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Fuzzy PIPRECIA and CRADIS Integrated Method In Electric Vehicle Selection

Elektrikli Araç Seçiminde Bulanık PIPRECIA ve CRADIS Bütünleşik Yöntemi

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Abstract

Fossil fuel-powered vehicles are known to cause environmental pollution due to their greenhouse gas emissions. As a result, there has been a growing focus on measures and developments aimed at reducing these emissions in recent years. The objective of this study is to compare the top 10 best-selling electric vehicles in Turkey in 2023 based on specific criteria and to rank them accordingly. The study compared 10 different electric vehicles based on their price, horsepower, range, 80% charging time with DC fast charging unit, battery capacity, and fuel consumption. The study employs the fuzzy PIPRECIA method to determine the importance levels of criteria and analyzes 10 different electric vehicle models using the CRADIS method. The findings reveal that fuel consumption and price are highly important criteria, and the Togg T10X V2 model vehicle ranks first when evaluated based on these criteria.

Keywords: *Electric Car, Fuzzy PIPRECIA Method, and CRADIS Method, Sustainability, Artificial intelligence*
JEL Codes: C02, C44, C61, L62, P18, S01

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Özet

Fosil yakıt ile çalışan araçlar sera gazı salınımı yapması nedeniyle çevre kirliliğine sebep olmaktadır. Bu nedenle son yıllarda sera gazı salınımı azaltacak tedbirler ve gelişmeler her geçen gün artmaktadır. Bu çalışmanın amacı, Türkiye'de 2023 yılında en çok satan 10 farklı elektrikli aracı belirli kriterler düzeyinde değerlendirerek karşılaştırmak ve elde ettikleri skorlara göre nihai bir sıralama elde etmektir. Çalışmada 10 farklı elektrikli aracı karşılaştırmak için kullanılan kriterler; aracın fiyatı, aracın beygir gücü, aracın tam dolu batarya ile gidebileceği menzil, aracın DC hızlı şarj ünitesi ile %80 şarj olma süresi, aracın batarya kapasitesi ve aracın yakıt tüketimidir. Çalışma kapsamında kriterlerin önem düzeyleri bulanık PIPRECIA yöntemi kullanılarak elde edilmekte ve CRADIS yönteminden yararlanılarak 10 farklı elektrikli araç modeli analiz edilmektedir. Çalışmadaki bulgulara göre aracın yakıt tüketimi ve aracın fiyatı önem düzeyi yüksek kriterler olarak belirlenmekte olup bu kriterler göre alternatif elektrikli araçlar değerlendirildiğinde birinci sırada Togg T10X V2 modeli araç yer almaktadır.

Anahtar Kelimeler: *Elektrikli Otomobil, Bulanık PIPRECIA Yöntemi, CRADIS Yöntemi, Sürdürülebilirlik, Yapay Zeka*
JEL Kodları: C02, C44, C61, L62, P18, S0

INTRODUCTION

In the contemporary era, the utilization of non-renewable energy sources has been identified as a catalyst for a multitude of environmental detriments. The foundation of these non-renewable sources on fossil fuels, coupled with their integration into the natural environment, precipitates a rapid augmentation in the atmospheric concentration of greenhouse gases. This escalation in greenhouse gases primarily engenders global climate change, which, in turn, inflicts comprehensive damage on nature, ranging from global warming to a reduction in biodiversity. In this context, nations, under the auspices of the United Nations Framework Convention on Climate Change Conference, with the ratification of the Paris Agreement by 195 member countries in December 2015, have committed to implementing measures aimed at reducing carbon dioxide emissions (Karakaya, 2016: 4).

By 2030, the European Union and the European Commission, aiming to reduce greenhouse gas emissions, have pledged a 60% reduction in emissions from road transportation. Additionally, the carbon footprint, denoted as the carbon dioxide equivalent of gases emitted from activities conducted by individuals, countries, and organizations, has been spotlighted to accentuate environmental awareness (Coşkun, 2022: 174). Numerous nations are developing incentive programs to increase the share of renewable energy sources in production. However, the nature-dependent characteristic of renewable energy sources presents challenges in meeting instantaneous demands, rendering energy planning on renewable sources exceedingly difficult. This is considered a significant barrier to the advancement of renewable energy sources (Yılmaz et. al., 2023: 3).

For a sustainable world, the energy sources utilized across various domains are progressively evolving. Renewable energy sources, by offering clean, recyclable, and inexhaustible energy, contribute to reducing greenhouse gas emissions and preserving ecological balance (Kahraman et. al, 2016:118). The one-time use and depletion of fossil fuels, their scarcity, and the environmental harm they cause have altered consumer behaviour in the automotive industry. In recent years, consumers opting to purchase vehicles have increasingly gravitated towards electric vehicles. Notably, in Turkey, the rate of electric vehicle purchases in 2023 saw a 251% increase compared to 2022. Globally, electric vehicle sales account for 18%, with projections estimating this figure to reach 60% by 2030. Electric vehicles, through their internal combustion engines, minimize gas emissions. According to the U.S. Department of Energy's Energy Efficiency report and the Renewable Energy Office's data, electric motors can convert between 59% and 62% of the energy they use into motion, a stark contrast to the 17% to 21% efficiency range of fuel-powered engines, underscoring the environmental conscientiousness of electric vehicles (www.trthaber.com).

Although the development of electric vehicles commenced in the mid-1800s, it was not until the early 20th century that they entered mass production and gained popularity. The growing interest in electric vehicles stems from the anticipation of fossil fuel depletion soon, despite current road transportation's reliance on fossil fuels (Kocabey, 2018: 17). Another factor influencing the shift towards electric vehicles is the rapid increase in their market share both globally and domestically, significantly impacting the market share of fossil fuel-powered vehicles. Consequently, consumers are increasingly inclined to purchase electric vehicles over those powered by fossil fuels (Dweri and Kablan, 2006: 714).

In the decision-making process, a decision-maker seeks to select the most advantageous option from among various alternatives based on specific criteria. This evaluation process involves the use of quantitative and qualitative methods to identify the optimal decision. However, many decision-makers prefer to base their decisions on numerical methods. Multi-Criteria Decision Making (MCDM) methods enable decision-makers to make the most beneficial decision by utilizing mathematical modelling to assess various alternatives against specific criteria. Classical MCDM methods are employed when the data influencing the decision are precise, whereas Fuzzy MCDM methods are utilized in the presence of imprecise, incomplete, or uncertain data ((Yavaş et al. 2014: 110).

One common scenario encountered by decision-makers is the purchase of automobiles. This study compares the top 10 electric vehicle models sold in Turkey in 2023, evaluated against criteria deemed influential in vehicle selection by experts. The study is organized into five sections, beginning with an introduction to the subject and the objective of the study. The second section contains a literature review, followed by a methodology explanation of the fuzzy PIPRECIA and CRADIS methods in the third section. The fourth section presents the evaluation of criteria influencing electric vehicle selection by experts, weighted using the Fuzzy PIPRECIA method, and ranked using the CRADIS method. The final section summarizes the findings in the conclusion.

1. LITERATURE REVIEW

In both national and international literature, a substantial number of studies exist concerning the selection of automobiles. It is observed that many of these studies focus on the selection of vehicles powered by fossil fuels. Among the conducted studies are the following. Yavaş et al. (2014) evaluated the characteristics considered during the purchase of automobiles through surveys applied to 40 customers of 8 different car companies, analysing the surveys with AHP and ANP methods. Chand and Avikal (2015) assessed the selection of the most suitable car using 6 criteria and 6 different car models through the AHP method. Patil et al. (2017) evaluated the selection of the most appropriate car based on road reliability, exterior-interior appearance, additional features of the car, and after-sales criteria using the fuzzy AHP method and Grey Relational Analysis. Sri Yogi (2018) assessed car models used in the Indian market using AHP and TOPSIS methods. Keleş (2019) weighted criteria using the ENTROPY method and ranked alternatives using the ELECTRE III method to compare B segment car options of 7 different brands.

Numerous national and international studies within the literature have addressed vehicle selection. Many of these studies focus on the selection of vehicles powered by fossil fuels. Among the research conducted are the following. Yavaş et al. (2014) evaluated the characteristics considered when purchasing automobiles through a survey of 40 customers from 8 different car companies, analysing the surveys with AHP and ANP methods. Chand and Avikal (2015) assessed the selection of the most suitable car using 6 criteria and 6 different car models through the AHP method. Patil et al. (2017) evaluated the selection of the most suitable car based on road safety, exterior-interior appearance, additional features of the car, and post-sale criteria using the fuzzy AHP method and Grey Relational Analysis. Sri Yogi (2018) assessed car models used in the Indian market with AHP and TOPSIS methods. Keleş (2019) weighted criteria with the ENTROPY method and ranked alternatives with the ELECTRE III method to compare B segment car options of 7 different brands. Singh and Avikal (2019) utilized fuzzy TOPSIS and AHP methods for the comparison of sedan model cars in India. Babacan (2020) evaluated the problems faced by individuals in meeting their car needs for the middle-income group using the VIKOR method. Güleryüz and Çokyaşar (2021) ranked 7 different C segment cars of brands determined by consumers according to 9 criteria using the TOPSIS method. Özgüner et al. (2022) selected cars for a logistics company engaged in road transportation using ENTROPY, ARAS, and TOPSIS methods among MCDM methods. Oflaz and Bircan (2022) made selections based on 9 criteria using AHP, TOPSIS, VIKOR, and EDAS methods for the evaluation of 7 different C SUV vehicles by consumers.

Few studies focusing on the selection of electric vehicles were found among the reviewed works. This section will address studies evaluating electric vehicles. Studies on electric vehicle selection include Onat et al. (2016), who addressed the technologies of hybrid and electric vehicles within a sustainability evaluation framework using the Fuzzy TOPSIS method, employing 16 criteria and the opinions of 3 experts. Coffman et al. (2017) identified variables determining the decision to purchase electric vehicles frequently used in the literature, such as charging time, charging network, fuel prices, vehicle ownership costs, driving range, public visibility, social norms, and consumer characteristics. Lin and Wu (2018) evaluated the decision to purchase electric vehicles from various perspectives, including gender, age, education level, and marital status. Hamurcu and Eren (2018) used ANP and TOPSIS methods for the selection of high-capacity electric buses among 5 alternatives, with criteria including capacity, speed, range, manoeuvrability, design, and performance. Biswas and Das (2019) used an integrated Fuzzy AHP-MABAC method for evaluating electric vehicles, utilizing criteria such as price, maximum speed, range, acceleration time, and fuel consumption. Gavcar and Kara (2020) evaluated 11 different electric vehicle models using battery power, range (maximum distance), friction coefficient, and price criteria with ENTROPY and TOPSIS methods. Khan et al. (2020) evaluated the selection of commercial taxis in Pakistan, including an electric vehicle option, using 10 criteria with the Fuzzy TOPSIS method. Öztayşi et al. (2021) evaluated 5 electric vehicle alternatives using the Fuzzy KEMIRA method with criteria including the vehicle's sale price, range on a full charge, maximum speed, comfort, and maintenance costs. Sonar and Kulkarni (2021) evaluated 6 electric vehicle alternatives with 6 different criteria using an Integrated AHP-MABAC method, identifying the maximum range the vehicle can travel as the most important criterion, with Hyundai Kona Electric ranked first among electric vehicle alternatives. Çoşkun (2022) made electric vehicle selections using SD and MULTIMOORA methods, defining criteria as price, horsepower, torque, maximum speed, 0-100 km/h acceleration, range, and DC charging time, comparing 5 different electric vehicles. Abdulvahitoğlu et al. (2022) obtained the most suitable among 7 different electric vehicle models using price, range, battery capacity, charging time (80%), efficiency, and power criteria through a standard deviation-based MULTIMOORA integrated Borda method. Çoşkun (2022) evaluated 8 different criteria for electric vehicles using CRITIC and ENTROPY methods as objective criterion weighting methods and WINGS and AHP methods as subjective criterion weighting methods. These criteria include range with a full battery, the vehicle's price, horsepower, torque, maximum speed, 0-100 km acceleration time, charging time, and battery.

2. METHODOLOGY

This section focuses on the methods utilized within the scope of the study. For the weighting of criteria, the study employed the Fuzzy PIPRECIA method. The fuzzy weights obtained were used on the top 10 best-selling electric vehicles of 2023 utilizing the CRADIS method, resulting in the final ranking.

2.1. Fuzzy Logic and Fuzzy Set

Fuzzy logic is a mathematical discipline used to describe uncertainties in our daily life, representing imprecision, ambiguity, and haziness, which corresponds to the English word "Fuzzy." The theorem of fuzzy logic, founded on fuzzy sets and the associated fuzzy numbers, was introduced to the literature by Lotfi A. Zadeh in 1965 [29]. Many expressions we use in daily life have a fuzzy structure and can be modelled with fuzzy logic. Lotfi A. Zadeh's article "Fuzzy Sets" posits that the Aristotelian logic system is insufficient, removed from human judgments, and argues that human thought possesses a fuzzy structure [30]. The fuzzy logic system has the capability to represent uncertain data with the aid of mathematical operators (Dağdeviren et. al. 2008: 776).

The foundation of fuzzy logic lies in fuzzy sets, which are used to create intermediate values of definite judgments. The membership degrees of a fuzzy set are based on continuous variables. In classical sets, the membership of an element in the defined space to the set is strictly defined as either belonging or not belonging. In fuzzy sets, however, this degree of membership possesses an ambiguous structure and is defined by a membership function (Sridharan, 2020: 315).

Unlike the classical logic system, fuzzy logic does not alternate strictly between belonging to the set (1) and not belonging (0). In the fuzzy logic approach, the degree of membership varies between 0 and 1, which allows for a more accurate description of ambiguity (Zadeh, 1997: 113). This variability facilitates the definition of verbal variables (Chen, 2000: 4). The gradual structure of fuzzy logic enables its application not only in engineering and other numerical fields but also in social domains (Dernancourt, 2013: 52).

2.2 The Fuzzy Pivot Pairwise Relative Criteria Importance Assessment (i.e. fuzzy PIPRECIA) method

The Fuzzy PIPRECIA method was first utilized by Stanujkic et al. in 2017 to address the deficiencies in the SWARA method, aiming to determine the weights of criteria within a Multi-Criteria Decision Making (MCDM) approach. The advantage of the PIPRECIA method, whose English equivalent is "Pivot Pairwise Relative Criteria Importance Assessment Extended," lies in its ability to determine criterion weights without the need for establishing an importance ranking (Puška et. al. 2022:7).

Decision-making is the process through which a decision-maker selects the most suitable alternative based on their values and preferences. In evaluating real-life problems, decision-makers do not use precise values. Expressing the relative values used by decision-makers numerically is possible with fuzzy MCDM methods. Linguistic evaluations in fuzzy MCDM methods enable decision-makers to achieve more accurate results concerning the problem at hand (Yenilmezel and Ertuğrul, 2023:4).

The Fuzzy PIPRECIA method was further developed by Stević et al. in 2018 for solving real-life problems. As a contemporary approach in the literature, the Fuzzy PIPRECIA method has been utilized in integration with various other MCDM methods. The table below includes studies related to the Fuzzy PIPRECIA method.

Table 1: Literature Review of the Fuzzy PIPRECIA Method

Subject of the Study	Author, Year	Method
Evaluating the conditions for implementing barcode technology in a paper production company	Stević et al. (2018)	Fuzzy PIPRECIA
Identifying and ranking risk factors encountered in road transportation, which is crucial for the efficient and economical management of the supply chain	Memiş et al. (2020)	Fuzzy PIPRECIA
Determining the importance level of criteria to assess the quality of e-learning materials	Jauković-Jocić et al. (2020)	Fuzzy PIPRECIA
Examining the operations of passenger traffic operators in the Republic of Serbia	Vesković et al. (2020)	Fuzzy PIPRECIA
Investigating criteria for information systems in the Danube region countries	Tomašević et al. (2020)	Fuzzy PIPRECIA
Evaluating the safety of railway transportation in Bosnia and Herzegovina	Blagosević et al. (2021)	Fuzzy PIPRECIA and Fuzzy MARCOS
Making regional aircraft selection	Bakır et al. (2021)	Fuzzy PIPRECIA
Assessing the criteria affecting the adoption of blockchain technology in the banking sector	Arman and Kundakcı (2022)	Fuzzy PIPRECIA
Evaluating sustainable agricultural tourism facilities	Puška et al. (2022)	Fuzzy PIPRECIA and Fuzzy MARCOS
Selecting blue-collar personnel for a manufacturing company	Yenilmezel and Ertuğrul (2023)	Fuzzy COPRAS and Fuzzy PIPRECIA
Investigating total productive maintenance factors in manufacturing organizations	Vikas and Mishra (2023)	Fuzzy PIPRECIA
Selecting the best maintenance strategy for a manufacturing company	Kundakçı (2023)	Fuzzy PIPRECIA and Fuzzy MOORA

The integration of fuzzy sets into the PIPRECIA method, resulting in the Fuzzy PIPRECIA, involves the following stages (Stević et. al., 2018: 7):

1. Stage: Decision-makers and criteria are identified. The determined criteria are listed without considering their importance.

2. Stage: To determine the relative importance of criteria, decision-makers individually assess each criterion against the previous one in the randomly ordered list of criteria, as illustrated in Equality (1).

$$\bar{s}_j^r = \begin{Bmatrix} > \bar{1}\, if\ C_j > C_{j-1} \\ = \bar{1}\, if\ \ C_j = C_{j-1} \\ < \bar{1}\, if\ \ C_j < C_{j-1} \end{Bmatrix} \quad (1)$$

The evaluation of criteria by decision-maker *r* is expressed as the variable $\bar{s}_j^r$. To obtain a $\bar{s}_j^r$ matrix, either the geometric mean or the arithmetic mean is utilized, and the average of the $\bar{s}_j^r$ matrix is calculated. If a criterion is considered less important compared to the previous criterion, Table

(2) is used; conversely, if a criterion is deemed more important than the previous one, Table (3) is employed. Decision-makers evaluate the criteria using the linguistic variables provided in Tables (2) and (3) (Stević et. al., 2018 :9).

Table 2: The Criteria Assessment Scale 1-2

	l	*m*	*u*	DFV
An almost equal value	1,000	1,000	1,050	1,008
Slightly more significant	1,100	1,150	1,200	1,150
Moderately more significant	1,200	1,300	1,350	1,292
More significant	1,300	1,450	1,500	1,433
Much more significant	1,400	1,600	1,650	1,575
Dominantly more significant	1,500	1,750	1,800	1,717
Absolutely more significant	1,600	1,900	1,950	1,858

Table 3: The Criteria Assessment Scale 0-1

	l	*m*	*u*	DVF
Slightly less significant	0,667	1,000	1,000	0,944
Moderately less significant	0,500	0,667	1,000	0,694
Less significant	0,400	0,500	0,667	0,511
Really less significant	0,333	0,400	0,500	0,406
Much less significant	0,286	0,333	0,400	0,337
Dominantly less significant	0,250	0,286	0,333	0,288
Absolutely less significant	0,222	0,250	0,286	0,251

3. Stage: The coefficient $\bar{k}_j$ is obtained as illustrated in Equality (2).

$$\bar{k}_j = \begin{Bmatrix} \bar{1}\, if \;\; j = 1 \\ 2 - \bar{s}_j \; if \;\; > 1 \end{Bmatrix} \quad (2)$$

4. Stage: The fuzzy weights $\bar{q}_j$ are calculated as demonstrated in Equality (3).

$$\bar{q}_j = \begin{Bmatrix} \bar{1}\, if j = 1 \\ \frac{\overline{q_j - 1}}{\bar{k}_j} \; if > 1 \end{Bmatrix} \quad (3)$$

5. Stage: The relative weight $\bar{w}_j$ of the criterion is determined as shown in Equality (4).

$$\bar{w}_j = \frac{\bar{q}_j}{\sum_{j=1}^{n} \bar{q}_j} \quad (4)$$

The subsequent stages pertain to the reverse fuzzy PIPRECIA method.

6. Stage: The coefficient $\bar{k}'_j$ is obtained with the help of Equality (5).

$$\bar{k}'_j = \begin{Bmatrix} \bar{1}\, if \;\; j = 1 \\ 2 - \bar{s}'_j \; if \;\; > 1 \end{Bmatrix} \quad (5)$$

7. Stage: The fuzzy weight $\bar{q}'_j$ is obtained with the help of Equality (6).

$$\bar{q}'_j = \begin{Bmatrix} \bar{1}\, if \;\; j = 1 \\ \frac{\bar{q}'_j - 1}{\bar{k}'_j} \; if \;\; > 1 \end{Bmatrix} \quad (6)$$

8. Stage: The relative weight $\bar{w}'_j$ of the criterion is determined as illustrated in Equality (7**).**

$$\bar{w}'_j = \frac{\bar{q}'_j}{\sum_{j=1}^{n} \bar{q}'_j} \quad (7)$$

9. Stage: The values obtained for determining the final weights of the criteria are clarified as shown in Equality (8).

$$\overline{w}_j'' = \frac{1}{2}(\overline{w}_j + \acute{\overline{w}}_j) \quad (8)$$

10 Stage: The consistency of the results obtained from both methods is verified using Spearman and Pearson correlation coefficients.

2.3 CRADIS Method

The CRADIS method, proposed by Puška et al. in 2021, is a ranking-based method. Its foundation lies in utilizing the distances of alternatives from the ideal and anti-ideal solutions, as well as the degree of deviation of the alternatives from optimal solutions (Kundakçı, 2023: 407). Here, the ideal solutions use the maximum values of the alternatives, while the anti-ideal solutions use the minimum values.

The CRADIS method, while being a new method that combines elements of the ARAS, TOPSIS, and MARCOS methods, evaluates alternatives through all criteria (Puška et. al., 2022: 12). The TOPSIS method assesses and ranks alternatives based on their distances to positive and negative ideal solution values (Keleş, 2023: 730). In the CRADIS method, the alternative closest to the ideal solution and furthest from the anti-ideal solution is considered the best. While this aspect is similar to the TOPSIS method, CRADIS differentiates itself by incorporating deviation values into the process, thereby overcoming a disadvantage of the TOPSIS method. Moreover, the method encompasses the optimality function of the ARAS method and the utility function of the MARCOS method, presenting itself as a robust method. The CRADIS method has been used in literature in integration with MCDM methods, and it is also considered as the fuzzy CRADIS method. The table below includes a literature review of the CRADIS and fuzzy CRADIS methods.

Table 4: Literature Review of CRADIS and Fuzzy CRADIS Methods

Subject of the Study	Author, Year	Method
Making green supplier selection	Puška et al. (2022)	Fuzzy LMAW and Fuzzy CRADIS
Selection of incinerators for healthcare waste	Puška et al. (2022)	FUCOM Method and CRADIS Method
Evaluating the performance of information and communication technology in G8 countries	Demir (2022)	CRADIS Method
Performance evaluation of natural disaster insurances	Taşçı (2023)	MEREC Method and CRADIS Method
Evaluating the performance of the transportation sector in Turkey	Doğan et al. (2023)	MEREC Method, IDOCRIW Method, CRADIS Method
Evaluating social development performance in E7 countries	Türkoğlu (2023)	LOPCOW Method and CRADIS method
Selection of pears grown in Serbia	Puška et al. (2023)	Fuzzy CRADIS and CRITIC Method
Performance evaluation of livable power center cities in Turkey and G7 countries	Keleş (2023)	LOPCOW Method and CRADIS Method

1 Stage: A decision matrix is created, and the values in the decision matrix are normalized according to benefit Equality (9) and cost Equality (10) characteristics.

$$For\ benefit\ criteria:\ n_{ij} = \frac{x_{ij}}{x_j^{max}} \quad (9)$$

$$For\ cost\ criteria: \quad n_{ij} = \frac{x_j^{min}}{x_{ij}} \tag{10}$$

2 Stage: The weighted normalized matrix is obtained by multiplying the normalized matrix values with the criterion weights as shown in Equality (11).

$$v_{ij} = n_{ij}.w_j \tag{11}$$

3 Stage: The largest v_{ij} and the smallest v_{ij} values in the weighted decision matrix are found for the ideal and anti-ideal solutions as indicated in Equality (12).

$$t_i = maxv_{ij}, \quad t_{ai} = minv_{ij} \tag{12}$$

4 Stage: Deviations from the ideal and anti-ideal solutions are calculated with the help of Equality (13) and Equality (14).

$$d^+ = t_i - v_{ij} \tag{13}$$

$$d^- = v_{ij} - t_{ai} \tag{14}$$

5 Stage: The degrees of deviation of individual alternatives from the ideal solution and the anti-ideal solution are calculated using Equality (15).

$$s_i^+ = \sum_{j=1}^{n} d^+, \qquad s_i^- = \sum_{j=1}^{n} d^- \tag{15}$$

6. Stage: The utility function of each alternative is calculated based on their deviations from optimal alternatives. Here, the optimal alternative with the smallest distance to the ideal solution is denoted as s_0^+ and the optimal alternative with the largest distance to the anti-ideal solution is denoted as s_0^-.

$$K_i^+ = \frac{s_0^+}{s_i^+} \qquad K_i^- = \frac{s_0^-}{s_i^-} \tag{16}$$

7. Stage: To obtain the final ranking, the average deviations from the utility degree of the alternatives are considered. Here, the best alternative is the one with the highest Q_i value.

$$Q_i = \frac{K_i^+ + \ K_i^-}{2} \tag{17}$$

3. FINDINGS

In the current study, the criteria used for selecting electric vehicles were determined through a literature review and expert opinions. The criteria identified within the scope of the study are as follows; K1: Price of the vehicle (TL), K2: Horsepower of the vehicle (kw), K3: Range of the vehicle with a fully charged battery (km), K4: Charging time to 80% with a DC fast charging unit (min), K5: Battery capacity of the vehicle (wh/km), K6: Fuel consumption of the vehicle (kw). In the first phase of the application, the Fuzzy PIPRECIA method was applied to the determined criteria to obtain the importance weights of the criteria. For this assessment according to the Fuzzy PIPRECIA method, opinions from 5 experts were gathered.

The alternatives defined within the framework of the study are considered as the top 10 best-selling electric vehicles in Turkey for the year 2023. These vehicles are; Togg T10X V2 (A1), Tesla Model Y (A2), Renault Megane E-Tech (A3), MG4 (A4), Skywell ET5 (A5), Opel Corsa-e (A6), Renault Zoe (A7), Opel Mokka-e (A8), Dacia Spring (A9), Mercedes-Benz EQB (A10). Research data were obtained from the official distributor pages of the vehicles, catalogs, and the (https://evdatabase.org/) page. Table (4) presents the alternatives and the observed values of the criteria for the alternatives as a decision matrix.

Table 5: Decision Matrix

Criteria	K1 (Price)	K2 (Horsepower)	K3 (Range)	K4 (Charging Time)	K5 (Battery Capacity)	K6 (Fuel Consumption)
Criterion Direction / Alternatives	min	max	max	min	max	min
A1	1,550,000	218	523	28	88,5	16,9
A2	2,305,854	299	445	20	57,5	15,7
A3	1,599,000	220	450	42	60	16,1
A4	969,000	167	350	37	51	16,6
A5	1,780,000	204	642	36	86	15,6
A6	1,175,900	156	354	30	50	14,8
A7	1,348,607	100	386	50	52	17,7
A8	1,309,000	136	327	30	54	15,9
A9	875,000	65	310	56	26,8	13,9
A10	1,776,000	190	469	30	66,5	16,5

In the study, the evaluations made by 5 decision-makers regarding 6 criteria are as presented in Table (5) and Table (6). The evaluations by the decision-makers have been obtained using the scales for assessing criteria in the fuzzy PIPRECIA method, as described in Table (2) and Table (3)

Table 6: Evaluations of Criteria by Decision-makers

	Decision-maker 1			Decision-maker 2			Decision-maker 3		
K1	1,500	1,750	1,800	1,500	1,750	1,800	1,300	1,450	1,500
K2	0,222	0,25	0,286	1,000	1,000	1,05	0,500	0,667	1,000
K3	1,300	1,450	1,500	1,600	1,900	1,950	1,600	1,900	1,950
K4	1,000	1,000	1,050	1,200	1,300	1,350	0,500	0,667	1,000
K5	0,400	0,500	0,667	0,500	0,667	1,000	1,000	1,000	1,050
K6	1,600	1,900	1,950	1,200	1,300	1,350	1,500	1,750	1,800

Table 7: Evaluations of Criteria by Decision-makers (continued)

	Decision-maker 4			Decision-maker 5		
K1	1,400	1,600	1,650	1,30	1,450	1,500
K2	0,333	0,400	0,500	0,250	0,286	0,333
K3	1,600	1,900	1,950	1,000	1,000	1,050

K4	1,100	1,150	1,200	1,500	1,750	1,800
K5	1,200	1,300	1,350	1,300	1,450	1,500
K6	1,500	1,750	1,800	1,600	1,900	1,950

Table 8: Application results of the fuzzy PIPRECIA method

	S_J			K_J			Q_J			W_J			DF
K1				1,000	1,000	1,000	1,000	1,000	1,000	0,050	0,083	0,163	0,091
K2	0,392	0,453	0,549	1,451	1,547	1,608	0,622	0,646	0,689	0,031	0,054	0,112	0,060
K3	1,397	1,583	1,635	0,365	0,417	0,603	1,032	1,551	1,888	0,052	0,129	0,307	0,146
K4	0,998	1,118	1,251	0,749	0,882	1,002	1,030	1,758	2,520	0,052	0,146	0,410	0,174
K5	0,792	0,911	1,072	0,928	1,089	1,208	0,852	1,615	2,716	0,043	0,134	0,442	0,170
K6	1,472	1,704	1,755	0,245	0,296	0,528	1,615	5,458	11,071	0,081	0,454	1,800	0,616

Table 9: Application results of the fuzzy PIPRECIA method (continued)

	S_J			K_J			Q_J			W_J			DF
K1	1,397	1,594	1,645	0,355	0,406	0,603	1,414	3,981	7,642	0,086	0,377	1,284	0,480
K2	0,392	0,453	0,549	1,451	1,547	1,608	0,622	0,646	0,689	0,038	0,061	0,116	0,066
K3	1,397	1,583	1,635	0,365	0,417	0,603	1,032	1,551	1,888	0,063	0,147	0,317	0,161
K4	0,998	1,118	1,251	0,749	0,882	1,002	1,030	1,758	2,520	0,063	0,167	0,424	0,192
K5	0,792	0,911	1,072	0,928	1,089	1,208	0,852	1,615	2,716	0,052	0,153	0,457	0,187
K6				1,000	1,000	1,000	1,000	1,000	1,000	0,061	0,095	0,168	0,101

Table 10: Final weights of the criteria

Criteria	w_j	Rank
K1: Price	0,285	2
K2: Horsepower	0,063	6
K3: Range	0,154	5
K4: Charging time	0,183	3
K5: Battery capacity	0,179	4
K6: The vehicle's fuel consumption	0,359	1

For electric vehicles, the most important criterion has been found to be K6: The vehicle's fuel consumption (0.359). This criterion is followed by K1: Price (0.285) as the second most important. The ranking of other criteria is as follows; K4: Charging time (0.183), K5: Battery capacity (0.179), K3: Range (0.154), and K2: Horsepower (0.063). The obtained criterion importance weights have been used in the CRADIS method to evaluate the electric vehicles within the scope of the study.

In the CRADIS method, Equality (9) and (10) have been used to normalize the decision matrix. While normalizing the decision matrix, K1 (Price), K4 (Charging Time), K6 (Fuel Consumption) criteria have been considered as cost criteria, and K2 (Horsepower), K3 (Range), K5 (Battery Capacity) have been considered as benefit criteria.

Table 11: Normalize Decision Matrix

Alternatives	Criteria	K1	K2	K3	K4	K5	K6
A1		0,565	0,729	0,815	0,714	1,000	0,822
A2		0,379	1,000	0,693	1,000	0,650	0,885
A3		0,547	0,736	0,701	0,476	0,678	0,863
A4		0,903	0,559	0,545	0,541	0,576	0,837
A5		0,492	0,682	1,000	0,556	0,972	0,891
A6		0,744	0,522	0,551	0,667	0,565	0,939
A7		0,649	0,334	0,601	0,400	0,588	0,785
A8		0,668	0,455	0,509	0,667	0,610	0,874
A9		1,000	0,217	0,483	0,357	0,303	1,000
A10		0,493	0,635	0,731	0,667	0,751	0,842

The elements of the normalized decision matrix are multiplied by the criterion weights obtained from the fuzzy PIPRECIA method to derive the weighted decision matrix using Equation (11). This is presented in Table (11).

Table 12: Weighted Normalized Decision Matrix

Alternatives	Criteria	K1	K2	K3	K4	K5	K6
A1		0,161	0,046	0,125	0,131	0,179	0,295
A2		0,108	0,063	0,106	0,183	0,116	0,318
A3		0,156	0,046	0,108	0,087	0,121	0,310
A4		0,258	0,035	0,084	0,099	0,103	0,300
A5		0,140	0,043	0,154	0,102	0,173	0,320
A6		0,212	0,033	0,085	0,122	0,101	0,337
A7		0,185	0,021	0,092	0,073	0,105	0,282
A8		0,191	0,029	0,078	0,122	0,109	0,314
A9		0,285	0,014	0,074	0,065	0,054	0,359
A10		0,141	0,040	0,112	0,122	0,134	0,302

Using the steps of the CRADIS method, the electric vehicles within the scope of the study have been ranked as shown in Table (10).

Table 13: Results of the CRADIS method

Alternatives	s_i^+	s_i^-	K_i^+	K_i^-	Q_i	Rank
A1	1,216	0,854	0,765	0,749	0,757	1
A2	1,258	0,812	0,739	0,712	0,726	3
A3	1,324	0,746	0,702	0,654	0,678	9
A4	1,273	0,797	0,730	0,699	0,714	5
A5	1,220	0,849	0,762	0,745	0,753	2
A6	1,262	0,808	0,737	0,708	0,722	4
A7	1,394	0,676	0,667	0,593	0,630	10
A8	1,310	0,760	0,710	0,667	0,688	8
A9	1,301	0,769	0,715	0,675	0,695	6
A10	1,300	0,768	0,714	0,674	0,694	7

In the current study, where the importance weights of the criteria were determined using the fuzzy PIPRECIA method and the alternatives were ranked using the CRADIS method, the Togg T10X V2 (A1) alternative ranks first. This alternative is followed by Skywell ET5 (A5) and Tesla Model Y (A2). In this ranking, the impact of the most important criteria determined by decision-makers, K6: The vehicle's fuel consumption and K1: Price, is significant. The decision matrix analysis shows that the data for the fuel and price criteria, which are the most important, match with the first-ranked alternative Togg T10X V2 (A1) and the second-ranked alternative Skywell ET5 (A5).

CONCLUSION

In the current study, where the importance weights of the criteria were determined using the fuzzy PIPRECIA method and the alternatives were ranked using the CRADIS method, the Togg T10X V2 (A1) alternative ranks first. This alternative is followed by Skywell ET5 (A5) and Tesla Model Y (A2). In this ranking, the impact of the most important criteria determined by decision-makers, K6: The vehicle's fuel consumption and K1: Price, is significant. The decision matrix analysis shows that the data for the fuel and price criteria, which are the most important, match with the first-ranked alternative Togg T10X V2 (A1) and the second-ranked alternative Skywell ET5 (A5).

In today's world, global warming and climate change have become elements threatening the ecological balance. The use of greenhouse gases, a process that accelerates these threat factors, mainly emerges from transportation sources. States aim to adopt measures to reduce greenhouse gas emissions through various agreements and projects, partly explaining the recent increase in investments in renewable energy sources. Innovations in transportation in recent years also fall within this scope.

Electric vehicles, which have a long historical background, did not attract interest in earlier periods due to long charging times, lower performance, and high costs. Although electric vehicle production dates to the 1800s, they could not sustain in the market due to inadequate technological developments of the era. Additionally, the lesser environmental awareness in the 1800s also played a significant role in the production-consumption of electric vehicles.

Since the beginning of the 20th century, the scarcity of energy and the damage caused by fossil fuel energy sources to the environment have become undeniable. States and organizations have made significant agreements and decisions on this matter. Many countries facilitate the purchase of electric and hybrid vehicles under "zero-emission incentive premiums". With innovations in electric vehicles and government incentives, there has been an increase in the demand and supply for electric vehicles compared to previous periods, expected to grow in the coming years, with market leaders frequently indicating that all transportation vehicles will eventually transition to electric vehicles. Moreover, in Europe and the United States, the process of replacing the engines of fossil fuel vehicles with electric counterparts has begun, known as "retrofitting" and is rapidly spreading.

Many Multi-Criteria Decision-Making (MCDM) methods are used for alternatives and related criteria in systems today. It is possible for the decision-maker to reach the target, selecting the best alternative among different options based on determined criteria. In MCDM methods, decision-makers evaluate many alternatives according to certain criteria and obtain a ranking. However, MCDM methods' need for precise data is a significant disadvantage, as real-life problems do not always offer the decision-maker the opportunity to work with exact data. Approaches integrating fuzzy logic systems with MCDM methods combine the closeness of fuzzy logic to human thought processes with the numerical analysis superiority of MCDM methods. Thus, "Fuzzy Multi-Criteria Decision-Making" (FMCDM) methods have been developed, where decision-makers can express the importance weights of criteria linguistically and overcome situations of uncertainty.

In this study, the criteria for selecting electric vehicles were weighted according to their importance level using the fuzzy PIPRECIA, a subjective criterion weighting method. The reason for using a fuzzy method in the study is its closeness to the human way of thinking. Also, the criteria identified in the study were determined with expert opinions and contributions from the literature, making the study more aligned with reality. The criteria evaluated for electric vehicle selection, "fuel consumption (K6)" and "price (K1)," were identified as the most important. In the second phase of the study, the criterion weights obtained were used in the CRADIS method to achieve a final ranking for 10 different electric vehicle models. According to the final ranking, Turkey's first domestic electric car, Togg T10X V2 (A1), ranks first.

The use of both methods in the study, which are current MCDM methods, contributes to the study. The literature reviews on vehicle selection problems evaluated in the study and related methods are among the privileges of the study. Additionally, the study contributes significantly to the literature due to the limited sources on the fuzzy PIPRECIA and CRADIS methods used. On the other hand, the "electric vehicle purchase" problem evaluated in the study is at a level that can assist consumers.

Future studies could evaluate the "electric vehicle purchase" problem with different MCDM methods. Moreover, the CRADIS method, a recent and scarcely researched method, could be compared or weighted against other MCDM methods. Similarly, the fuzzy PIPRECIA method, a subjective criterion weighting method, could be compared with different fuzzy MCDM methods. Subsequent studies could present different works by evaluating subjective criterion weighting methods alone or together with objective criterion weighting methods.

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