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The Interval-Valued Spherical Fuzzy Based Methodology and its Application to Electric Car Selection

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ABSTRACT

Imagining, thinking, producing, developing and changing what you produce are among the main traits that make human beings human. Human beings question their raison d'être, their life, the quality of their lives; in other words, they ask why and how. All these inquiries result in the production of information, a flow of the information produced, and sometimes a product. Today, in a world where production takes place at an unprecedented pace, one needs to possess the technology to keep up with developments. This is a dynamic capability and must be continuously developed to make it endure. Electric vehicles, a gift of technological developments of the world of today, are a combination of imagination, a needs assessment, and sustainable innovations. This study addressed the problem of electric car selection and included a case study involving six criteria and ten alternatives. The proposed decision model has integrated AHP and ELECTRE methods with interval-valued spherical fuzzy sets. The novelty of this study stems from evaluating the performance of electric cars using IVSF-AHP-ELECTRE and selecting accordingly for the first time. In this study, the level of importance of battery capacity, autonomous driving, charging network, price, efficiency and performance criteria were determined. A ranking was then made for the electric car alternatives based on these criteria.

Keywords: *Interval-valued spherical fuzzy, AHP, ELECTRE, Electric car*

Aralık Değerlikli Küresel Bulanık Metodoloji ve Elektrikli Araba Seçimi Uygulaması

ÖZ

Hayal etmek, düşünmek, üretmek, ürettiğini geliştirmek, değiştirmek insanı insan yapan belli başlı özelliklerdendir. İnsan, var oluş nedenini sorgular, hayatı sorgular, yaşam kalitesini özetle nedeni, nasılı sorgular ve tüm bu sorgulamalar bilgi üretimine, üretilen bilginin akışına, kimi zaman da ürüne dönüşür. Var edilen ürün, bir amaca hizmet eder. Üretmenin tarihin hiçbir anında olmadığı kadar baş döndürücü bir hızla gerçekleştiği günümüz dünyasında gelişime ayak uydurabilmek, teknolojiye sahip olabilmeye bağlıdır. Bu sahiplik dinamik bir yetenektir ve kalıcı olması için sürekli geliştirilmelidir. Teknolojik gelişmelerin günümüz dünyasına armağanı olan elektrikli araçlar; hayal gücü, ihtiyaç tespiti ve sürdürülebilir inovasyonların bileşkesidir. Bu çalışmada elektrikli araç seçim problemi ele alınmış, altı kriter ve on alternatif içeren bir vaka çalışması sunulmuştur. Önerilen karar modeli, AHP ve ELECTRE yöntemlerini aralık değerlikli küresel bulanık kümelerle bütünleştirmiştir. Makalenin özgünlüğü, IVSF-AHP-ELECTRE önerisinin elektrikli araç performanslarının değerlendirilmesi ve aralarında seçim yapılmasında ilk defa uygulanmasından kaynaklanmaktadır. Çalışmada batarya kapasitesi, otonom sürüş, şarj ağı, fiyat, verimlilik ve performans kriterlerinin önem dereceleri belirlenmiş; bu kriterlere göre alternatif elektrikli araçlar arasında derecelendirme/sıralama yapılmıştır.

Anahtar kelimeler: *Aralık değerli küresel bulanık mantık, AHP, ELECTRE, Elektrikli araç*

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I. INTRODUCTION

The working principle of electric vehicles is that the entire load of a conventional internal combustion engine is transferred to a battery-powered engine. Although the electric vehicle sector is thought of as new, it is a line of business that has existed for a very long time. The first electric car was developed by Professor Stratingh in 1835 in the Netherlands. Then, Robert Davidson made a model electric locomotive that could reach 6.4 km/h in 1838. In 1882, Siemens produced the world's first electric trolley bus in Berlin. In 1895, Morris and Salomon developed a two-seater electric vehicle. In 1897, 15 electric taxis were introduced in England. In 1903, cars that could use either electric or gasoline power were made and thus, the first hybrid configuration model was introduced [1].

Unfortunately, the emergence and widespread use of oil as a cheap fuel decreased the demand for electric vehicles over time. Lobbying by oil producers and internal combustion engine manufacturers against electric vehicles gained momentum and public interest in electric vehicles decreased. Customers' lack of knowledge and hesitation about electric vehicles also contributed to a decrease in interest about them. Technical concerns, such as range, battery life, efficiency and charging stations led to negative point of view towards electric vehicles along with other concerns, such as reliability, trading difficulties and the secondhand market. With changing circumstances, the relentless struggle between electric and fossil fuel-powered vehicles is on a different level today. Factors, such as advances in technology, decreasing fossil fuel reserves, increasing environmental awareness, global warming and increasing taxes have turned the attention of manufacturers back onto electric vehicles. Although the popularity of electric vehicles is increasing day by day, there are still important problems that have not been fully solved. The most important problems are high cost, insufficient range, long charging times and lack of a widespread charging network. Electric vehicles do provide high torque, but they are unable to deliver it at high performance for a long time. This can also be listed as another problem. Moreover, the batteries of electric vehicles are heavy, which can cause problems such as longer braking distances and skidding in turns. Also, it should be noted that the combination of weight and high torque causes tire wear quickly.

Despite the aforementioned disadvantages, prices of electric cars have started to decrease due to improvements in battery and engine technology and this has led to an increase in sales. In addition, development costs and sales prices of internal combustion engines are increasing due to the strict emission rules applied worldwide. Another feature of electric vehicles is that they work quietly. These circumstances help make electric vehicles seem preferable.

This study is based on the comparison and selection of prominent electric cars with different equipment and features according to the aforementioned criteria. Evaluating the performance of electric cars is a complex, multi-criteria problem involving both quantitative and qualitative factors. Decision making is defined as choosing the best alternative among the available alternatives. To implement this process, it is necessary to collect information from decision makers, model the process, analyze the results, and list the alternatives. In many real life problems, it is not easy to get accurate data from decision makers. Therefore, the uncertainty of information must be taken into account. The fuzzy set theory developed by Zadeh is used to solve problems involving uncertainty, and it is reported to give good results in such problems [2]. Studies on fuzzy sets and development processes over the years are given in Figure 1.

The Analytical Hierarchy Process (AHP) is one of the most preferred Multi-Criteria Decision Making (MCDM) methods. Developed by Saaty [3], this method involves a hierarchical order. At the top level of the hierarchy there is the goal. At one level lower, there are the main criteria and, if any, sub criteria below the main criteria. At the lowest step there are decision options, namely alternatives. AHP can be applied easily with many criteria, and it is a very effective method of making group decisions. Thanks to a sensitivity analysis, the flexibility of the result can be easily tested. AHP can evaluate both quantitative and qualitative criteria in decision making and include the preferences, judgments, intuitions and experiences of the group or individuals in the decision process. It is one of the most useful multi-criteria decision-making methods with a hierarchical structure that enables complex problems to be solved [4].

The Elimination Et Choix Traduisant la Realité (ELECTRE) method is a method that allows options to be ranked. Concordance, discordance, and threshold values are used. The ELECTRE method is based on a measure of the dominance of the options relative to each other depending on certain criteria and the weights of these criteria [5]. The basis of the ELECTRE method is establishing a superiority relationship between preferred and non-preferred alternatives. In the ELECTRE method, concordance and discordance indices are created to establish a superiority relationship. These indices show the measure of satisfaction or dissatisfaction that allows to choose which alternative is the more dominant [6].

In this study, a case study including six criteria and ten alternatives is presented. This decision model integrates the AHP and ELECTRE methods with interval-valued spherical fuzzy (IVSF) sets. The novelty of this study stems from evaluating the performance of electric vehicles using IVSF-AHP-ELECTRE and for the first time making a selection accordingly. IVSF-AHP-ELECTRE enables decision makers to independently reflect their hesitations in the decision process by using a linguistic evaluation measure based on spherical fuzzy sets.

This study consists of the following sections: Part 2 summarizes the literature review on the topic. Part 3 includes the proposed MCDM method and the IVSF-AHP-ELECTRE method. Part 4 applies the proposed model to the selection problem. Finally, in Part 5, the findings are discussed and evaluated, and conclusions reached.

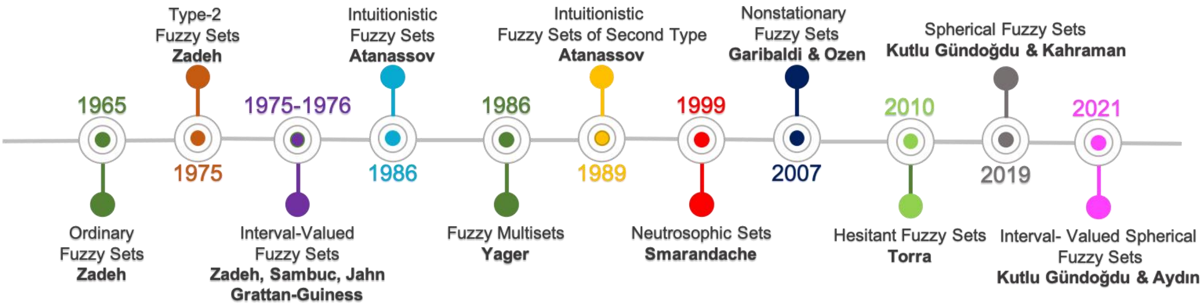

Figure 1. *Historical development of fuzzy sets.*

II. LITERATURE REVIEW

In this literature review part, AHP and ELECTRE methods and research on spherical fuzzy sets and fuzzy extensions of these methods and some other methods are presented. Spherical fuzzy sets are one of the recently developed methods and therefore there are few applications in published literature.

The literature study indicates that there are studies in different fields related to ELECTRE. In their study, Yayla and Karacasu worked on the evaluation of urban public transportation investments and created a decision support model for the evaluation of transportation investments using the ELECTRE method. Ertuğrul and Karakaşoğlu proposed an approach consisting of using ELECTRE and Fuzzy Analytical Hierarchy Process (FAHP) methods together to help decision making in enterprises. In this approach, the FAHP method was used to determine the weights of the criteria. Then, the ELECTRE method was used in ranking the alternatives [6]. Yürekli used the ELECTRE method to select the most suitable attack helicopter in his study and evaluated six different helicopter alternatives according to the criteria used. With the determined criteria and other variables used in the model, the problem was solved with five different types of the ELECTRE methods that were used for selection and ranking. After solving the problem with each method, a general evaluation was made, and the result was discussed [7]. Yücel and Ulutaş made a study to select new locations for the branches of a cargo company using the ELECTRE method [8]. Rouyendegh and Erol suggested using the fuzzy

ELECTRE method for selecting projects [9]. In their study, Ermatita et al. used the ELECTRE method in gene mutation detection simulation in the field of bioinformatics [10]. Using the Dempster-Shafer theory, Fei et al. proposed an ELECTRE-based multi-criteria decision making method for supplier selection [11]. Yu et al. worked with ELECTRE methods in a prioritized multi-criteria decision-making environment [12]. Otay and Atik studied multi-criteria gas station location assessments using Spherical AHP and the Weighted Aggregates Sum Product Assessment (WASPAS) method [13]. Spherical fuzzy sets were introduced by Kutlu Gündoğdu and Kahraman in 2019, and a spherical fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method was proposed. [14]. Ashraf et al. studied spherical fuzzy sets [15]. Kutlu Gündoğdu et al. studied the spherical fuzzy VIKOR method for a waste management application [16]. Furthermore, Kutlu Gündoğdu and Karaşan suggested a new approach for warehouse site selection based on spherical fuzzy VIKOR [17]. Kutlu Gündoğdu and Kahraman developed a spherical fuzzy AHP for renewable energy applications [18]. Tepe suggested a comparison of the spherical fuzzy analytic hierarchy process and the Pythagorean fuzzy analytic hierarchy process for coding program selection [19]. Donyatalab et al. studied the Spherical Fuzzy Linear Assignment Method. In the developed method, a comparative analysis was performed between the proposed Spherical Fuzzy Linear Assignment (SF-LAM) model and both the Spherical Fuzzy Analytical Hierarchy process (SF-AHP) and Spherical Fuzzy WASPAS methods to find the best location to build a wind farm [20].

III. METHODOLOGY

The definitions of Interval Valued Spherical Fuzzy Sets (IV- SFS) are given below [21].
$\tilde{A}_S$ is defined as an interval-valued spherical fuzzy set in Equation 1.

$$\tilde{A}_S = \left\{ \left\langle u, \left(\left[\mu^L_{\tilde{A}_S}(u), \mu^U_{\tilde{A}_S}(u) \right], \left[v^L_{\tilde{A}_S}(u), v^U_{\tilde{A}_S}(u) \right], \left[\pi^L_{\tilde{A}_S}(u), \pi^U_{\tilde{A}_S}(u) \right] \right) \right| u \in \mathrm{U} \right\} \quad (1)$$

$$0 \leq \mu^L_{\tilde{A}_S}(u) \leq \mu^U_{\tilde{A}_S}(u) \leq 1,$$

$$0 \leq v^L_{\tilde{A}_S}(u) \leq v^U_{\tilde{A}_S}(u) \leq 1,$$

$$0 \leq \left(\mu^U_{\tilde{A}_S}(u)\right)^2 + \left(v^U_{\tilde{A}_S}(u)\right)^2 + \left(\pi^U_{\tilde{A}_S}(u)\right)^2 \leq 1$$

The definitions of the operations regarding the interval-valued spherical fuzzy set are given in Equations 2 to 5.

$$\tilde{\alpha}_1 \oplus \tilde{\alpha}_2 = \left\{ \begin{matrix} \left[((a_1)^2 + (a_2)^2 - (a_1)^2(a_2)^2)^{1/2}\right], \left[((b_1)^2 + (b_2)^2 - (b_1)^2(b_2)^2)^{1/2}\right], \left[c_1c_2,\ d_1d_2\right] \\ \left[\begin{matrix} \left((1-(a_2)^2)(e_1)^2 + (1-(a_1)^2)(e_2)^2 - (e_1)^2(e_2)^2\right)^{1/2}, \\ \left((1-(b_2)^2)(f_1)^2 + (1-(b_1)^2)(f_2)^2 - (f_1)^2(f_2)^2\right)^{1/2} \end{matrix} \right] \end{matrix} \right\} \quad (2)$$

$$\tilde{\alpha}_1 \otimes \tilde{\alpha}_2 = \left\{ \begin{matrix} [a_1a_2, b_1b_2], \left[((c_1)^2 + (c_2)^2 - (c_1)^2(c_2)^2)^{1/2}, ((d_1)^2 + (d_2)^2 - (d_1)^2(d_2)^2)^{1/2}\right], \\ \left[\begin{matrix} \left((1-(c_2)^2)(e_1)^2 + \left((1-(c_1)^2)\right)(e_2)^2 - (e_1)^2(e_2)^2\right)^{1/2}, \\ \left((1-(d_2)^2)(f_1)^2 + \left((1-(d_1)^2)\right)(f_2)^2 - (f_1)^2(f_2)^2\right)^{1/2} \end{matrix} \right] \end{matrix} \right\} \quad (3)$$

$$\lambda.\tilde{\alpha} = \left\{ \begin{matrix} \left[\left(1-(1-a^2)^\lambda\right)^{1/2}, \left(1-(1-b^2)^\lambda\right)^{1/2}\right], \left[c^\lambda, d^\lambda\right], \\ \left[\left((1-a^2)^\lambda - (1-a^2-e^2)^\lambda\right)^{1/2}, \left((1-b^2)^\lambda - (1-b^2-f^2)^\lambda\right)^{1/2}\right] \end{matrix} \right\} for\ \lambda > 0 \quad (4)$$

$$w_1.\tilde{\alpha}_1 \oplus w_2.\tilde{\alpha}_2 \oplus \cdots w_n.\tilde{\alpha}_n = \left\{ \begin{array}{l} \left[\left(1 - \prod_{j=1}^{n}(1-a_j^2)^{w_j}\right)^{1/2}, \left(1 - \prod_{j=1}^{n}(1-b_j^2)^{w_j}\right)^{1/2} \right], \left[\prod_{j=1}^{n} c_j^{w_j}, \prod_{j=1}^{n} d_j^{w_j} \right], \\ \left[\left(\prod_{j=1}^{n}(1-a_j^2)^{w_j} - \prod_{j=1}^{n}(1-a_j^2-e_j^2)^{w_j}\right)^{1/2}, \left(\prod_{j=1}^{n}(1-b_j^2)^{w_j} - \prod_{j=1}^{n}(1-b_j^2-f_j^2)^{w_j}\right)^{1/2} \right] \end{array} \right\} \quad (5)$$

The Score function of IV-SFS and the accuracy function of IV-SFS are defined in Equation 6 and Equation 7.

$$Score(\tilde{\alpha}) = S(\tilde{\alpha}) = \frac{a^2+b^2-c^2-d^2-\left(e/_2\right)^2-\left(f/_2\right)^2}{2} \quad (6)$$

$$Accuracy\ (\alpha) = H\ (\alpha) = \frac{a^2+b^2+c^2+d^2+e^2+f^2}{2} \quad (7)$$

The AHP and ELECTRE methods used in the study are comprised of several steps. First of all, a hierarchical structure is created for AHP. Secondly, binary comparisons are made using the spherical fuzzy judgment matrices based on the linguistic terms given in Table 1. Then, the equations given above are used to obtain the score indices and the interval-valued spherical fuzzy local weights of the criteria are calculated. The highest score indicates the best value.

The ELECTRE method starts with creating the decision matrix. Later, the normalized decision matrix and the weighted normalized decision matrix are created. Concordance Sets and Discordance Sets are determined. Each concordance set corresponds to one discordance set only. Following this process, Harmony Superiority Matrices and Discord Superiority Matrices are created. After the Harmony Superiority Matrices and the Discord Superiority Matrices have been created, the Total Dominance Matrix is created and the ranking of the importance of the decision points is determined. The ELECTRE steps are given in Equations 8 to 15. The IV-SFS equations given above were used for all these calculations [21].

$$A = \begin{pmatrix} \alpha_{11} & \alpha_{12} & \cdots & \alpha_{1n} \\ \alpha_{21} & \alpha_{22} & \cdots & \alpha_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \alpha_{m1} & \alpha_{m2} & \cdots & \alpha_{mn} \end{pmatrix} \quad (8)$$

$$x_{ij} = \frac{\alpha_{ij}}{\sqrt{\sum_{k=1}^{m}(\alpha_{kj}^2)}} \quad (9)$$

$$Y = \begin{bmatrix} w_1x_{11} & w_2x_{12} & w_nx_{1n} \\ w_1x_{21} & w_2x_{22} & w_nx_{2n} \\ \cdots & \cdots & \cdots \\ w_1x_{m1} & w_2x_{m2} & w_nx_{mn} \end{bmatrix} \quad (10)$$

$$C_{kl} = \{j, y_{kj} \geq y_{lj}\} \quad (11)$$

$$D_{kl} = \{j, y_{kj} < y_{lj}\}$$

$$C_{kl} = \sum_{j \in C_{kl}} w_j \quad (12)$$

$$C = \begin{bmatrix} - & c_{12} & c_{13} & \cdots & c_{1m} \\ c_{21} & - & c_{23} & \cdots & c_{2m} \\ . & & & & . \\ . & & & & . \\ . & & & & . \\ c_{m1} & c_{m2} & c_{m3} & \cdots & - \end{bmatrix}$$

$$d_{kl} = \frac{\max\limits_{j \in D_{kl}} |y_{kj} - y_{lj}|}{\max\limits_{j} |y_{kj} - y_{lj}|} \tag{13}$$

$$D = \begin{bmatrix} - & d_{12} & d_{13} & \cdots & d_{1m} \\ d_{21} & - & d_{23} & \cdots & d_{2m} \\ . & & & & . \\ . & & & & . \\ . & & & & . \\ d_{m1} & d_{m2} & d_{m3} & \cdots & - \end{bmatrix}$$

$$\underline{c} = \frac{1}{m.(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} c_{kl} \tag{14}$$

$If\, c_{kl} \geq \underline{c} \rightarrow f_{kl} = 1,$

$If\, c_{kl} < \underline{c} \rightarrow f_{kl} = 0$

$$\underline{d} = \frac{1}{m.(m-1)} \sum_{k=1}^{m} \sum_{l=1}^{m} d_{kl} \tag{15}$$

$If\, d_{kl} \geq \underline{d} \rightarrow g_{kl} = 1,$

$If\, d_{kl} < \underline{d} \rightarrow g_{kl} = 0$

The linguistic measures used in binary comparisons in the process are given in Table 1 [21].

***Table 1**. Linguistic measures of interval valued spherical fuzzy sets.*

	$([(\mu^L_{\tilde{A}_S}(u), \mu^U_{\tilde{A}_S}(u)], [v^L_{\tilde{A}_S}(u), v^U_{\tilde{A}_S}(u)], [\pi^L_{\tilde{A}_S}(u), \pi^U_{\tilde{A}_S}(u)])$
Absolutely more importance (AMI)	([0.85, 0.95], [0.10, 0.15], [0.05, 0.15])
Very high importance (VHI)	([0.75, 0.85], [0.15, 0.20], [0.15, 0.20])
High importance (HI)	([0.65, 0.75], [0.20, 0.25], [0.20, 0.25])
Slightly more importance (SMI)	([0.55, 0.65], [0.25, 0.30], [0.25, 0.30])
Equal importance (EI)	([0.50, 0.55], [0.45, 0.55], [0.30, 0.40])
Slightly low importance (SLI)	([0.25, 0.30], [0.55, 0.65], [0.25, 0.30])
Low importance (LI)	([0.20, 0.25], [0.65, 0.75], [0.20, 0.25])
Very low importance (VLI)	([0.15, 0.20], [0.75, 0.85], [0.15, 0.20])
Absolutely low importance (ALI)	([0.10, 0.15], [0.85, 0.95], [0.10, 0.15])

IV. APPLICATION

Electric cars are becoming more important in our lives. This study is based on the comparison and ranking of electric cars in terms of the criteria based on experts' opinions. In the preparation phase of the study, experts working in the electric vehicle business sector were contacted and all possible criteria were discussed with them. In the preliminary interviews, 15 criteria were determined, and a detailed investigation was conducted in this sector regarding these criteria. As a result of the interviews with the electric vehicle manufacturers and the opinions of the experts, it was decided that with 6 criteria, the electric cars could be evaluated. The criteria examined in the study were determined to be C1: autonomous driving, C2: performance, C3: charging network, C4: price, C5: efficiency and C6: battery capacity. Figure 2 shows the hierarchical structure that includes the main criteria and the alternatives used for comparison in the study.

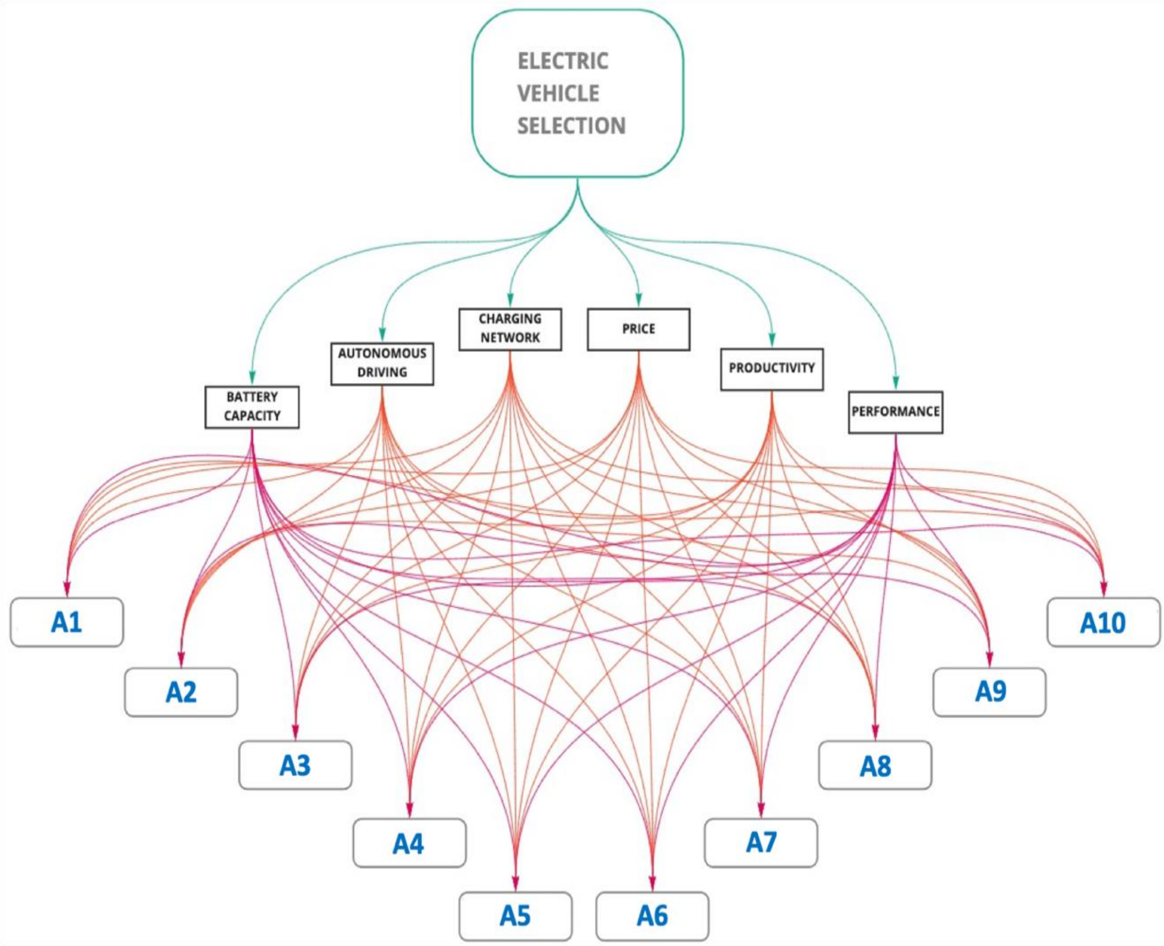

Figure 2. *Hierarchical structure of the main criteria and alternatives.*

In the study, the main criteria were evaluated according to the linguistic terms given in Table 1 produced by the decision-maker expert group.

For the linguistic measure given in Table 1, binary comparison matrices were calculated according to the corresponding numerical values in the classical AHP method and the results are given in Table 2. The basis of the ELECTRE method, which is one of the multi-criteria decision-making methods, is to establish a superiority relationship between preferred and undesired alternatives. In order to establish this relationship, concordance and discordance indices are created. In the pairwise comparison of alternatives for the concordance set, if one alternative is greater or equal than the other, that criterion is included in the concordance set. If one alternative is less than the other in the pairwise comparison of the alternatives for the discordance set, that criterion is included in the discordance set.

Table 2. *Judgments of decision makers based on interval valued spherical fuzzy approach.*

		C1	C2	C3	C4	C5	C6	Average	Score	Weight
C1	$\mu^L_{\tilde{A}_S}(u)$	0.50	0.55	0.65	0.55	0.65	0.75	0.62	0.587282567	0.171165386

	$\mu^U_{\tilde{A}_S}(u)$	0.55	0.65	0.75	0.65	0.75	0.85	0.72		
	$\nu^L_{\tilde{A}_S}(u)$	0.45	0.25	0.20	0.25	0.20	0.15	0.24		
	$\nu^U_{\tilde{A}_S}(u)$	0.55	0.30	0.25	0.30	0.25	0.20	0.29		
	$\pi^L_{\tilde{A}_S}(u)$	0.30	0.25	0.20	0.25	0.20	0.15	0.22		
	$\pi^U_{\tilde{A}_S}(u)$	0.40	0.30	0.25	0.30	0.25	0.20	0.28		
C2	$\mu^L_{\tilde{A}_S}(u)$	0.25	0.50	0.65	0.20	0.55	0.65	0.52	0.532143131	0.155094821
	$\mu^U_{\tilde{A}_S}(u)$	0.30	0.55	0.75	0.25	0.65	0.75	0.60		
	$\nu^L_{\tilde{A}_S}(u)$	0.55	0.45	0.20	0.65	0.25	0.20	0.34		
	$\nu^U_{\tilde{A}_S}(u)$	0.65	0.55	0.25	0.75	0.30	0.25	0.41		
	$\pi^L_{\tilde{A}_S}(u)$	0.25	0.30	0.20	0.20	0.25	0.20	0.24		
	$\pi^U_{\tilde{A}_S}(u)$	0.30	0.40	0.25	0.25	0.30	0.25	0.30		
C3	$\mu^L_{\tilde{A}_S}(u)$	0.20	0.20	0.50	0.15	0.20	0.55	0.35	0.556701684	0.16225249
	$\mu^U_{\tilde{A}_S}(u)$	0.25	0.25	0.55	0.20	0.25	0.65	0.42		
	$\nu^L_{\tilde{A}_S}(u)$	0.65	0.65	0.45	0.75	0.65	0.25	0.53		
	$\nu^U_{\tilde{A}_S}(u)$	0.75	0.75	0.55	0.85	0.75	0.30	0.62		
	$\pi^L_{\tilde{A}_S}(u)$	0.20	0.20	0.30	0.15	0.20	0.25	0.23		
	$\pi^U_{\tilde{A}_S}(u)$	0.25	0.25	0.40	0.20	0.25	0.30	0.30		
C4	$\mu^L_{\tilde{A}_S}(u)$	0.25	0.65	0.75	0.50	0.25	0.75	0.59	0.586640313	0.170978199
	$\mu^U_{\tilde{A}_S}(u)$	0.30	0.75	0.85	0.55	0.30	0.85	0.69		
	$\nu^L_{\tilde{A}_S}(u)$	0.55	0.20	0.15	0.45	0.55	0.15	0.29		
	$\nu^U_{\tilde{A}_S}(u)$	0.65	0.25	0.20	0.55	0.65	0.20	0.36		
	$\pi^L_{\tilde{A}_S}(u)$	0.25	0.20	0.15	0.30	0.25	0.15	0.21		
	$\pi^U_{\tilde{A}_S}(u)$	0.30	0.25	0.20	0.40	0.30	0.20	0.27		
C5	$\mu^L_{\tilde{A}_S}(u)$	0.20	0.25	0.65	0.55	0.50	0.75	0.55	0.554961605	0.161745338
	$\mu^U_{\tilde{A}_S}(u)$	0.25	0.30	0.75	0.65	0.55	0.85	0.64		
	$\nu^L_{\tilde{A}_S}(u)$	0.65	0.55	0.20	0.25	0.45	0.15	0.33		
	$\nu^U_{\tilde{A}_S}(u)$	0.75	0.65	0.25	0.30	0.55	0.20	0.40		
	$\pi^L_{\tilde{A}_S}(u)$	0.20	0.25	0.20	0.25	0.30	0.15	0.23		
	$\pi^U_{\tilde{A}_S}(u)$	0.25	0.30	0.25	0.30	0.40	0.20	0.29		
C6	$\mu^L_{\tilde{A}_S}(u)$	0.15	0.25	0.25	0.15	0.15	0.50	0.28	0.61335324	0.178763767
	$\mu^U_{\tilde{A}_S}(u)$	0.20	0.30	0.30	0.20	0.20	0.55	0.33		
	$\nu^L_{\tilde{A}_S}(u)$	0.75	0.55	0.55	0.75	0.75	0.45	0.62		
	$\nu^U_{\tilde{A}_S}(u)$	0.85	0.65	0.65	0.85	0.85	0.55	0.72		
	$\pi^L_{\tilde{A}_S}(u)$	0.15	0.25	0.25	0.15	0.15	0.30	0.22		
	$\pi^U_{\tilde{A}_S}(u)$	0.20	0.30	0.30	0.20	0.20	0.40	0.29		

Interval-valued spherical weights obtained according to the binary comparisons are given in Table 3.

Table 3. *Interval valued spherical fuzzy weight matrix based on the fuzzy approach.*

		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
C1	$\mu^L_{\tilde{A}_S}(u)$	0.43	0.31	0.37	0.46	0.23	0.65	0.65	0.65	0.65	0.65
	$\mu^U_{\tilde{A}_S}(u)$	0.37	0.23	0.31	0.43	0.13	0.61	0.61	0.61	0.61	0.61
	$v^L_{\tilde{A}_S}(u)$	0.79	0.72	0.76	0.87	0.67	0.93	0.93	0.93	0.93	0.93
	$v^U_{\tilde{A}_S}(u)$	0.81	0.76	0.79	0.90	0.72	0.95	0.95	0.95	0.95	0.95
	$\pi^L_{\tilde{A}_S}(u)$	0.12	0.09	0.11	0.14	0.04	0.08	0.08	0.08	0.08	0.08
	$\pi^U_{\tilde{A}_S}(u)$	0.16	0.15	0.15	0.20	0.17	0.11	0.11	0.11	0.11	0.11
C2	$\mu^L_{\tilde{A}_S}(u)$	0.29	0.41	0.44	0.22	0.35	0.59	0.63	0.41	0.59	0.63
	$\mu^U_{\tilde{A}_S}(u)$	0.22	0.35	0.41	0.13	0.29	0.56	0.59	0.35	0.56	0.59
	$v^L_{\tilde{A}_S}(u)$	0.75	0.81	0.88	0.70	0.78	0.91	0.94	0.81	0.91	0.94
	$v^U_{\tilde{A}_S}(u)$	0.78	0.83	0.91	0.75	0.81	0.94	0.96	0.83	0.94	0.96
	$\pi^L_{\tilde{A}_S}(u)$	0.08	0.12	0.14	0.03	0.10	0.10	0.08	0.12	0.10	0.08
	$\pi^U_{\tilde{A}_S}(u)$	0.14	0.15	0.19	0.17	0.14	0.13	0.10	0.15	0.13	0.10
C3	$\mu^L_{\tilde{A}_S}(u)$	0.42	0.36	0.36	0.36	0.23	0.45	0.45	0.45	0.45	0.45
	$\mu^U_{\tilde{A}_S}(u)$	0.36	0.30	0.30	0.30	0.13	0.42	0.42	0.42	0.42	0.42
	$v^L_{\tilde{A}_S}(u)$	0.80	0.77	0.77	0.77	0.69	0.88	0.88	0.88	0.88	0.88
	$v^U_{\tilde{A}_S}(u)$	0.82	0.80	0.80	0.80	0.74	0.91	0.91	0.91	0.91	0.91
	$\pi^L_{\tilde{A}_S}(u)$	0.12	0.10	0.10	0.10	0.03	0.14	0.14	0.14	0.14	0.14
	$\pi^U_{\tilde{A}_S}(u)$	0.16	0.15	0.15	0.15	0.17	0.20	0.20	0.20	0.20	0.20
C4	$\mu^L_{\tilde{A}_S}(u)$	0.61	0.61	0.61	0.61	0.65	0.37	0.37	0.43	0.31	0.43
	$\mu^U_{\tilde{A}_S}(u)$	0.58	0.58	0.58	0.58	0.61	0.31	0.31	0.37	0.23	0.37
	$v^L_{\tilde{A}_S}(u)$	0.90	0.90	0.90	0.90	0.93	0.76	0.76	0.79	0.72	0.79
	$v^U_{\tilde{A}_S}(u)$	0.93	0.93	0.93	0.93	0.95	0.79	0.79	0.81	0.76	0.81
	$\pi^L_{\tilde{A}_S}(u)$	0.11	0.11	0.11	0.11	0.08	0.11	0.11	0.12	0.09	0.12
	$\pi^U_{\tilde{A}_S}(u)$	0.13	0.13	0.13	0.13	0.11	0.15	0.15	0.16	0.15	0.16
C5	$\mu^L_{\tilde{A}_S}(u)$	0.42	0.36	0.23	0.42	0.36	0.45	0.45	0.45	0.45	0.45
	$\mu^U_{\tilde{A}_S}(u)$	0.36	0.30	0.13	0.36	0.30	0.42	0.42	0.42	0.42	0.42
	$v^L_{\tilde{A}_S}(u)$	0.80	0.77	0.69	0.80	0.77	0.88	0.88	0.88	0.88	0.88
	$v^U_{\tilde{A}_S}(u)$	0.82	0.80	0.74	0.82	0.80	0.91	0.91	0.91	0.91	0.91
	$\pi^L_{\tilde{A}_S}(u)$	0.12	0.10	0.03	0.12	0.10	0.14	0.14	0.14	0.14	0.14
	$\pi^U_{\tilde{A}_S}(u)$	0.16	0.15	0.17	0.16	0.15	0.20	0.20	0.20	0.20	0.20
C6	$\mu^L_{\tilde{A}_S}(u)$	0.38	0.44	0.31	0.44	0.24	0.63	0.66	0.66	0.63	0.47
	$\mu^U_{\tilde{A}_S}(u)$	0.31	0.38	0.24	0.38	0.13	0.59	0.63	0.63	0.59	0.44
	$v^L_{\tilde{A}_S}(u)$	0.75	0.78	0.71	0.78	0.66	0.90	0.93	0.93	0.90	0.87
	$v^U_{\tilde{A}_S}(u)$	0.78	0.81	0.75	0.81	0.71	0.93	0.95	0.95	0.93	0.90
	$\pi^L_{\tilde{A}_S}(u)$	0.11	0.12	0.09	0.12	0.04	0.11	0.09	0.09	0.11	0.15
	$\pi^U_{\tilde{A}_S}(u)$	0.15	0.16	0.15	0.16	0.17	0.13	0.11	0.11	0.13	0.21

Since the proposed MCDM technique included the interval-valued spherical fuzzy AHP-ELECTRE method, the results obtained by the process steps of the ELECTRE method are given in Tables 4, 5, 6, 7 and 8, respectively. Matrices of the concordance sets are given in Table 4.

Table 4. *Concordance matrix.*

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**
A1	0.00	0.48	0.49	0.33	0.49	0.65	0.65	0.65	0.48	0.83
A2	0.35	0.00	0.33	0.17	0.33	0.67	0.84	0.84	0.50	0.84
A3	0.34	0.34	0.00	0.51	0.33	0.67	0.67	0.67	0.50	0.67
A4	0.33	0.32	0.16	0.00	0.49	0.65	0.83	0.83	0.48	0.83
A5	0.51	0.51	0.67	0.51	0.00	0.84	0.84	0.84	0.67	0.84
A6	0.35	0.33	0.33	0.35	0.16	0.00	0.33	0.33	0.00	0.33
A7	0.35	0.16	0.33	0.17	0.16	0.00	0.00	0.16	0.00	0.18
A8	0.35	0.00	0.33	0.17	0.16	0.17	0.17	0.00	0.00	0.18
A9	0.52	0.50	0.50	0.52	0.33	0.17	0.50	0.50	0.00	0.50
A10	0.17	0.16	0.33	0.17	0.16	0.17	0.17	0.16	0.00	0.00

Table 5 shows the matrices of the discordance sets.

Table 5. *Discordance matrix.*

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**
A1	0.00	1.51	1.06	1.01	2.68	1.84	1.75	1.83	2.72	0.79
A2	1.89	0.00	2.00	0.95	2.01	1.18	0.69	0.00	2.04	0.69
A3	1.51	1.42	0.00	1.00	2.88	1.33	1.28	1.10	2.30	1.52
A4	1.46	1.00	1.69	0.00	2.02	1.15	0.44	0.63	2.05	0.44
A5	0.94	0.61	1.08	0.77	0.00	0.58	0.68	0.11	1.45	0.70
A6	2.59	2.55	3.05	2.48	3.61	0.00	0.00	0.25	1.00	0.39
A7	2.37	3.31	2.77	3.01	3.62	1.90	0.00	0.20	2.87	0.28
A8	1.59	3.18	2.65	3.22	3.51	1.26	1.00	0.00	1.75	1.00
A9	1.58	1.82	2.23	1.72	2.86	0.00	0.00	0.00	0.00	0.00
A10	2.71	2.72	2.64	2.46	3.22	1.37	1.00	0.72	2.17	0.00

The harmony superiority matrices are given in Table 6.

Table 6. *Harmony superiority matrix.*

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**
A1	0	1	1	0	1	1	1	1	1	1
A2	0	0	0	0	0	1	1	1	1	1

A3	0	0	0	1	0	1	1	1	1	1
A4	0	0	0	0	1	1	1	1	1	1
A5	1	1	1	1	0	1	1	1	1	1
A6	0	0	0	0	0	0	0	0	0	0
A7	0	0	0	0	0	0	0	0	0	0
A8	0	0	0	0	0	0	0	0	0	0
A9	1	1	1	1	0	0	1	1	0	1
A10	0	0	0	0	0	0	0	0	0	0

The discord superiority matrices are given in Table 7.

Table 7. *Discord superiority matrix.*

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**
A1	0	0	0	0	1	1	1	1	1	0
A2	1	0	1	0	1	0	0	0	1	0
A3	0	0	0	0	1	0	0	0	1	0
A4	0	0	1	0	1	0	0	0	1	0
A5	0	0	0	0	0	0	0	0	0	0
A6	1	1	1	1	1	0	0	0	0	0
A7	1	1	1	1	1	1	0	0	1	0
A8	0	1	1	1	1	0	0	0	1	0
A9	0	1	1	1	1	0	0	0	0	0
A10	1	1	1	1	1	0	0	0	1	0

Table 8 shows the total dominance matrix obtained by multiplying Table 6 and Table 7.

Table 8. *Total dominance matrix.*

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**
A1	0	0	0	0	1	1	1	1	1	0
A2	0	0	0	0	0	0	0	0	1	0
A3	0	0	0	0	0	0	0	0	1	0
A4	0	0	0	0	1	0	0	0	1	0
A5	0	0	0	0	0	0	0	0	0	0
A6	0	0	0	0	0	0	0	0	0	0
A7	0	0	0	0	0	0	0	0	0	0
A8	0	0	0	0	0	0	0	0	0	0
A9	0	1	1	1	0	0	0	0	0	0
A10	0	0	0	0	0	0	0	0	0	0

The ranking of the alternatives compared is given in Table 9.

Table 9. *Ranking of the compared alternatives.*

	Rank
A1	1
A9	2
A4	3
A2	4
A3	5
A5	6
A6	7
A7	8
A8	9

A10	10

V. CONCLUSION

In this study, an important multi-criteria decision-making strategy problem of electric car selection has been solved with the interval-valued spherical fuzzy AHP-ELECTRE method. According to the data obtained in this study, the A1 electric car alternative was in first place, the A9 electric car alternative was in second place and the A4 electric car alternative was in the third place. These results show that electric vehicle manufacturers that attach importance to battery capacity, efficiency – and thus range – autonomous driving capabilities and charging network are ahead of other competitors and are thought to be more preferable. The price, efficiency, and performance criteria have an important role in electric car selection. In this study, the aforementioned criteria were evaluated together with the experts, and the significance level of each criterion was determined. The study was performed by integrating AHP-ELECTRE into interval-valued spherical fuzzy sets and it is the first study presented in this field as far as it is known. Aydın and Gündoğdu applied this method for Industry 4.0 using the Interval-Valued Spherical Fuzzy MULTIMOORA Method in their studies [21]. In this study, its application was carried out by integrating MOORA to both spherical fuzzy sets and interval-valued spherical fuzzy sets. What makes this study novel is that weighted values were calculated with AHP, while the ranking and selection processes was carried out with ELECTRE.

VI. DISCUSSION

There are many different criteria when it comes to electric cars because the electric vehicle industry offers a new philosophy as well as the technical innovations involved. The widespread use of electric cars cannot be simply defined as a matter of vehicle substitution. Electric cars bring very important issues to the table, such as car manufacturers taking their engine manufacturing technique to a completely different level, changes in taxes, changes in the location and power of the car dealerships, and the replacement of gas stations with charging stations. This situation affects all participants. While new lines of work are emerging, discussions on the share of electric vehicles in the automotive market are growing. Current internal combustion engine manufacturers are calculating how much of their manufacturing should be allocated to electric vehicles and under what conditions. While calculating the changes these manufacturers will make in their factories, to their employees and to their partnerships is an important problem. Another problem is that the functionality of the car dealerships, which are an important player in vehicle sales, is declining. The stakeholder power of the car dealerships decreases with the online sales of electric vehicles without intermediaries. However, considering the investments made by the current vehicle manufacturers in their dealerships, it does not seem easy to abandon this in one go. Another issue on the agenda is about how green electric vehicles really are. While these discussions are still going on, the electric vehicle business – trying to improve their features day by day – is developing partnerships to solve important problems involving battery capacity, autonomous driving, price, range, efficiency, performance and charging networks. The battery stores the electrical energy as chemical energy and enables it to be used as electrical energy when desired. This amount of energy is called the battery capacity. Today, the area where electric vehicle manufacturers compete with each other the most is in the battery capacity. Parameters such as the technology used in the battery, the size of the battery capacity, and the battery life, directly affect electric vehicles. Another parameter that directly affects electric vehicles is the charging network. One of the important questions that people who buy electric vehicles think about is where and how they will charge their vehicles. Thanks to the equipment on the electric vehicles, it can be charged anywhere, from a 220V home socket to a 400V three-phase industrial socket. The use of charging stations located on the roadside or in places where lots of people spend time is easier for the end user and these stations can even be installed in homes. When the charging network is widespread and easily accessible it triggers electric vehicle selection.

Autonomous driving, which is often referred to within the concept of electric vehicles, is a vehicle-driving technology that can sense its environment and move without human input. These vehicles use artificial intelligence technology to move around without the need for a driver. The presence of autonomous driving is a very important parameter in electric vehicle selection. Studies on autonomous driving are increasing day by day and now autonomous driving technology is categorized as partial, conditional, or full automation. There is a lot of work to be done in the field of autonomous driving. Of course, price, efficiency and performance are among the issues that attract the most attention from the end user, because the end user wants to buy the best quality product at the most reasonable cost. Comparing different techniques for the same application in future studies is advised. When different electric vehicle brands become more comparable in terms of technical features, the criteria used in this study can be applied with sub-criteria for future studies. This is because under present conditions – even though the study started with the goal of having more criteria – criteria elimination had to be used so that different electric car models could be compared against the same criteria, which is the limitation of this study for now. With the development of the technologies used, the study can be improved by adding different criteria to the evaluation.

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