 and concern BEVs available for current sale through dealer networks operating on the Polish automotive market. The values of the objective (quantitative) criteria for the tested alternatives are presented in Table 2.

Table 2. Performance of alternatives on objective criteria.

Criterion	A1	A2	A3	A4	A5	A6
C1	384	394	560	403	396	535
C2	185	185	167	160	160	160
C3	27.0	29.5	32.0	31.0	29.5	39
C4	170	170	204	214	179	174
C5	527	520	475	468	585	543
C6	203,900	209,900	191,900	209,900	212,250	212,890
C7	35	35	35	89	36	35

A weight (w) was assigned to each objective and subjective criterion, and the nature of the criteria was determined. Table 3 shows the nature of the criteria and their weights before and after the standardization process. Weights were set from 0 to 2. A value of 1 was the typical weight value. If a decision-maker wanted to reduce the influence of a given criterion on the ranking, he or she would have to lower the value of the criterion below the value of 1. Similarly, if he or she wanted to increase the influence of a given criterion on the ranking, he or she would have to raise the value of the criterion above the value of 1.

Table 3. Nature and weights of the criteria.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Nature	Profit	Profit	Cost	Profit	Profit	Cost	Cost	Profit	Profit	Profit
Weight w	1.5	0.5	1.5	0.5	2	1.5	1	1.5	1.5	1
Weight w'	0.12	0.04	0.12	0.04	0.16	0.12	0.08	0.12	0.12	0.08

For subjective criteria, the decision-maker compared pairwise alternatives, obtaining comparison matrices (M), intermediate matrices (M'), performance of alternatives on subjective criteria ($C(\mathrm{A})$), and covariance matrices ($Mcov$). The pairwise comparison matrices, indirect matrices, and covariance matrices are presented in Appendix A, while Table 4 shows the performance of the alternatives based on the subjective criteria.

Table 4. Performance of alternatives based on the subjective criteria.

Criterion	A1	A2	A3	A4	A5	A6
C8	0.2711	0.7627	0.5763	0.9311	0.8729	0.5763
C9	0.1928	0.8390	0.8440	0.9201	0.7027	0.4913
C10	0.5960	0.9155	0.5960	0.9205	0.2700	0.5960

The performance of each j-th alternative on the objective criteria (presented in Table 2) and the performance on the subjective criteria (presented in Table 4) were vector normalized. Table 5 shows the normalized performance vectors of the alternatives ($\vec{X}_j$) on the full criteria set.

Table 5. Normalized performance of the alternatives.

Criterion	A1	A2	A3	A4	A5	A6
C1	0.3474	0.3565	0.5066	0.3646	0.3583	0.4840
C2	0.4446	0.4446	0.4013	0.3845	0.3845	0.3845
C3	0.3493	0.3816	0.4140	0.4010	0.3816	0.5045
C4	0.3732	0.3732	0.4478	0.4698	0.3929	0.3820
C5	0.4128	0.4073	0.3721	0.3666	0.4582	0.4253
C6	0.4023	0.4141	0.3786	0.4141	0.4188	0.4200
C7	0.2946	0.2946	0.2946	0.7491	0.3030	0.2946
C8	0.1579	0.4442	0.3356	0.5423	0.5084	0.3356
C9	0.1107	0.4816	0.4845	0.5281	0.4033	0.2820
C10	0.3547	0.5448	0.3547	0.5478	0.1607	0.3547

In the next steps, the motivating ($\vec{\Psi}$) and demotivating ($\vec{\Phi}$) preference vectors for the criteria were determined, and on their basis, the preference vector ($\vec{V}$) was calculated, which was normalized and then weighted with the criterion weights (w') and normalized to 1. The subsequent preference vectors obtained are presented in Table 6.

Table 6. Vectors: motivating ($\vec{\Psi}$), demotivating ($\vec{\Phi}$), preference vector ($\vec{V}$), normalized vector ($\vec{V}'$), and normalized weighted ($\vec{V}''$).

Vector	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
$\vec{\Psi}$	502	180.5	29.5	197.75	539	205,400	35	0.8453	0.8427	0.8356
$\vec{\Phi}$	394.5	160	31.75	171	486.25	211,662.5	35.75	0.5763	0.5442	0.5960
$\vec{V}$	107.5	20.5	−2.25	26.75	52.75	−6262.5	−0.75	0.269	0.2985	0.2396
$\vec{V}'$	0.0973	0.0493	−0.0291	0.0587	0.0413	−0.0124	−0.0063	0.1567	0.1714	0.1426
$\vec{V}''$	0.0384	0.0065	−0.0115	0.0077	0.0218	−0.0049	−0.0017	0.0619	0.0677	0.0375

Then, the normalized weighted preference vector ($\vec{V}''$) was transformed into a transformation matrix (T). This matrix, together with the vectors of normalized alternative performances ($\vec{X}_j$) were used to calculate the utility vectors ($\vec{U}_j$) of individual alternative BEVs. Additionally, based on the transformation matrix and covariance matrices ($Mcov$), the variances ($mcov'$) and then the standard deviations of the alternatives ($\sigma'_{j,1}$) were calculated. The utilities of the alternatives, their ranking, and standard deviations, as well as the maximum and minimum utility values (after adjusting for the standard deviation) are presented in Table 7. Moreover, Figure 2 presents the utilities and standard deviations graphically.

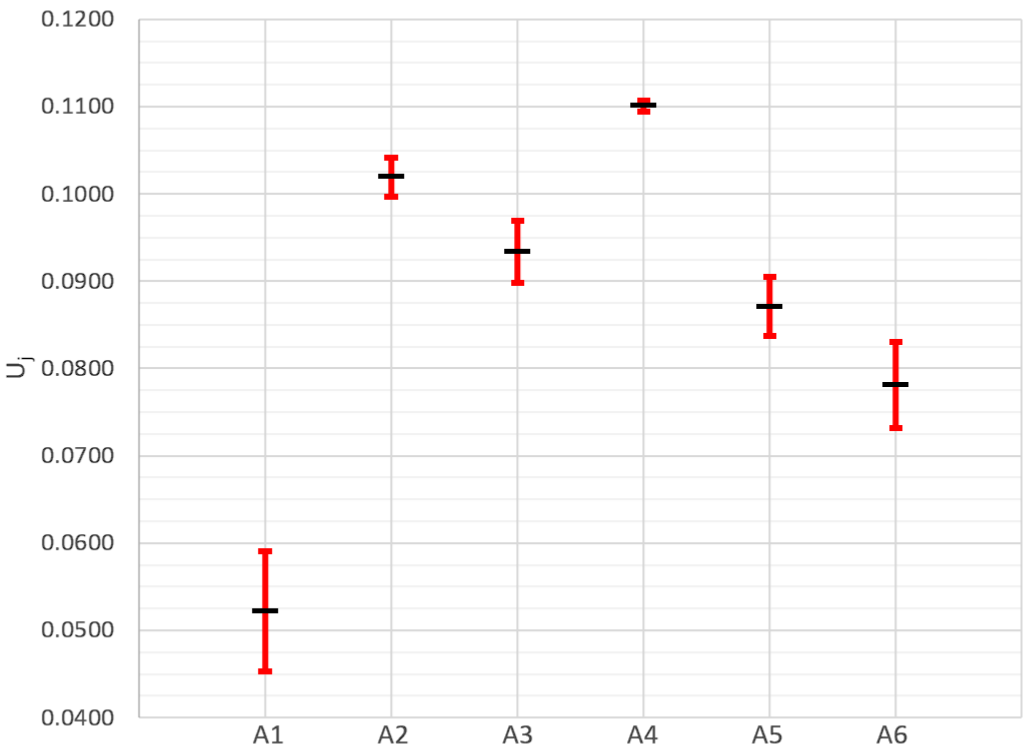

Figure 2. Plot of utility of alternatives and utilities adjusted for standard deviations.

Table 7. Alternative utilities, ranking, standard deviations, and standard deviation-adjusted utilities.

	A1	A2	A3	A4	A5	A6
$\overline{u_{j,1}}$	0.0522	0.1020	0.0934	0.1101	0.0871	0.0781
Rank	6	2	3	1	4	5
$\sigma'_{j,1}$	0.0069	0.0022	0.0036	0.0006	0.0034	0.0050
$\overline{u_{j,1}} - \sigma'_{j,1}$	0.0453	0.0997	0.0898	0.1095	0.0837	0.0732
$\overline{u_{j,1}} + \sigma'_{j,1}$	0.0591	0.1042	0.0969	0.1107	0.0905	0.0831

The analysis of the obtained solution indicates that, according to the adopted criteria, the most useful BEV is A4—Nissan Ariya 214 KM/63 kWh. Second in the ranking is A2—Kia EV6 170 KM/58 kWh/RWD, and the third place is occupied by A3—Kia Niro EV 204 KM/65 kWh. Further alternatives are A5—Škoda ENYAQ iV 60, A6—Volkswagen ID.4 Pro/174 KM/77 kWh, and A1—Hyundai IONIQ 5 170 KM/58 kWh 2WD. The first place taken by the A4 alternative was influenced primarily by the subjective criteria C8—external appearance, C9—interior appearance and functionality, and C10—driving comfort, and the objective criterion C4—engine power. In turn, the second alternative in the ranking, A2, achieved the highest performance on the criteria C2—maximum speed and C7—distance to an authorized service centre, and on the criteria C3—time to fully charge the batteries and C10—comfort, and it took second place. The last alternative in the ranking, A1—Hyundai IONIQ 5 170 KM/58 kWh 2WD, obtained the lowest overall usability primarily due to the subjective criteria C8—external appearance and C9—interior appearance and functionality.

When considering the utilities adjusted for standard deviations, it should be noted that the decision-maker's uncertainty regarding the subjective criteria means that the position of the alternatives A3 and A5 in the ranking may change. However, the remaining alternatives have stable positions in the ranking and the decision-maker's uncertainty regarding subjective assessments does not affect their ranking.

The analysis of standard deviations shows that the decision-maker, when assessing individual BEVs, was relatively consistent in his subjective judgements. The first alternative in the ranking, A4, has the smallest standard deviation. Alternative A2, which ranked second, also has the second lowest standard deviation value. For the third-ranked alternative A3, the standard deviation value is slightly larger than the fourth-ranked alternative A5. The last alternatives in the ranking, A6 and A1, are characterized by the greatest deviations. To summarize the obtained ranking, it should be noted that the differences between both the utilities of the alternatives and the values of the standard deviation are so large that the decision-maker can easily rank the alternatives both in the case of risk aversion and risk propensity. Only in the case of a tendency to gamble may the decision-maker consider changing the order of the A3 and A5 alternatives. However, these are not first choice alternatives as they are ranked behind the leading alternatives A4 and A2.

The criteria weights were determined based on the decision-maker's preferences. Therefore, in order to determine how much the weight values influence the final ranking, a sensitivity analysis was performed. The weight of each criterion was changed linearly in the range [0, 2] (leaving the weights of the remaining criteria in accordance with Table 3) and the utilities of the alternatives were calculated. The results are presented in Figure 3. As can be seen in Figure 3, for most criteria the individual alternatives are far apart throughout the domain. This means that the obtained result is quite resistant to changes in weights. The reordering of alternatives occurs when the lines on the graph intersect. Such an intersection can only be seen in the charts for the criteria C8 and C10. However, for the criteria C1–C7 and C9, a change in weight within the range of [0, 2] does not affect the order of alternatives in the ranking. In the case of the C8 and C10 criteria, the ranking is stable within [0.24, 2] and [0.137, 2], respectively. However, the change in the ranking in this case only concerns the exchange of two non-leading alternatives. Taking into account that the standard weight of the C8 criterion was 1.5 and for C10 it was 1, the obtained solution was stable.

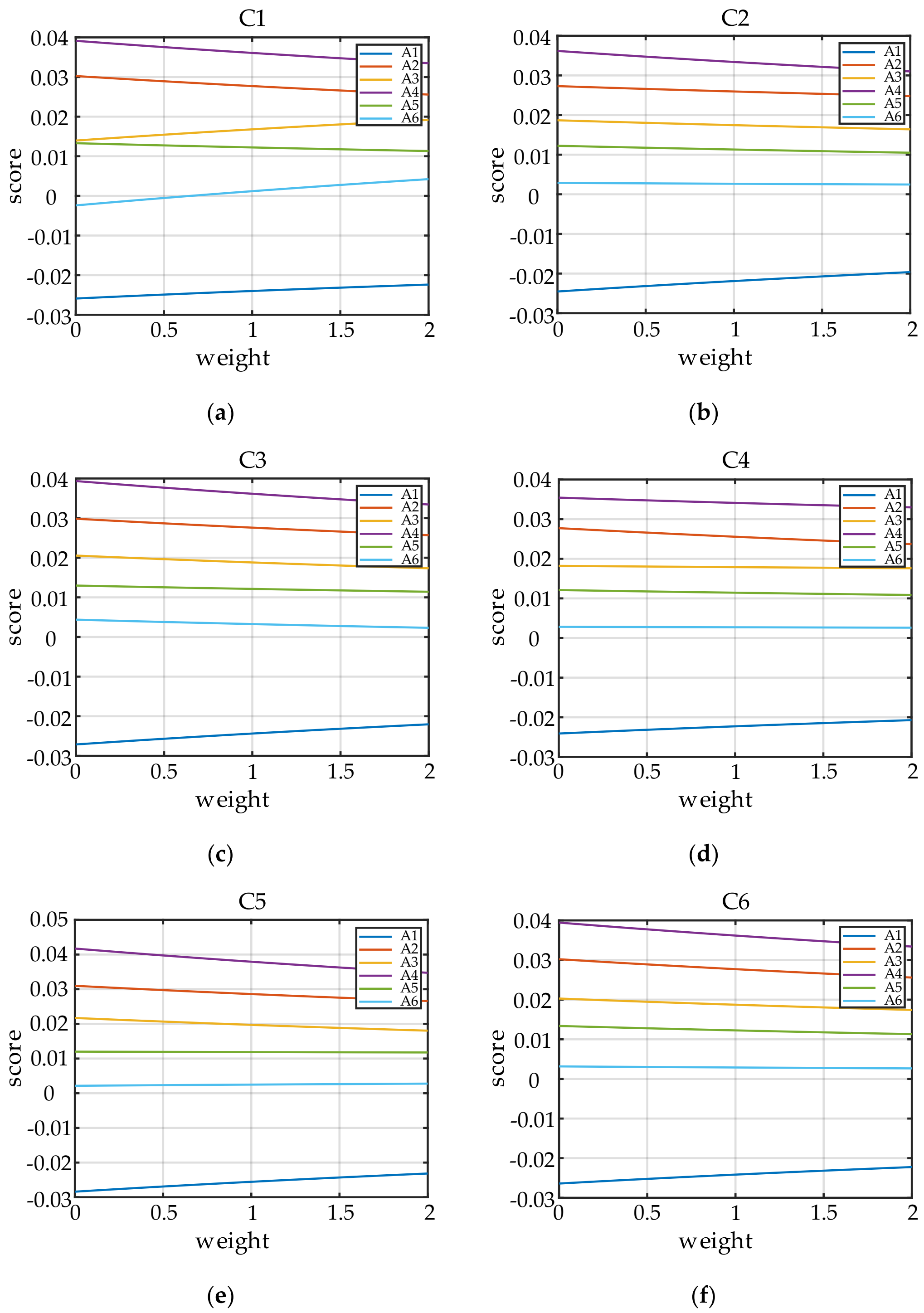

Figure 3. *Cont.*

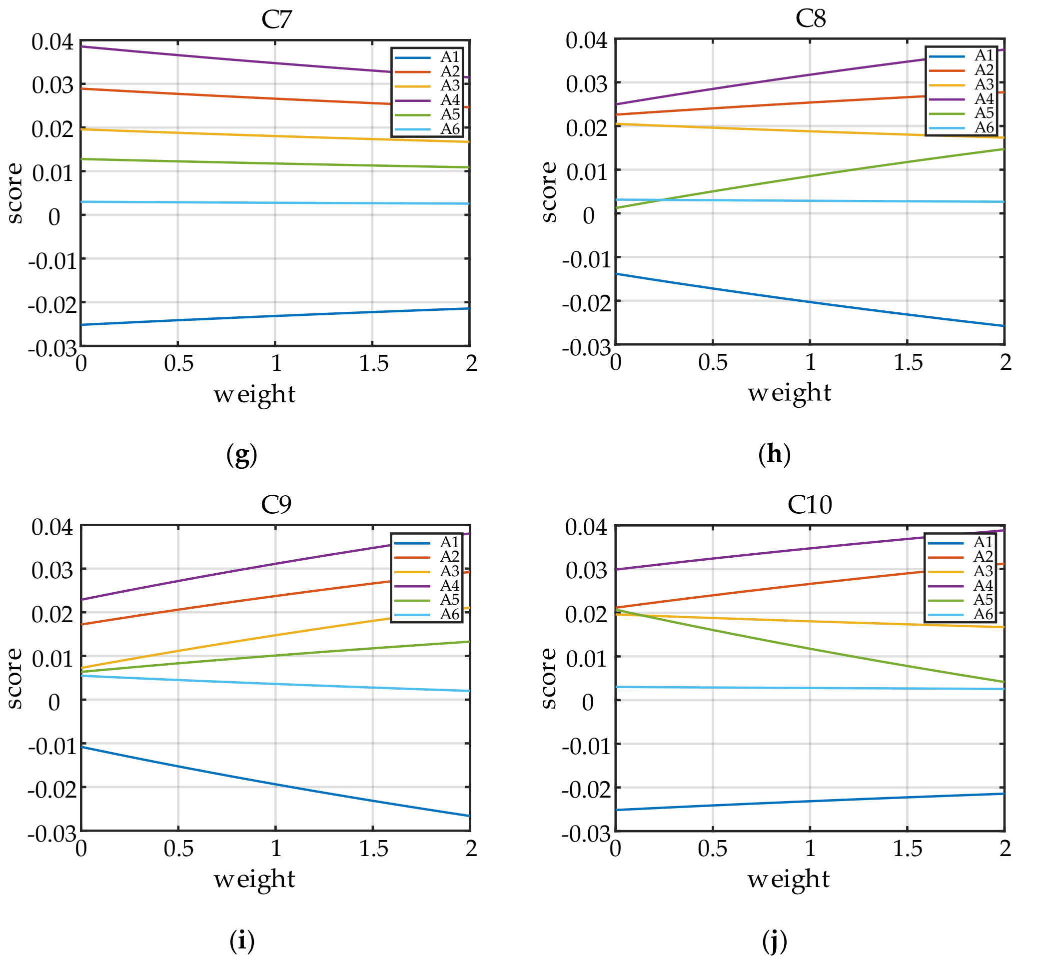

Figure 3. Sensitivity analysis for the criteria weights: (**a**) C1—range on one charge; (**b**) C2—maximum speed; (**c**) C3—time to fully charge the batteries with electricity from the wall plug; (**d**) C4—engine power; (**e**) C5—minimum trunk capacity; (**f**) C6—car price; (**g**) C7—distance of the authorized service centres from the decision-maker's place of residence; (**h**) C8—external appearance; (**i**) C9—appearance and functionality of the interior; (**j**) C10—driving comfort.

4.2. Assessment Based Solely on Objective Criteria

In order to examine the impact of subjective criteria on the obtained vehicle ranking, the study was repeated, excluding subjective criteria and considering only quantitative objective criteria. For this reason, the repeated study omitted the steps of the PVM-VSI method closely related to subjective criteria: pairwise comparisons of alternatives, the construction of intermediate matrices, and the calculation of ratings and covariances for subjective criteria, as well as the calculation of utility standard deviations.

The input data included only objective criteria. In particular, these were the values of the alternatives presented in Table 2. Due to the limited number of criteria, the normalized weight values have changed. The new weights are presented in Table 8.

Table 8. Weights of criteria in the repeated study.

	C1	C2	C3	C4	C5	C6	C7
Weight w	1.5	0.5	1.5	0.5	2	1.5	1
Weight w'	0.1765	0.0588	0.1765	0.0588	0.2353	0.1765	0.1176

The normalized values of the alternatives were identical to the values from Table 5, and these values included the criteria C1–C7, without the subjective criteria C8–C10. The values of the motivating ($\vec{\Psi}$) and demotivating ($\vec{\Phi}$) preference vectors, the preference vector ($\vec{V}$), and its normalized form ($\vec{V}'$) for the criteria C1–C7 were also the same as in the first study (see: Table 6). Due to the change in the normalized values of weights (w'), the value of the normalized weighted preference vector ($\vec{V}''$) has changed. The new values of this preference vector are presented in Table 9.

Table 9. Normalized weighted preference vector ($\vec{V}''$) obtained in the repeated study.

Vector	C1	C2	C3	C4	C5	C6	C7
$\vec{V}''$	0.1276	0.0216	−0.0382	0.0257	0.0723	−0.0162	−0.0055

Based on the $\vec{V}''$ vector, the transformation matrix (T) was determined, and then, based on the T matrix and the vectors of normalized efficiency of alternatives ($\vec{X}_j$), the utility vectors ($\vec{U}_j$) of individual BEVs were calculated. Table 10 shows the utility values and ranking of BEVs obtained in the study based solely on objective criteria.

Table 10. Utilities and ranking in a repeated analysis based solely on objective criteria.

	A1	A2	A3	A4	A5	A6
$\overline{u_{j,1}}$	0.0719	0.0712	0.0881	0.0672	0.0742	0.0829
Rank	4	5	1	6	3	2

The evaluation results indicate that, taking into account only the objective criteria, the best alternative is A3—Kia Niro EV 204 KM/65 kWh, the second place goes to A6—Volkswagen ID.4 Pro/174 KM/77 kWh, and the third to A5—Škoda ENYAQ iV 60. The next positions in the ranking are taken by A1—Hyundai IONIQ 5 170 KM/58 kWh 2WD, A2—Kia EV6 170 KM/58 kWh/RWD, and A4—Nissan Ariya 214 KM/63 kWh, respectively. The A3 alternative took first place in the ranking due to the highest performance on the criteria C1—range, C6—price, and C7—distance to an authorized service centre, and the high importance of these criteria. The A6 alternative, ranked second, owes its position to a high (but not the highest) performance on the criteria C1—range, and C5—trunk capacity. In turn, the C5 criterion—trunk capacity—had the greatest impact on the relatively good position of the A5 alternative.

When comparing the course and results of an assessment based on a full set of criteria (objective and subjective criteria) and on a limited set of criteria (only objective criteria), several observations can be made. These results are also an answer to the research question about how subjective criteria and the imprecision of judgements influence the results of the multi-criteria assessment of BEVs.

- Firstly, by comparing Tables 3 and 8, as well as Tables 6 and 9, it can be seen that the omission of the subjective criteria C8–C10 only results in a proportional increase in the importance of the objective criteria C1–C7, without in any way changing, for example, their ordering according to importance.
- Secondly, in the examined case, subjective criteria had a significant impact on the obtained evaluation results (utility of alternatives). This influence was greater than the weights of the subjective criteria would indicate. Although the highest weight was assigned to the objective criterion C5, and the objective criteria C1, C3, and C6 had the same weights as the subjective criteria C8 and C9, the final significance of the criteria took a different order. The final criteria significances (reflected in the absolute values of the vector $\vec{V}''$) result from both the criteria weights and the statistical characteristics (quartiles) of the performance of alternatives on the criteria. Table 6 shows that the most important objective criterion is C1. As for the subjective criteria,

the final importance of each of the C8 and C9 criteria is almost twice as important as the criterion C1, and the criterion C10 is almost as important as C1.

- Thirdly, the above-mentioned high importance of the subjective criteria significantly influenced the differences between the ranking based on a full set of criteria and a limited set of criteria. The alternative A4, which was the ranking based on the full set of criteria, placed last after removing the subjective criteria. This is not surprising because, as indicated in Section 4, the alternative A4 took the first place mainly due to the subjective criteria. Similarly, the alternative A2 dropped from Position 2 in the ranking based on the full set of criteria to Position 5 in the ranking using only the objective criteria. The remaining alternatives in the ranking based solely on the objective criteria improved their positions relative to the ranking based on the full set of criteria. The alternative A1 advanced from Position 6 to 4, A5 improved its position from 4 to 3, A3 moved from the middle of the pack (3) to the winner of the ranking, and A6 improved by as many as 3 positions and advanced from Position 5 to 2.

Taking into account the above observations and the fact that in the case of a tendency to gamble, the alternatives A3 and A5 provide the basis (based on the value of standard deviations) for replacing them, the research hypothesis can be considered confirmed: Subjective criteria and the imprecision of judgements have a significant impact on the results of the multi-criteria assessment of BEVs.

5. Discussion

The PVM-VSI method was compared with two methods using the outranking relationship (PROMETHEE II and ELECTRE III) and two methods based on the value/utility theory (TOPSIS and AHP, with TOPSIS also considered as a benchmarking method). Rankings based on both objective and subjective criteria were examined. The PROMETHEE method uses the V-shape preference function using a preference threshold (p). The V-shape criterion is similar to the definition of the discordance index in the ELECTRE III method. In fact, these two functions are the same when in the ELECTRE III method the indifference threshold (q) is zero and the veto threshold (v) is not used. The values of the preference threshold used in the PROMETHEE II and ELECTRE III methods are presented in Table 11. According to the recommendations given in the literature, the values of this threshold are between the credible minimum and maximum values of the criterion, as well as between the minimum and maximum values of the range between the criterion values [40].

Table 11. Preference thresholds used in the PROMETHEE II and ELECTRE III methods.

Criterion	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Preference threshold	75	12	5	20	45	10,000	25	2	2	3

The calculation results for the PROMETHEE II method are presented in Table 12. The best alternative was A2—Kia EV6 170 KM/58 kWh/RWD, and the second place was taken by the alternative A3—Kia Niro EV 204 KM/65 kWh. The worst alternative turned out to be the A6 alternative—Volkswagen ID.4 Pro/174 KM/77 kWh.

Table 12. Results for the PROMETHEE II method along with its place in the ranking.

	A1	A2	A3	A4	A5	A6
Phi+	0.2856	0.3439	0.3940	0.3568	0.3523	0.2380
Phi−	0.3857	0.2245	0.3048	0.3536	0.2680	0.4340
Phi	−0.1001	0.1194	0.0892	0.0032	0.0843	−0.1960
Rank	5	1	2	4	3	6

The calculation results for the ELECTRE III method are presented in Table 13. The ELECTRE ranking is similar to the PROMETHEE ranking, which is justified due to the methodological similarities between the ELECTRE III and PROMETHEE II methods. The rankings obtained using these methods differ only by the position of the A5 alternative. In the ELECTRE III ranking, the A5 alternative—Škoda ENYAQ iV 60 turned out to be the best, along with the A2 alternative—Kia EV6 170 KM/58 kWh/RWD. The third place was taken by the A3 alternative—Kia Niro EV 204 KM/65 kWh, and the order of the remaining alternatives is the same as in the PROMETHEE ranking. The fourth and fifth places were taken by A4—Nissan Ariya 214 KM/63 kWh and A1—Hyundai IONIQ 5 170 KM/58 kWh 2WD, respectively. The last place was taken by the A6 alternative—Volkswagen ID.4 Pro/174 KM/77 kWh.

Table 13. Results for the ELECTRE III method along with its place in the ranking.

	A1	A2	A3	A4	A5	A6
Top-down distillation	4	1	3	4	1	4
Bottom-up distillation	5	1	1	1	1	6
Final rank	5	1	3	4	1	6

The calculation results for the TOPSIS method are presented in Table 14. The results obtained are very similar to those obtained for the PROMETHEE method. The only difference is the exchange of the alternatives in Positions 5 and 6. The TOPSIS method indicated A1—Hyundai IONIQ 5 170 KM/58 kWh 2WD as the worst alternative, and the penultimate place was taken by the A6 alternative—Volkswagen ID.4 Pro/174 KM/77 kWh.

Table 14. Results for the TOPSIS method along with its place in the ranking.

	A1	A2	A3	A4	A5	A6
Score	0.378673	0.753559	0.666874	0.636000	0.633930	0.532856
Rank	6	1	2	4	3	5

The calculation results for the AHP method are presented in Table 15. The results obtained for the two worst alternatives are identical to those for the TOPSIS method. The best alternative turned out to be the A4 alternative—Nissan Ariya 214 KM/63 kWh, and the second place was taken by the A2 alternative—Kia EV6 170 KM/58 kWh/RWD. In the case of alternatives occupying Positions 1 to 4, the AHP method obtained the results that differed the most from the results of the previously analysed ELECTRE, PROMETHEE, and TOPSIS methods.

Table 15. Results for the AHP method along with its place in the ranking.

	A1	A2	A3	A4	A5	A6
Score	0.125001	0.177100	0.155619	0.235776	0.158884	0.147621
Rank	6	2	4	1	3	5

Table 16 summarizes the results of all methods with the results of the PVM-VSI method for the ten criteria. The PVM-VSI ranking turned out to be the most similar to the AHP method ranking. The only difference is the replacement of the A3—Kia Niro EV 204 KM/65 kWh and A5—Škoda ENYAQ iV 60 alternatives. It should be noted that the possibility of such an exchange of places was already indicated in the results of the PVM-VSI method due to the utilities adjusted for standard deviations. The PVM-VSI and AHP methods indicated A4 as the best alternative—Nissan Ariya 214 KM/63 kWh, and the PROMETHEE, ELECTRE, and TOPSIS methods indicated the A2 alternative—Kia EV6 170 KM/58 kWh/RWD.

Table 16. Summary of ranking results for the PVM-VSI, PROMETHEE, TOPSIS, ELECTRE III, and AHP methods.

	A1	A2	A3	A4	A5	A6
PVM-VSI	6	2	3	1	4	5
PROMETHEE II	5	1	2	4	3	6
TOPSIS	6	1	2	4	3	5
ELECTRE III	5	1	3	4	1	6
AHP	6	2	4	1	3	5

The A4 alternative is worse than the A2 alternative in terms of four criteria (C2, C3, C5, and C7) and better than it in terms of four criteria (C1, C4, C8, and C9). For two criteria (C6 and C10), the criteria values are the same. If you add up the weights for which the A4 alternative is better than the A2 alternative, the sum will be five. The sum of the weights in which the A2 alternative is better than the A4 alternative is also five. The criterion in which the differences between these alternatives are the largest is C7—distance from the service. It can be suspected that this is the key reason why the PROMETHEE and TOPSIS methods placed this alternative in Position 4. Considering that most of the remaining criteria were better for the A4 alternative than for the A2 alternative, such a low position of the A4 alternative seems questionable.

The C7 criterion is a criterion with an unusual object, where the A4 alternative is the unusual object. For this type of criterion, all values are similar to each other (in the presented study, the values are 35 or 36), and only one of the values differs significantly from the others (A4: 89). Such criteria may distort the rankings in some methods. One such distortion is the excessive favouring of an unusual object [45]. In the case of the C7 criterion, it is costly, so instead of favouring the A4 alternative, the C7 criterion devalues it. This justifies the low position of the A4 alternative in the rankings of the PROMETHEE, ELECTRE, and TOPSIS methods. Taking into account the above results, it can be concluded that for this case study, the PVM-VSI and AHP methods turned out to be resistant to the occurrence of unusual objects. An additional advantage of the PVM-VSI method over AHP and other methods is the additional information provided by this method regarding the uncertainty (imprecision) of the obtained result.

Taking into account that two methods indicated the A4 alternative as the best, and three methods indicated the A2 alternative, it can be concluded that the A4—Nissan Ariya 214 KM/63 kWh and A2—Kia EV6 170 KM/58 kWh/RWD alternatives are equivalent and are the best choice. The ELECTRE III method also indicated the A5 alternative—Škoda ENYAQ iV 60 as equivalent to the A2 alternative, but the other methods rated this alternative as average (third and fourth position). This result leads to the answer to the first research question. The Kia EV6 170 KM/58 kWh/RWD and Nissan Ariya 214 KM/63 kWh cars can be considered the most suitable for a household in Poland in the selected medium-sized city.

6. Conclusions

The subject of the article was the selection of BEVs for households in Poland on the example of a household in Gorzów Wielkopolski and examining the impact of subjective criteria on the obtained results. The analysis of the literature showed the importance of the problem related to the choice of BEVs resulting from the policy leading to pollution reduction, which has resulted in an increase in sales of electric cars in recent years. In the process of selecting BEVs, the PVM-VSI method was used to build a ranking of alternatives. An additional feature is the ability to measure the imprecision of the decision-maker’s response when determining the value of subjective criteria and to take this imprecision into account in the final ranking. This method was used in the study because it allows for the separation of objective and subjective criteria, as well as for capturing and measuring the imprecision of subjective judgements. The obtained results were compared with those obtained using the following methods: PROMETHEE II, TOPSIS, ELECTRE III, and AHP.

The practical aim of the article was to analyse BEVs used in households in Poland and to select the vehicle with the highest utility in a specific case study. However, the scientific goal, and at the same time the contribution of the article, was to examine the potential impact of subjective criteria on the assessment of the usefulness of individual BEVs. It should be noted here that the criteria subjectively assessed by the decision-maker are characterized by imprecise judgements, which may also affect the final assessment results. Both goals were achieved using an MCDA method called PVM-VSI.

The article creates two rankings of BEVs. The first one includes seven objective criteria (measurable, qualitative) obtained from the technical specifications of individual vehicles and three subjective criteria (immeasurable, qualitative) expressed in the form of the decision-maker's judgements. In the second study, only seven objective criteria were used. In a study using objective and subjective criteria, the first place in the ranking was occupied by the A4 vehicle—Nissan Ariya 214 KM/63 kWh. In the decision-maker's opinion, it offers the most attractive appearance, interior functionality, and comfort. However, in the ranking based solely on objective criteria, the winner was the A3 vehicle—Kia Niro EV 204 KM/65 kWh, which dominates over the others in terms of the range, price, and distance to service, and also performs well in terms of engine power and maximum speed. It should also be noted that the winner of the first study ranked last in this ranking. Moreover, the values of standard deviations provide a basis for replacing the A3 and A5 alternatives. This indicates the importance of subjective criteria and the imprecision of information, as these factors can influence the order of alternatives in the ranking. At the same time, it is an answer to the second research question (How do subjective criteria and imprecision of judgements influence the results of the multi-criteria assessment of BEVs?) and confirms the hypothesis: Subjective criteria and the imprecision of judgements have a significant impact on the results of the multi-criteria assessment of BEVs. Analysing the results in terms of the answer to the first research question (Which BEV car(s) are most suitable for a household in Poland in the example medium-sized city?), it was found that these are the Kia EV6 170 KM/58 kWh/RWD and Nissan Ariya 214 KM/63 kWh cars. This is due to the fact that in the rankings constructed using six methods, they won three and two rankings, respectively.

The research conducted is a case study for purchasing a car. Even in the case of a study using only objective criteria, it takes into account the distance from the service, which varies for different cities. In addition, weights are established that express the decision-maker's preferences and are specific to him and people with similar needs. However, these studies constitute a template that can be used for any city and any group of people with similar preferences. First of all, it should be determined for which group of people (with what preferences) the study is being conducted. This allows the selection of weights appropriate for them. In the second order, a city should be indicated. This determines the distance from a possible service centre and the available car models. The contribution and innovation of the article is the application of the PVM-VSI method to the study of electric cars. This allowed us to determine the impact of the imprecision of the decision-maker's response and subjective criteria on the ranking of alternatives.

The conducted research is not free from research limitations. The main limitation is the fact that the research is a case study of a specific decision-maker and his subjective judgements supplementing the objective criteria. A different decision-maker, expressing different subjective judgements, could obtain a completely different ordering of vehicles, especially since, as it has been shown, subjective criteria can have a decisive impact on the ranking of alternatives. A solution to this limitation could be the modification of the PVM-VSI method to a stochastic form, analysing a set of many different pseudo-random judgements for subjective criteria, similar to the methods from the SMAA (stochastic multi-criteria acceptability analysis) family. Work on such a development of the PVM-VSI method will be one of the directions of further research. Another interesting direction of research will be to deepen analyses of the three-stage approach to risk in the PVM-VSI method. In particular, it would be worth considering examples of decision-making problems in which the order in the rankings changes depending on the selected level of risk acceptance.

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Appendix A

Table A1. Pairwise comparison matrix for the criterion C8—external appearance.

	A1	A2	A3	A4	A5	A6
A1	1	1/3	1/2	1/5	1/4	1/2
A2	3	1	2	1/3	1/2	2
A3	2	1/2	1	1/4	1/3	1
A4	5	3	4	1	2	4
A5	4	2	3	1/2	1	3
A6	2	1/2	1	1/4	1/3	1

Table A2. Pairwise comparison matrix for the criterion C9—interior appearance and functionality.

	A1	A2	A3	A4	A5	A6
A1	1	1/4	1/4	1/5	1/3	1/2
A2	4	1	1	1/2	2	3
A3	4	1	1	1/2	2	3
A4	5	2	2	1	3	4
A5	3	1/2	1/2	1/3	1	2
A6	2	1/3	1/3	1/4	1/2	1

Table A3. Pairwise comparison matrix for the criterion C10—driving comfort.

	A1	A2	A3	A4	A5	A6
A1	1	1/4	1	1/4	2	1
A2	4	1	4	1	5	4
A3	1	1/4	1	1/4	2	1
A4	4	1	4	1	5	4
A5	1/2	1/5	1/2	1/5	1	1/2
A6	1	1/4	1	1/4	2	1

Table A4. Intermediate comparison matrix for the criterion C8—external appearance.

	A1	A2	A3	A4	A5	A6
A1		0.1120	0.1080	0.1152	0.1140	0.1080
A1 (A2)		0.0960	0.1040	0.117333	0.1160	0.1040
A1 (A3)		0.1140	0.1080	0.1170	0.1160	0.1080
A1 (A4)		0.1056	0.1008	0.1152	0.1104	0.1008
A1 (A5)		0.1080	0.1020	0.1170	0.1140	0.1020
A1 (A6)		0.1140	0.1080	0.1170	0.1160	0.1080
A2 (A1)	0.0480		0.0840	0.1056	0.1020	0.0840
A2	0.0480		0.0720	0.1120	0.1080	0.0720
A2 (A3)	0.0240		0.0720	0.1080	0.1040	0.0720

Table A4. *Cont.*

	A1	A2	A3	A4	A5	A6
A2 (A4)	0.0800		0.0880	0.1120	0.1040	0.0880
A2 (A5)	0.0720		0.0840	0.1140	0.1080	0.0840
A2 (A6)	0.0240		0.0720	0.1080	0.1040	0.0720
A3 (A1)	0.0720	0.1040		0.1104	0.1080	0.0960
A3 (A2)	0.0840	0.1080		0.1160	0.1140	0.0960
A3	0.0720	0.1080		0.1140	0.1120	0.0960
A3 (A4)	0.0900	0.1020		0.1140	0.1080	0.0960
A3 (A5)	0.0880	0.1040		0.1160	0.1120	0.0960
A3 (A6)	0.0720	0.1080		0.1140	0.1120	0.0960
A4 (A1)	0.0000	0.0800	0.0600		0.0900	0.0600
A4 (A2)	−0.0960	0.0480	−0.0240		0.0840	−0.0240
A4 (A3)	−0.0720	0.0720	0.0240		0.0880	0.0240
A4	0.0000	0.0480	0.0240		0.0720	0.0240
A4 (A5)	−0.0720	0.0240	−0.0240		0.0720	−0.0240
A4 (A6)	−0.0720	0.0720	0.0240		0.0880	0.0240
A5 (A1)	0.0240	0.0880	0.0720	0.1008		0.0720
A5 (A2)	−0.0240	0.0720	0.0240	0.1040		0.0240
A5 (A3)	−0.0240	0.0840	0.0480	0.1020		0.0480
A5 (A4)	0.0600	0.0840	0.0720	0.1080		0.0720
A5	0.0240	0.0720	0.0480	0.1080		0.0480
A5 (A6)	−0.0240	0.0840	0.0480	0.1020		0.0480
A6 (A1)	0.0720	0.1040	0.0960	0.1104	0.1080	
A6 (A2)	0.0840	0.1080	0.0960	0.1160	0.1140	
A6 (A3)	0.0720	0.1080	0.0960	0.1140	0.1120	
A6 (A4)	0.0900	0.1020	0.0960	0.1140	0.1080	
A6 (A5)	0.0880	0.1040	0.0960	0.1160	0.1120	
A6	0.0720	0.1080	0.0960	0.1140	0.1120	

Table A5. Intermediate comparison matrix for the criterion C9—interior appearance and functionality.

	A1	A2	A3	A4	A5	A6
A1		0.1140	0.1140	0.1152	0.1120	0.1080
A1 (A2)		0.0960	0.1140	0.1170	0.1080	0.1020
A1 (A3)		0.1140	0.1140	0.1170	0.1080	0.1020
A1 (A4)		0.1104	0.1104	0.1152	0.1056	0.1008
A1 (A5)		0.1160	0.1160	0.1173	0.1120	0.1040
A1 (A6)		0.1160	0.1160	0.1170	0.1140	0.1080
A2 (A1)	0.0240		0.0960	0.1008	0.0880	0.0720
A2	0.0240		0.0960	0.1080	0.0720	0.0480
A2 (A3)	0.0240		0.0960	0.1080	0.0720	0.0480
A2 (A4)	0.0600		0.0960	0.1080	0.0840	0.0720
A2 (A5)	−0.0240		0.0960	0.1040	0.0720	0.0240
A2 (A6)	−0.0240		0.0960	0.1020	0.0840	0.0480
A3 (A1)	0.0240	0.0960		0.1008	0.0880	0.0720
A3 (A2)	0.0240	0.0960		0.1080	0.0720	0.0480
A3	0.0240	0.0960		0.1080	0.0720	0.0480
A3 (A4)	0.0600	0.0960		0.1080	0.0840	0.0720
A3 (A5)	−0.0240	0.0960		0.1040	0.0720	0.0240
A3 (A6)	−0.0240	0.0960		0.1020	0.0840	0.0480
A4 (A1)	0.0000	0.0900	0.0900		0.0800	0.0600
A4 (A2)	−0.0720	0.0720	0.0720		0.0240	−0.0240
A4 (A3)	−0.0720	0.0720	0.0720		0.0240	−0.0240
A4	0.0000	0.0720	0.0720		0.0480	0.0240
A4 (A5)	−0.0960	0.0840	0.0840		0.0480	−0.0240
A4 (A6)	−0.0720	0.0880	0.0880		0.0720	0.0240
A5 (A1)	0.0480	0.1020	0.1020	0.1056		0.0840

Table A5. *Cont.*

	A1	A2	A3	A4	A5	A6
A5 (A2)	0.0720	0.1080	0.1080	0.1140		0.0840
A5 (A3)	0.0720	0.1080	0.1080	0.1140		0.0840
A5 (A4)	0.0800	0.1040	0.1040	0.1120		0.0880
A5	0.0480	0.1080	0.1080	0.1120		0.0720
A5 (A6)	0.0240	0.1040	0.1040	0.1080		0.0720
A6 (A1)	0.0720	0.1080	0.1080	0.1104	0.1040	
A6 (A2)	0.0880	0.1120	0.1120	0.1160	0.1040	
A6 (A3)	0.0880	0.1120	0.1120	0.1160	0.1040	
A6 (A4)	0.0900	0.1080	0.1080	0.1140	0.1020	
A6 (A5)	0.0840	0.1140	0.1140	0.1160	0.1080	
A6	0.0720	0.1120	0.1120	0.1140	0.1080	

Table A6. Intermediate comparison matrix for the criterion C10—driving comfort.

	A1	A2	A3	A4	A5	A6
A1		0.0760	0.0640	0.0760	0.0480	0.0640
A1 (A2)		0.0640	0.0640	0.0760	0.0600	0.0640
A1 (A3)		0.0760	0.0640	0.0760	0.0480	0.0640
A1 (A4)		0.0760	0.0640	0.0760	0.0600	0.0640
A1 (A5)		0.0736	0.0640	0.0736	0.0480	0.0640
A1 (A6)		0.0760	0.0640	0.0760	0.0480	0.0640
A2 (A1)	0.0160		0.0160	0.0640	−0.0480	0.0160
A2	0.0160		0.0160	0.0640	0.0000	0.0160
A2 (A3)	0.0160		0.0160	0.0640	−0.0480	0.0160
A2 (A4)	0.0160		0.0160	0.0640	0.0000	0.0160
A2 (A5)	0.0400		0.0400	0.0640	0.0000	0.0400
A2 (A6)	0.0160		0.0160	0.0640	−0.0480	0.0160
A3 (A1)	0.0640	0.0760		0.0760	0.0480	0.0640
A3 (A2)	0.0640	0.0760		0.0760	0.0600	0.0640
A3	0.0640	0.0760		0.0760	0.0480	0.0640
A3 (A4)	0.0640	0.0760		0.0760	0.0600	0.0640
A3 (A5)	0.0640	0.0736		0.0736	0.0480	0.0640
A3 (A6)	0.0640	0.0760		0.0760	0.0480	0.0640
A4 (A1)	0.0160	0.0640	0.0160		−0.0480	0.0160
A4 (A2)	0.0160	0.0640	0.0160		0.0000	0.0160
A4 (A3)	0.0160	0.0640	0.0160		−0.0480	0.0160
A4	0.0160	0.0640	0.0160		0.0000	0.0160
A4 (A5)	0.0400	0.0640	0.0400		0.0000	0.0400
A4 (A6)	0.0160	0.0640	0.0160		−0.0480	0.0160
A5 (A1)	0.0720	0.0780	0.0720	0.0780		0.0720
A5 (A2)	0.0672	0.0768	0.0672	0.0768		0.0672
A5 (A3)	0.0720	0.0780	0.0720	0.0780		0.0720
A5 (A4)	0.0672	0.0768	0.0672	0.0768		0.0672
A5	0.0720	0.0768	0.0720	0.0768		0.0720
A5 (A6)	0.0720	0.0780	0.0720	0.0780		0.0720
A6 (A1)	0.0640	0.0760	0.0640	0.0760	0.0480	
A6 (A2)	0.0640	0.0760	0.0640	0.0760	0.0600	
A6 (A3)	0.0640	0.0760	0.0640	0.0760	0.0480	
A6 (A4)	0.0640	0.0760	0.0640	0.0760	0.0600	
A6 (A5)	0.0640	0.0736	0.0640	0.0736	0.0480	
A6	0.0640	0.0760	0.0640	0.0760	0.0480	

Table A7. Covariance matrix for the alternative A1.

	C8	C9	C10
C8	0.003124782	0.001889396	0.000560384
C9	0.001889396	0.002821249	0.000713749
C10	0.000560384	0.000713749	0.000549274

Table A8. Covariance matrix for the alternative A2.

	C8	C9	C10
C8	0.000485935	0.000197974	0.000074462
C9	0.000197974	0.000164876	0.000051663
C10	0.000074462	0.000051663	0.000027022

Table A9. Covariance matrix for the alternative A3.

	C8	C9	C10
C8	0.001330649	0.000369619	0.000354931
C9	0.000369619	0.000169700	0.000245636
C10	0.000354931	0.000245636	0.000549274

Table A10. Covariance matrix for the alternative A4.

	C8	C9	C10
C8	0.000023776	0.000009428	0.000000779
C9	0.000009428	0.000028220	0.000012117
C10	0.000000779	0.000012117	0.000024270

Table A11. Covariance matrix for the alternative A5.

	C8	C9	C10
C8	0.000149874	0.000227836	0.000313472
C9	0.000227836	0.000586916	0.000555488
C10	0.000313472	0.000555488	0.001635840

Table A12. Covariance matrix for the alternative A6.

	C8	C9	C10
C8	0.001330649	0.000959414	0.000354931
C9	0.000959414	0.001409873	0.000506974
C10	0.000354931	0.000506974	0.000549274

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