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RESEARCH PAPER

Multicriteria Methodology for Selection of a Personal Electric Vehicle

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ABSTRACT

A methodology that can support the decision process for selecting an Electric Vehicle (EV) is crucial. Considering the quantity, diversity, and complexity of existing EV models, their advantages and disadvantages, and people's increasing concern for sustainability, selecting and buying a personal EV appropriate to one's needs and requirements is not a simple task. Currently, criteria such as price, consumption per 100 km, range, comfort, brand, safety, and technology can be used to analyse available EV models. In this context, the decision-making process can be supported by the Multicriteria Decision Analysis (MCDA), "a method that clearly structures and evaluates complex problems with several alternatives, conflicting criteria, and complex scenarios. The novelty of this paper is to present a hybrid MCDA approach, combining two powerful methods (AHP and PROMETHEE) into a single framework to assist EV selection by any given person who has no multicriteria knowledge. A survey was conducted to define relevant criteria for a private person selecting an EV. The approach was validated for EV selection, considering the available offer within a target value, based solely on available public data, and excluding qualitative criteria. The paper discusses a case study whereby the proposed approach, using both quantitative and qualitative criteria, assists a decision-maker in selecting an EV from a set of alternatives, validated by the decision-maker, proving the importance and relevance of supporting the decision-making process.

Keywords: Multicriteria; PROMETHEE; AHP; Electric vehicles.

1. INTRODUCTION

The transport sector continues to be one of the activity sectors with the highest energy consumption. It is one of the main sources of greenhouse gases (GHG) and causes high levels of air and noise pollution. As a result, they can severely damage human health and the ecosystems involved, so we must take action to change the current state of our environment (Bączkiewicz and Kizielewicz, 2021).

Freight volume has increased considerably since the 1990s, despite a relative decrease following the economic recession in 2008. This increase has been largely accommodated by road transport, which accounted for 49% of EU freight transported in 2013, and to a lesser extent, sea and rail

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transport (Transports in Europe: key facts and trends, 2021). This growth means that road transport now accounts for almost three-quarters of the energy used in transport in the EU (Transports in Europe: key facts and trends, 2021). Road transport is the most used means of transport, either in the private or business context, and is essential to human activity as it is responsible for the mobility of people and goods (Transports in Europe: key facts and trends, 2021; Wolf et al. and 2019).

In the 2000s, societal needs urged environmental awareness, and circular economy (CE) strategies, combining political leadership, technological innovation, and behavioural changes (Fux, 2019). Efforts have been made to reduce emissions: shifts in vehicle motorization solutions (hybrid, electrical, and more recently hydrogen) in every transportation mode and the switch to more sustainable mobility modes. EV's stage of development has led more people than ever before to adopt the technology as green and environmentally friendly - they do not emit harmful gases into the environment on the journey (Introduction to electric car, 2021). In addition to being less polluting, they are quieter, more economical in terms of consumption, and do not use fossil fuels (Advantages and disadvantages of the Electric Car, 2021).

Considering the quantity, diversity, and complexity of existing EV models, selecting a personal EV which is more appropriate to one's needs and requirements, and pondering their advantages and drawbacks is far from simple. In many actual decision-making situations, several possible solutions may be considered, requiring decision-makers to consider different points of view (Moraes Vieira et al. and 2017). Multicriteria Decision Analysis (MCDA) method has proven effective in solving (Burak et al. and 2022). An MCDA can be defined as a set of techniques that are designed to search for several alternatives within multicriteria and conflicting objectives. The criteria must be consistent with the decision's proposed result and alternatives must have the same conception and definition to be ranked in a MCDA tool (Silva et al. and 2020). Over the years several MCDA methods have been proposed (Goodwin et Wright, 2004). Two of the most popular are the Analytic Hierarchy Process (AHP) (Saaty, 1990) and the Preference Ranking Organization MeTHod for Enrichment Evaluations (henceforth PROMETHEE) (Brans et Mareschal, 1994).

AHP is a decision-making technique developed by Thomas L. Saaty in the 1970s. AHP breaks the objective goal into hierarchies and forms a pairwise comparison among the criteria which leads to the weighted calculation of each criterion (Goswami et al. and 2020).

PROMETHEE was first proposed by Brans and Mareschal in 1984, as a method for ranking a finite set of alternatives. The PROMETHEE method involves concepts and parameters that have some physical or economical interpretation that is easy for most Decision Makers (DM) to understand. It is based on their "net flow", which means the difference in how much an alternative a is better than the other one b, and how much an alternative b is better than one a (Silva et al, 2020).

The former pertains to the normative (or American) school of thought, which is represented by methods that perform preference aggregation through value functions (for instance, MAUT, MAVT, AHP, ANP, SMART). Despite the popularity of AHP and PROMETHEE, none of these methods is better than the other, with both having strengths and weaknesses (Oliveira et al. and 2018).

This paper proposes the use of a hybrid approach that incorporates the AHP and the PROMETHEE to solve a complex multicriteria decision problem for the selection of a personal electric vehicle (EV). Due to the availability of software and the ease of understanding, such a comparison will be made using a hybrid Multicriteria Decision Aid (MCDA), "which combines the Analytic Hierarchy Process (AHP) and the PROMETHEE methods to establish a ranking based on performance in the selected criteria. The AHP method was used to define criteria and their respective weights during the problem structuring phase, and the PROMETHEE method was used to evaluate the alternatives—various EV models—and aggregate each criterion.

The paper is organised as follows: this section introduces and frames the problem, presents the methods that can be used to achieve a methodology to support the decision-making process for selecting an EV, and describes how the remainder of the paper is organised. Section 2 introduces the main concepts of the MCDA briefly, outlines the typical steps involved in the deployment of MCDA processes, describes the AHP and PROMETHEE methods, and proposes a hybrid AHP-PROMETHEE approach. Section 3 provides a detailed description of its application to EV selection decision-making using only publicly available data. Section 4 describes in detail how it was used in a case study with a decision-maker. Section 5 summarises the findings and makes some closing remarks.

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2. METHODOLOGY

According to Dodgson et al. (2009), "MCDA is an approach to assist the decision-making process at various levels, including the organization and synthesis of available information, to empower decision-makers with a holistic and structured view of the problem.

An MCDA aims to provide various options for a set of alternatives considering a coherent and consistent set of quantitative and qualitative criteria, sometimes with conflicting objectives, for a problem-solving approach, from the less preferred to the most preferred, being chosen according to the objective to be achieved (Brans et Mareschal, 1994)(de Almeida et al, 2021). According to Silva et al. (2018), different approaches and techniques of MCDM can be proposed depending on various schools of thought and/or demands of specific situations.

According to Dodgson et al. (2009) and Srdjevic et al. (2012), "the MCDA model is not to assist the decision makers to find the "best" decision, but rather to help decision makers so that their decision-making fits their needs and is consistent with their preferences and overall understanding of the problem. Usually, this decision corresponds to the best solution under the constraints and not to an optimal solution.

MCDA analysis is used to deal with the difficulties that decision-makers encounter when there is a large amount of information to deal with. The principle of this method is to break decision problems into smaller, understandable parts, analyse each part separately, and then integrate the parts in a logical way. MCDA provides support for identifying components of a decision-making problem, organizing the elements into hierarchical structures, understanding participants (Srdjevic et al. and 2012), "and assisting them with the methodology such as weighting the criteria (Weber and Borcherding, 1993). Usually, an MCDA methodology encompasses four major steps that can be broken down in more steps: 1) Structuring the decision-making problem; 2) preferences' articulation and modelling; 3) Aggregation of evaluations of alternatives (preferences); 4) sensitivity and robustness analysis and recommendations (Bana e Costa and Vansnick, 1997)(Tenório et al, 2020).

2.1 PROMETHEE Method

The PROMETHEE method is based on the ordering of a finite set of actions, where each criterion is associated with a certain weight that is assigned according to its importance.

The PROMETHEE method is a non-compensatory method to handle ranking problems and evaluate a set of alternatives under multicriteria, which are often conflicting. The model establishes a preference structure between the alternatives by considering a preference function, defined by the decision-maker, for each criterion to obtain a partial and complete ranking of the alternatives (Moreira et al, 2021).

PROMETHEE's preference structure is based on pairwise comparisons, considering the deviation between two alternatives on a given criterion. Thus, the greater the deviation, the greater the preference. The preference translates into the ranking of a criterion in relation to another Thus, for each criterion the decision maker has a function in mind. (Moreira et al. and 2022).

The preference functions differ from each other, depending on the criteria that are used. Brans et al. (2016) list these functions as: Usual criterion, U-shape criterion, V-shape criterion, Level criterion, V-shape with indifference criterion, Gaussian criterion functions. After describing the problem and determining the criteria, alternatives, and the weights, the PROMETHEE method can be applied step by step (Brans et al. and 2016),

Although the PROMETHEE family is comprised of several methods, the main ones are: (i) PROMETHEE I partial ranking, (ii) PROMETHEE II complete ranking, and (iii) Geometrical Analysis for Interactive Aid (henceforth GAIA). PROMETHEE I partial ranking generates a ranking of alternatives. However, in some cases, the returned ranking might be incomplete (or partial) since it allows indifference and incomparability situations between alternatives. Conversely, PROMETHEE II relies directly on the net preference flow to rank the alternatives. Hence, it always provides a complete ranking of the alternatives, and thus all alternatives are comparable (Brans et al, 2016; Xu et al. 2022).

The GAIA plane is a geometrical representation of the alternatives' relative positions in terms of their contributions to the various criteria. The GAIA directly results from applying the principal component analysis to the matrix of normed flows defined for alternative a and criterion j. To preserve the original multidimensional information as faithfully as possible, the n-dimensional criteria space is projected onto a two-dimensional space yielded by the two most representative principal components (linear combinations of the original criteria) The GAIA plane is unique in that it projects both the alternatives and the criteria in the same space. Furthermore, it allows the projection of the criteria weights vector using the so-called decision axis. The decision axis, in conjunction with the walking weights, can be used to perform a sensitivity analysis of the results according to the weight changes (Mareschal, 2013) (1 to 4).

$$\begin{cases} \pi(a,b) = \sum_{j=1}^{k} P_j(a,b) * w_j & (1) \\ \varphi^{+}(a) = \frac{1}{n-1} * \sum_{b} \pi(a,b) & (2) \\ \varphi^{-}(a) = \frac{1}{n-1} * \sum_{b} \pi(b,a) & (3) \\ \varphi(a) = \varphi^{+}(a) - \varphi^{-}(a) & (4) \end{cases}$$

2.2 AHP method

The AHP is one of the most well-known MCDA methods for ranking the various alternatives for achieving a goal. It is based on the foundation of adding weights to the attributes. This ranking is achieved through a quantitative comparison quantitative comparison of pairs of alternatives (Loken, 2007).

The AHP methodology can be explained in the following steps (Saaty, 1990):

1. The AHP's first step is to divide the decision problem into a hierarchy of sub-problems, by organising the relevant factors of the problem into a hierarchic structure, from a global goal to criteria, sub-criteria and alternatives, in successive levels.
2. The second step of the method entails the elicitation of pairwise comparison judgments from the decision-making body.
3. The third step is to determine the consistency of pair wise comparison matrices. If the consistency ratio (CR) is equal or less than 0.1 value, the comparisons are consistent.
4. In the final step, priorities of alternatives are found by combining the weights of criteria and the ratings of the alternatives.

The weights of each criterion are derived by means of pair wise comparisons in AHP method. The fundamental comparison scale for AHP which is proposed by Saaty et. al (1990) is shown in table 1.

Table 1 - Saaty's numerical scale (Saaty, 1990)

Importance	Definition	Explanation
1	Equal importance	The two elements are equally important
3	Moderate importance	One of the elements is moderately important compared to the other element
5	Strong importance	One of the elements is important compared to the other element
7	Very strong importance	One of the elements is very important compared to the other element
9	Extreme importance	One of the elements is extremely important compared with the other element
2,4,6,8	Intermediate values scale	Necessary when you want a level of commitment

2.3 Hybrid Approach methodology

In recent years, different authors have proposed MCDA hybrid approaches. Macharis et al. (2004) were the first to recommend the integration of some useful AHP features with PROMETHEE. Xu et al. (2019) also applied a hybrid AHP-PROMETHEE framework to evaluate competing alternative jet fuels. Burak et al. (2022) applied HF-AHP-PROMETHEE II, so that "Hesitant Fuzzy

Analytic Hierarchy Process" (HF-AHP) is first implemented to determine the importance weights of criteria, and then "Hesitant Fuzzy Preference Ranking Organization Method for Enriching Evaluations II" (HF-PROMETHEE II) is used to assess and rank the irrigation method alternatives, as examples. The idea of combining methodologies to perform an MCDA analysis builds upon the realisation that no single MCDA method performs best in all types of decision problems and is impervious to weaknesses. Thus, the goal was to generate beneficial synergies by combining two powerful methods (AHP and PROMETHEE) into a single framework, bringing the best of both worlds together and ultimately improve the reliability of the decision-making process.

According to Baynal et al. (2016), "the AHP method treats complex problems in a hierarchy, so that the problem can be clearly explained. The problem gets more complicated in the PROMETHEE method when the number of criteria exceeds seven. There is no tangible method for calculating weights in PROMETHEE. This process can be done analytically in AHP. Relative importance is best understood by pairwise comparisons. In the AHP method, there are many subsystems, causing much more data to be worked out. In the PROMETHEE method, solutions can be obtained with less data.

Sang et al. (2022) use a fuzzy decision-making, DEMATEL, and PROMETHEE methods and prospect theory to evaluate electric buses charging stations sites. Deng et al. (2022) present a decision-making method for solving the ranking problem on incomplete multi-scale information systems based on the PROMETHEE method and establishing a bridge between both. The PROMETHEE method in conjunction with AHP was also used by Sari et al. (2020) in their comparison of methods for beekeeping suitability.

Marinoni (2005) presents a combination between a sophisticated decision support methodology with powerful spatial analysis and visualisation capabilities that can be applied to evaluating decision alternatives that are made up of regular or irregular shaped zones of raster cells. He considers stochastic PROMETHEE, as well as deterministic approaches and gives general recommendations on the use of stochastic simulation methods using a framework for the approach's application.

The results of the PROMETHEE can be explained with high visuality. Therefore, the effect of each criterion on the result can be better understood. The GAIA technique also helps visualising the results.

Taking the above points into consideration, both methods present better results when integrated (Oliveira et al. and 2018). According to Baynal et al. (2016) and Turcksin et al. (2011) the AHP-PROMETHEE approach has eight steps.

The proposed AHP-PROMETHEE methodology is comprised of two broad stages, which are further broken down into detailed steps: (i) Decision problem modelling and elicitation of criteria weights, and (ii) PROMETHEE computations. The first stage encompasses four steps: identifying a portfolio of EV alternatives (Step 1), "selecting a coherent and consistent family of criteria to appraise each one of the identified alternatives (Step 2), "setting a hierarchical decision tree based on the information gathered in the previous steps (Step 3), "and determining the criteria weights using the AHP (Step 4). Determine the calculation table and preference functions for the PROMETHEE solution (Step 5). Determine a partial ranking with PROMETHEE I and a full ranking with PROMETHEE II (Step 6). Performing visual analysis of the results using the GAIA plane (Step 7), "and performing a sensitivity analysis with PROMETHEE (Step 8).

Steps 5 to 7 are performed using a decision-making software: Visual PROMETHEE

3. APPLICATION OF THE MULTICRITERIA ANALYSIS METHODOLOGY

The proposed methodology is applied to the selection of a personal EV. The MCDA will be structured in three main stages: data collection to support the hybrid methodology, AHP method for steps 1 to 4 and PROMETHEE method for steps 5 to 8.

3.1 Data collection

First, the possible alternatives submitted for evaluation are identified. Based on research on electric vehicles, it has been concluded that electric vehicles with a range of at least 150 km, energy consumption not exceeding 250 Wh/km, and a price below 50,000 € are considered in this research since they seem reasonable values for a user who wants to exchange his combustion-powered vehicle for an EV.

The next step includes the identification of the evaluation criteria. Several types of research were done on the various EV models, and the most important criteria in choosing an EV were defined as price, consumption per 100 km, range, comfort, brand, safety, and technology (Important Factors for Introducing Electrical Vehicles, 2015).

To help the decision-maker determine the weight of each criterion, a questionnaire using "google forms" was applied to find out the criterion of choice for purchasing an EV (figure 1).

The questionnaire was sent via a social network to 27 people who intended to buy a car and was answered by 197 individuals, ages 18 and 73 years old. The method used a convenience sample: people who the authors knew intended to buy an EV were asked to share the link with other people that they knew were considering buying an EV (the snowball sampling method). The choice for this type of field research was due to the channels. According to Noy (2008), "the snowball sampling method makes use of the members of a population to obtain a sample of it. The method consists of an indication of one member of the population by another who is also part of the population to be included in the sample. The indication process follows until the desired sample is achieved.

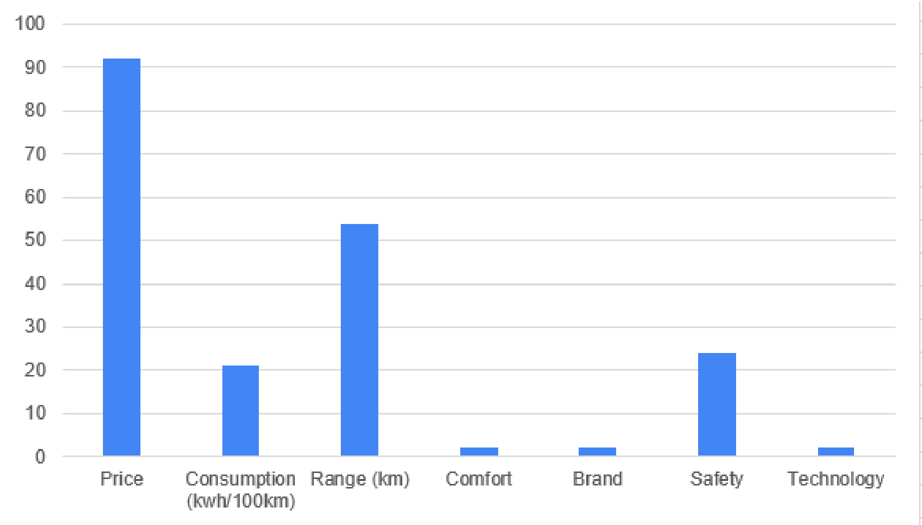

Figure 1 - Graph of questionnaire answers

From figure 1, we can see that, according to the survey, the criteria price and range in Km (autonomy) are the two most important criteria in choosing an EV. Despite this, and because qualitative criteria are subjective and should be evaluated by the decision-maker through a test drive, and based on experts' evaluations under the same conditions, they were replaced by only quantitative criteria to assess the available EV to a target value so that results could be presented. Thus, comfort, brand, safety, and technology criteria were replaced by load volume, battery capacity, power, and performance criteria.

3.2 AHP Approach

At the top of the hierarchical structure is the main goal, the selection of the best EV. At the second level of the structure are the seven most relevant criteria for the selection process, and finally, at the third level, are the various EV models.

Once the hierarchies have been defined, a pairwise comparison of a total of seven criteria from the second level with respect to the first hierarchical level is required. The Saaty fundamental scale is used for this comparison.

The goal of this phase is to determine the relative importance of each criterion in meeting the goal. Because there is only one element in the first hierarchical level, only one matrix is built to measure the degree of intensity by pairs using the seven criteria.

The previous matrix is then normalised by equating all criteria to the same unit, dividing each value of the matrix by the total of the respective column. By calculating the average value, the weight assigned to each criterion is obtained, i.e. and the relative importance that each criterion has in selecting an EV.

The criteria "Price" and "Autonomy" have the highest impact on the goal. This analysis concurs with the results of the questionnaire, and the matrices created previously (figure 2).

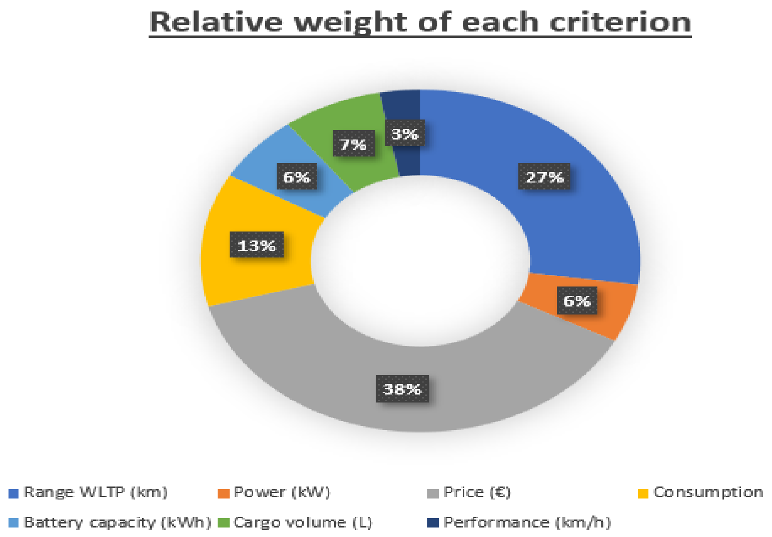

Figure 2 - Relative weight of each criterion

Table 2 - Average Random Consistency (Saaty, 1990)

Size of the matrix (n)	3	4	5	6	7	8
Random Consistency (RI)	0.58	0.9	1.12	1.24	1.32	1.41

A pairwise comparison matrix is of acceptable consistency if the corresponding Consistency Ratio (CR) does not exceed 0.10. The Consistency Ratio is computed as follows (5):

$$CR = \frac{CI}{RC}, \qquad with\ \ CI = \frac{\lambda_{max} - n}{n-1} \qquad (5)$$

where λ_{max} denotes the maximum eigenvalue of the pairwise comparison matrix, n represents the matrix size (in this case, the number of criteria) and the acronyms CR, CI and RI stand for Consistency Ratio, Consistency Index and Random Consistency Index, respectively. RI is obtained from a randomly generated pairwise comparison matrix of size n.

Since CR = 0.078 < 0.10 was obtained, the criteria weights obtained can be used in the decision-making process.

3.3 PROMETHEE Approach

The resulting data was then organized into an evaluation matrix, providing objective and quantitative information on each alternative's performance, on each relevant criterion.

Aside from the evaluation matrix, the PROMETHEE method requires additional information, namely the preference functions associated with each criterion and corresponding thresholds.

This information was defined indirectly by the decision-makers, as it is based on their answers to a set of questions presented by the "Preference Function Assistant" of the Visual PROMETHEE.

With the necessary information (the evaluation table and the preference functions), "the remaining steps are automatically completed by the Visual PROMETHEE software, with no human intervention required. After evaluating the alternatives, the outranking flows (φ^+, φ^- and φ), "displayed in figures 3 and 4, are outputted.

The analysis of both rankings for the selection of an EV indicates that, based on the criteria, Opel Corsa-e is the most preferred alternative. The model Dacia Spring-electric, Peugeot e-308, Seat mii electric and VW e-up they are not far from being best option.

Eletric Vehicles	Range	Power	Price	Consumption	Battery Cap...	Cargo Volume	Performance
Unit	km	kW	€	€	kWh	L	km/h
Cluster/Group							
Preferences							
Min/Max	max	max	min	min	max	max	max
Weight	27,20	5,50	38,00	12,60	6,40	7,30	3,00
Preference Fn.	Linear	Linear	Linear	Linear	Linear	Linear	Linear
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	62	59,02	€ 0,03	€ 1,67	10,42	79,38	20,55
- P: Preference	151	115,00	€ 0,25	€ 3,96	24,76	183,71	40,87
- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Statistics							
Minimum	200	33,00	€ 16.800,00	€ 4,29	26,80	211,00	125,00
Maximum	484	300,00	€ 50.900,00	€ 12,00	75,00	585,00	225,00
Average	339	120,18	€ 36.280,73	€ 7,33	45,80	357,68	154,68
Standard Dev.	75	56,20	€ 7.950,68	€ 1,96	12,25	90,57	19,96
Evaluations							
renault zoe	395	100,00	€ 36.490,00	€ 8,32	52,00	338,00	140,00
VW ID.3 pro	420	107,00	€ 36.749,00	€ 9,28	58,00	385,00	160,00
Nissan leaf e+	385	160,00	€ 38.550,00	€ 8,96	56,00	420,00	157,00
Opel Corsa e	330	100,00	€ 30.115,00	€ 7,20	45,00	309,00	150,00
Peugeot e-208	339	100,00	€ 32.420,00	€ 7,20	45,00	265,00	150,00
Peugeot e-2008	330	100,00	€ 36.470,00	€ 7,20	45,00	434,00	150,00
Kia e-niro	405	150,00	€ 41.750,00	€ 10,24	64,00	451,00	167,00
Skoda Enyaq	362	109,00	€ 39.214,00	€ 8,32	52,00	585,00	160,00
Opel mokka-e	322	100,00	€ 35.405,00	€ 7,20	45,00	350,00	150,00
Hyundai Kauai	484	159,00	€ 41.055,00	€ 10,24	64,00	332,00	167,00
Hyundai Ioniq EV	311	100,00	€ 40.580,00	€ 6,13	38,30	356,00	165,00
DS 3 Crossback ...	320	100,00	€ 42.200,00	€ 7,20	45,00	350,00	150,00
Tesla model 3 st...	448	239,00	€ 50.900,00	€ 8,16	51,00	542,00	225,00
Volvo xc40 recha...	418	300,00	€ 49.357,00	€ 12,00	75,00	419,00	180,00
Dacia Spring Eletric	230	33,00	€ 16.800,00	€ 4,29	26,80	300,00	125,00
Sea mii eletric	260	61,00	€ 21.000,00	€ 5,17	32,30	251,00	130,00
VW e-up	260	61,00	€ 22.824,00	€ 5,17	32,30	250,00	130,00
Mini cooper se	233	135,00	€ 34.750,00	€ 4,62	28,90	211,00	150,00
Mazda mx30	200	105,00	€ 36.240,00	€ 4,80	30,00	366,00	140,00
Kia e-soul	407	100,00	€ 37.000,00	€ 6,27	39,20	315,00	157,00
Citroen e-c4	330	100,00	€ 36.107,00	€ 7,20	45,00	380,00	150,00
Bmw i3	260	125,00	€ 42.200,00	€ 6,06	37,90	260,00	150,00

Figure 3 - Introduction of alternative' features in PROMETHEE

PROMETHEE Flow Table

Rank	action	Phi	Phi+	Phi-
1	Opel Corsa e	0,2458	0,3707	0,1249
2	Dacia Spring Eletric	0,2159	0,4491	0,2332
3	Peugeot e-208	0,2148	0,3598	0,1449
4	Sea mii eletric	0,2116	0,4083	0,1967
5	VW e-up	0,1751	0,3902	0,2152
6	Opel mokka-e	0,1311	0,3126	0,1816
7	Citroen e-c4	0,1157	0,3065	0,1909
8	VW ID.3 pro	0,0702	0,3317	0,2614
9	renault zoe	0,0673	0,3015	0,2342
10	Peugeot e-2008	0,0601	0,2843	0,2242
11	Mini cooper se	0,0397	0,3531	0,3134
12	Kia e-soul	0,0363	0,2888	0,2525
13	Nissan leaf e+	-0,0274	0,2642	0,2916
14	Skoda Enyaq	-0,0368	0,2667	0,3035
15	Hyundai Kauai	-0,0450	0,3312	0,3762
16	Mazda mx30	-0,0732	0,2980	0,3712
17	Tesla model 3 standard	-0,1102	0,2985	0,4087
18	Kia e-niro	-0,1494	0,2405	0,3899
19	Hyundai Ioniq EV	-0,1937	0,1590	0,3528
20	Volvo xc40 recharge	-0,2111	0,2643	0,4753
21	DS 3 Crossback e-tense	-0,3244	0,0763	0,4007
22	Bmw i3	-0,4124	0,0682	0,4805

Figure 4 - Flow table

The decision problem is represented in the GAIA plane to better understand the results. In this case, alternatives are represented by squared points and criteria by vectors. Criteria expressing similar preferences point in the same direction whereas conflicting criteria point in opposite directions. The criterion vector's length is an indicator of its discriminative power. Hence, longer vectors are associated with more effective criteria for differentiating alternatives. The GAIA plane also provides information regarding criteria weights through vector pi (also called the decision axis). Vector pi is depicted as a thick red line and can be interpreted as a weighted average of the criteria axes. It represents the direction of the compromise when considering the assigned criteria weights. Alternatives that are in the direction of the decision axis are the most promising ones since they score higher on the most important criteria. The quality level of the GAIA projection is given by the Delta parameter, which is 84.2% in the case presented. This value means that only 15.8% of the total information gets lost by the projection. Figure 5 displays the results of the GAIA analysis.

Figure 5 - PROMETHEE GAIA

Since some steps of the MCDA process can be permeated by subjectivity and uncertainty, it was considered relevant to validate the results by studying the impact of modifying the initially specified criteria weights on the PROMETHEE complete ranking.

This was performed by identifying stability intervals for criteria weights. The amplitude of these intervals also makes it easy to identify the criteria with the highest impact on the ranking, but in this case, since we have a lot of alternatives, the intervals of the weights will be very low. For example, if the weight of the criterion "Price" was changed to 70% instead of 38%, the model Dacia Spring Electric would be the most favoured electric vehicle since it is the model with the lowest price compared to the other models.

4. CASE STUDY

A case study was performed to address a decision-maker's intention to buy a car in a higher EV segment, considering both quantitative criteria – price, autonomy, and consumption – and the qualitative criteria – comfort, brand, safety, and technology.

4.1 Data collection

It was necessary to access the various pages of the models for the collection of quantitative data during the data collection process. The Lexus UX 300e, Tesla Model 3 Standard Range, Volvo XC40 recharge electric, and Jaguar i-pace all received a qualitative criteria score based on test driving.

This article presents as a contribution a proposal of a hybrid multi-criterion model, where one method is used to generate weights to the criteria (AHP), "the other to order the alternatives; as well as a set of criteria is proposed to assess this environmental socio-environmental problem.

4.2 AHP

The AHP method was used to define the decision process. The main objective, the selection of the best EV, is the top of the hierarchical structure. The second level comprises the seven criteria considered for the evaluation process, and the third level is comprised of the four possible EV alternatives (figure 6).

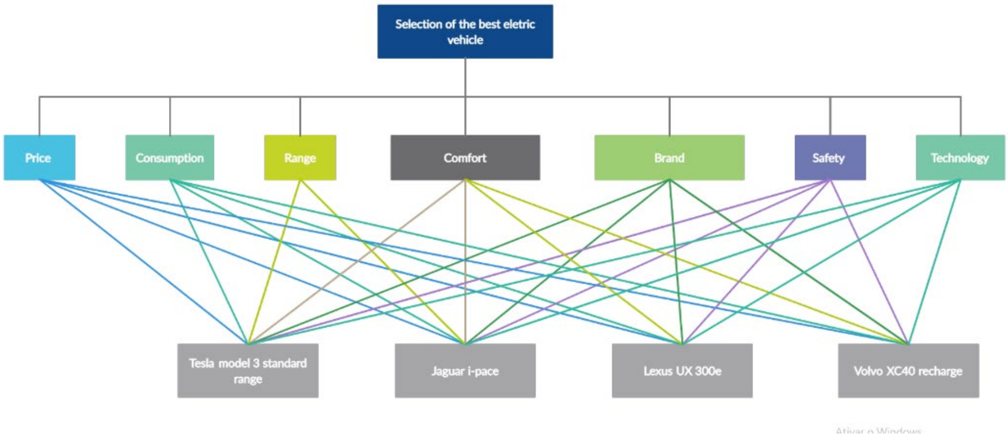

Figure 6 - Hierarchical structure of the problem

Next, the decision-maker evaluates the seven criteria and assigns the respective weights by applying the AHP method (Table 3).

Table 3 - weights of criteria

Criteria	Price	Consumption	Range	Comfort	Brand	Safety	Technology
Weight (%)	14.75	16.39	11.48	16.39	13.11	14.75	13.11

4.3 PROMETHEE

The use of the Visual PROMETHEE software resulted in the interface below. Columns present the criteria and rows the available alternatives. A set of 7 criteria and 4 models is laid out in this way (figure 7).

Scenario1		Price	Consumption	Range	Comfort	Brand	Safety	Technology
Unit		€	kWh/100km	km	5-point	5-point	5-point	5-point
Cluster/Group								
Preferences								
Min/Max		min	min	max	max	max	max	max
Weight		14,75	16,39	11,48	16,39	13,11	14,75	13,11
Preference Fn.		Linear	Linear	Linear	Usual	Usual	Usual	Usual
Thresholds		absolute	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference		€ 15.048,36	0,41	15,36	n/a	n/a	n/a	n/a
- P: Preference		€ 32.155,53	1,18	41,36	n/a	n/a	n/a	n/a
- S: Gaussian		n/a	n/a	n/a	n/a	n/a	n/a	n/a
Statistics								
Minimum		€ 49.357,00	2,34	400,00	4,00	3,00	4,00	5,00
Maximum		€ 83.038,00	3,71	448,00	5,00	5,00	5,00	5,00
Average		€ 58.948,75	3,16	418,00	4,25	4,50	4,75	5,00
Standard Dev.		€ 13.952,26	0,53	18,49	0,43	0,87	0,43	0,00
Evaluations								
tesla model 3 sta...		€ 50.900,00	2,34	448,00	good	average	good	very good
jaguar i pace		€ 83.038,00	3,71	406,00	good	very good	very good	very good
lexus UX 300e		€ 52.500,00	3,07	400,00	very good	very good	very good	very good
volvo xc40 recha...		€ 49.357,00	3,54	418,00	good	very good	very good	very good

Figure 7 - Introduction of case study features in PROMETHEE

After evaluating the alternatives, the outranking flows (φ^+, φ^- and φ), "displayed in figure 8, are outputted.

The analysis of both rankings for the selection of the best EV indicates that Lexus UX 300e is the most preferred alternative ranking first on both the PROMETHEE I and the PROMETHEE II.

PROMETHEE Flow Table

Rank	action	Phi	Phi+	Phi-
1	lexus UX 300e	0,2562	0,3215	0,0653
2	volvo xc40 recharge	0,0113	0,1459	0,1347
3	tesla model 3 standard	-0,0537	0,2796	0,3333
4	jaguar i pace	-0,2138	0,0929	0,3067

Figure 8 - Flow table

To better understand the results obtained, the decision problem is represented in the GAIA plane. In this study, the quality value is calculated as 92,1% which indicates that 7,9% of overall data is lost (figure 9).

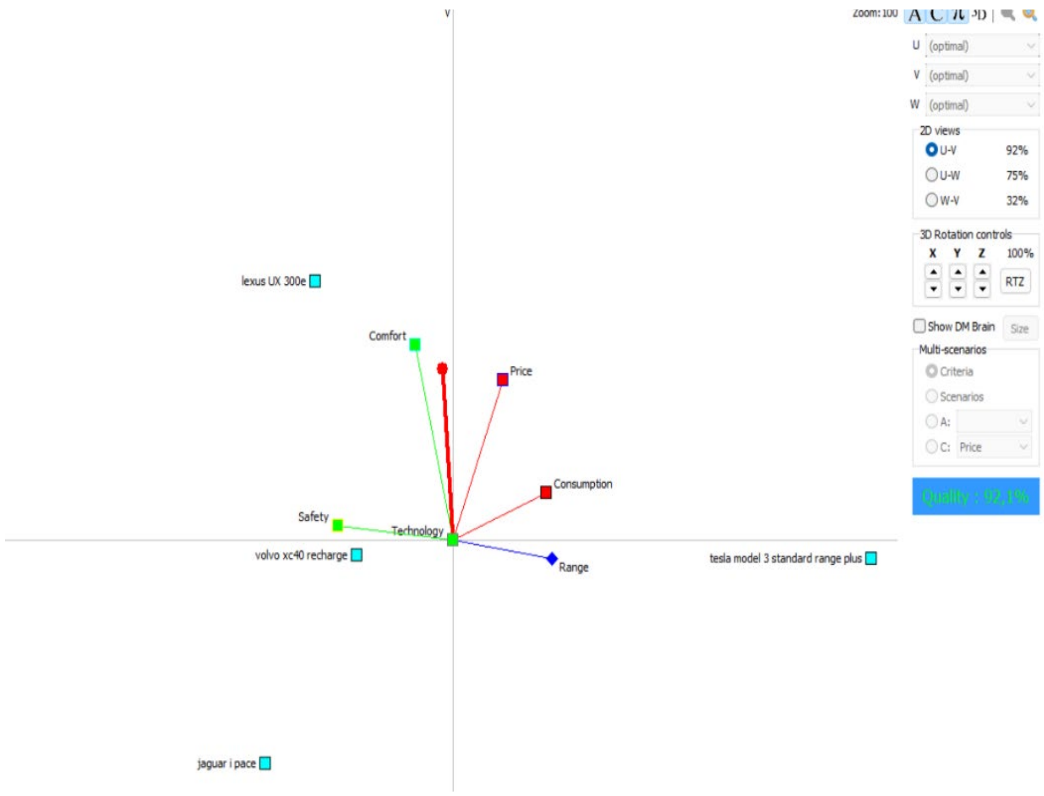

Figure 9 - PROMETHEE-GAIA

Sensitivity analysis was conducted using Walking Weight and the Visual Stability Intervals window for better visualization.

For example, changes can be observed for the consumption criterion if its weight is changed to 20.81%, with a swapping of positions between second and third. Figure 10 shows that by increasing the criterion to 40%, the Tesla model takes first place as the best model.

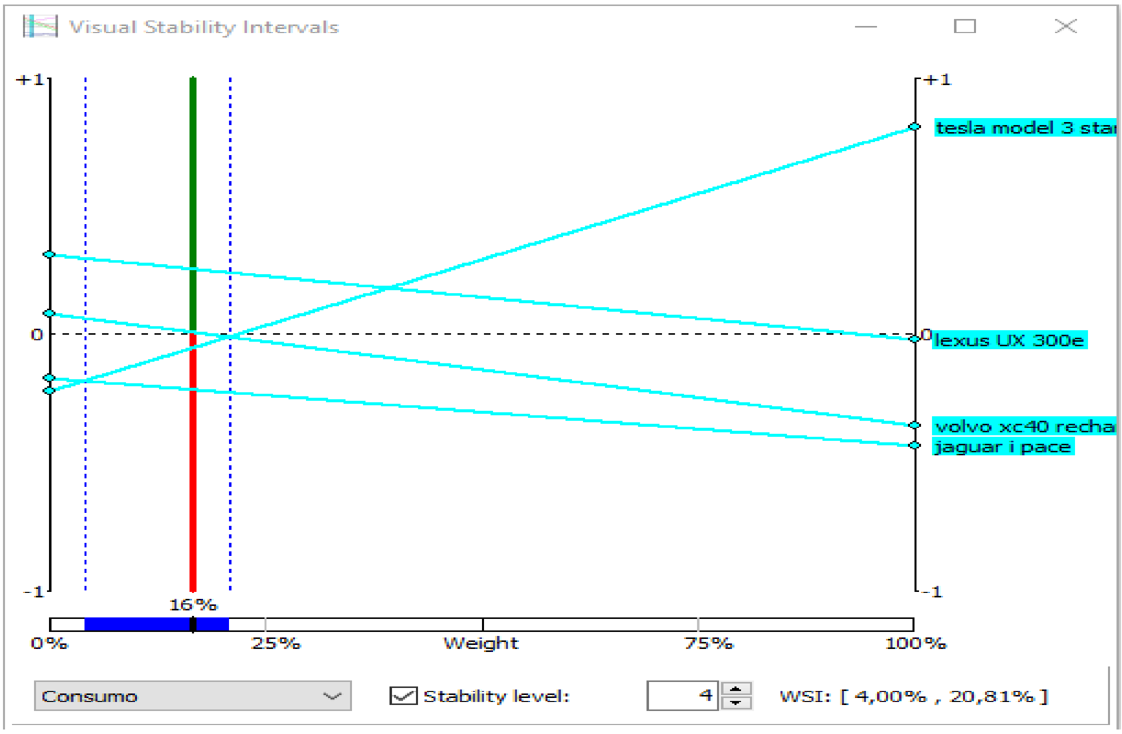

Figure 10 - Visual Stability Intervals - Consumption

5. CONCLUSIONS

This paper addresses a multicriteria methodology for selecting an EV, which is required to support decision-making regarding a choice made difficult by EV emerging technology and improvements, as well as the increase in EV charging spots, drivers' sustainability concerns, and trends. A hybrid AHP and PROMETHEE methods approach is proposed for this purpose, whereby the strengths of both methodologies are combined into a single tool. The application of such an integrated approach to the EV purchase decision problem is detailed in each of the steps of the AHP-PROMETHEE methodology.

A survey was conducted to support the methodology and the family of relevant criteria.

The hybrid approach used in this paper is based on the advantages of combining several distinct AHP features, namely in the structuring of the decision problem and the criteria' weights determination phase, which is based on pairwise comparisons, with PROMETHEE for the computation phase. Since PROMETHEE does not provide any formal guidance for determining criteria weights, incorporating AHP weights increases the accuracy of the method. In turn, PROMETHEE enriches the AHP by associating a preference function with each criterion and providing a set of tools to thoroughly analyse the decision problem.

The hybrid AHP-PROMETHEE method was used to conduct the first analysis, which was limited to the available quantitative data for the set of EV most commercialised in 2021. This was due to the fact that to be able to consider qualitative data, a test drive with the same conditions would be required. Based on that analysis, the Opel Corsa-e is the best alternative with the highest score. The models Dacia Spring-electric, Peugeot e-308, Seat mii electric and VW e-up close to the best options.

A case study was done to support a decision-maker who wanted to buy an high-end EV. After considering quantitative and qualitative criteria, it was determined that the Lexus UX 300e was the model which best met the decision-maker's expectations.

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