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Comparative Performance Measurement in the Full Electric Vehicle Market

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Abstract

In this study, Entropy, WASPAS and MOORA methods, which are multi-criteria decision-making techniques, are used to measure the performance of the best-selling full electric cars in Türkiye as of October 2023 by the Automotive Distributors and Mobility Association using 12 different criteria. The weights of the criteria were calculated with the Entropy method. Then, the electric cars were ranked by evaluating their performance with the WASPAS and MOORA-based methods. In the study, it was concluded that the top three criteria with the highest weights were power (HP), fast charging time and battery capacity, while the top three highest performing electric cars were TOGG T10X V2 Long Range, Volvo XC40 RWD (Single Motor) and Tesla Y Long Range RWD (4x2).

Keywords: Full Electric Car, Electric Vehicle (EV), Entropy, WASPAS, MULTIMOORA.

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1. INTRODUCTION

Greenhouse gas emissions are one of the most important causes of global warming. Fossil fuels used in transportation and electricity generation increase greenhouse gas emissions and therefore cause global warming. Renewable energy sources have become more important with the increase in air and water pollution as a result of rapid production and consumption, the gradual depletion of limited resources, and the awareness of leaving a livable world to future generations (Çoşkun, 2022a, p. 69).

The Paris Agreement, which entered into force in November 2016, aims to keep the global average temperature increase below 2 degrees. In this context, European Union countries have committed to reduce greenhouse gas emissions by 40%, CO2 emissions from vehicles by 55%, and those from pickup trucks by 50% by 2030. The law also proposes to eliminate emissions from pickup trucks and cars by 2035 (European Environment Agency, 2022). Road transportation plays an important role in achieving this goal (Biswas & Das, 2019, p. 531). Electric vehicles have begun to become more visible with the increasing incentives provided to electric vehicles not only by European countries, but also by China and the United States of America, the competition for a share in the electric vehicle (EV) market has intensified and consumers have become more sensitive to the environment (Gavcar & Kara, 2020, p. 352). In parallel with the efforts to reduce oil consumption, energy technologies that provide less carbon emissions have been supported, alternative energy policies have been adopted and important studies have been carried out in the public and private sectors. With the high demand for hybrid and electric vehicles in recent years, automobile manufacturers have started to focus on electric vehicle production. Brands around the world such as General Motors, BMW, Ferrari, Daimler, Honda, Hyundai, Jaguar, Land Rover, Renault, Toyota, Volkswagen and Volvo have announced that they will gradually end the production of diesel and gasoline vehicles in different periods after 2025 and switch to electric vehicle production only (Çoşkun, 2022a, p. 69).

According to the Economic and Market Report of The European Automobile Manufacturers' Association – ACEA (2023); While automobile sales increased by approximately 9% on a global scale in the first three quarters of 2023, battery electric vehicle sales increased by 55%. The share of battery electric models is expected to increase to 14.5% by the end of 2023. Information obtained from the World Electric Vehicle Sales Database also confirms these rates and shows that the acceleration in electric vehicle sales continues rapidly. In the report on electric vehicle sales volumes prepared by Neil King and published on evvolumes.com, the unit volume of global EV sales is expected to increase from 10.5 million in 2022 to 14.1 million in 2023 and over 31 million in 2027. The 2023 sales forecast equates to a 34% increase in EV sales compared to 2022. It is estimated that it will exceed 74.5 million units in 2035 and that two-thirds of global light vehicle sales will be made up of EVs (King, 2023). China is the main driving force of this global volume and growth. Supported by the Chinese market and increasing public incentives, China's BYD (Build Your Dreams) has become the world's largest EV manufacturer, surpassing Tesla in 2022. It is expected to continue this in 2023.

The sales rates recorded for electric cars in the European region and globally are similar to the rates in the Turkish market. According to the Automobile and Light Commercial Vehicle Market Assessment 2023 November bulletin of the Automotive Distributors & Mobility Association (2023) published on December 4, 2023, 6214 electric cars were sold in Türkiye in the January-November 2022 period, and 60101 electric cars were sold in the January-November 2023 period. In the same period, automobile and light commercial vehicle sales increased by 66.2%, while the EV increase was 867.2%. According to the data of the Turkish Electric and Hybrid Vehicles Association – TEHAD (2023), electric vehicle sales in Türkiye, which were 44 in 2016 and 77 in 2017, reached 844 in 2020 and 2849 in 2021. In 2022, it reached a total of 8210 units, an increase of 188% compared to 2021. Again, according to the information in TEHAD, charging station investments of various companies have increased rapidly, and charging services for electric vehicles have become available in all 81 provinces. According to the data of the Turkish Statistical Institute (TUIK, 2023), there is a rapidly growing market. According to TUIK's Motor Land Vehicles October 2023 report, the rate of traffic registrations of electric vehicles increased from 1.2% in January-October 2022 to 5.9% in 2023, according to all fuel groups.

Acting with the awareness of the importance of EA production and use, Türkiye wants to exist in the sector with the TOGG (Türkiye'nin Otomobili Girişim Grubu) branded electric vehicle factory established in Bursa-Gemlik district and capture the opportunity it missed in the automobile sector in the EA market. Thus, dependence on fossil fuels needed for automobiles will be reduced, savings will be made on imports of fossil fuels, and a contribution will be made to the fight against global warming and climate change.

Increasing supplies of manufacturers and technological developments; governments' taxation approaches and environmental policies; changing demand trends as a result of individuals' changing perceptions and attitudes towards sustainability; have already started to make electric vehicles a component of a large market. Research on sustainable transportation systems that can meet energy needs with alternative energy sources, instead of conventional transportation systems with internal combustion engines and rubber wheels, which have a negative impact on environmental pollution, especially due to greenhouse gas emissions, has intensified today. Among alternative approaches, especially electric vehicles are one of the most popular options for the future that can be used instead of vehicles with conventional systems. In this regard, vehicles with internal combustion engines negatively affect the quality of human life, primarily due to the greenhouse gas emissions they create and the noise they cause. In Smadi and Hussein's (2020) research on emission comparison between alternative vehicles, EVs, which are shown to have zero local emissions, eliminate dependence on fossil-based fuels, while also offering energy efficient, flexible and reliable solutions with recovery technologies (Smadi & Hussein, 2020). However, considering the features of EVs, there are different criteria that may or may not be related to each other. These criteria must be evaluated for maximum or minimum purposes in terms of benefit or cost. Multi-criteria decision-making techniques are methods developed to make these evaluations (Çoşkun, 2022b, p. 175). One of the most important steps of the decision process is the evaluation of the criteria of various alternatives, that is, the process of weighting. The weighting operations performed as a result of the evaluation of the criteria by experts in the field are subjective weighting, and the prioritization operations performed based on the values of the quantities of the criteria are objective weighting (Demircioğlu & Coşkun, 2018, p. 184-185). Techniques such as Analytical Hierarchy Process (AHP), The Decision-Making Trial and Evaluation Laboratory (DEMATEL), Stepwise Weight Assessment Ratio Analysis (SWARA) and Weighted Influence Non-linear Gauge System (WINGS), subjective weighting methods, Criteria Importance Through Intercriteria Correlation (CRITIC), ENTROPY, Mean Weight (MW) and Standard Deviation (SD) are objective weighting methods. This study aims to evaluate and compare the criteria that are effective in the selection of electric vehicles using the Entropy technique, Weighted Aggregated Sum Product Assessment (WASPAS) method and MOORA (Multi-objective Optimization By Ratio Analysis) method. For this purpose, in the study, the performance of the 11 best-selling fully electric cars in Türkiye as of October 2023 by the Automotive Distributors and Mobility Association was measured with the help of 12 different criteria. In the study, unlike other studies, the optimal lambda value was also calculated for WASPAS method and it was investigated whether the performance ranking changed. In addition, the study contributes to the EV sector as it is the first study to include TOGG, a domestic and national electric vehicle. In the following sections of the study, a literature review is included, then Entropy, WASPAS and MOORA methods are explained, analyses are performed and the results are interpreted. In the last section, general evaluation and policy recommendations are made.

2. LITERATURE REVIEW

Performance evaluation of electric vehicles has become popular in recent years with the developing electric vehicle market. Although there are many studies in the literature on the performance of internal combustion vehicles, there are a limited number of studies on the performance evaluation of electric vehicle models. The vehicle selection problem has been examined with various methods and multi-criteria decision-making methods have been frequently used in vehicle selection problems. Within the scope of this study, studies in the literature addressing vehicle selection problems were examined.

Baležentis et al. (2012) used the fuzzy MULTIMOORA technique to evaluate four alternatives under eight criteria for a personnel selection problem in a company. In the study by Aksoy et al. (2015), multi-criteria decision-making methods were used to evaluate the performance of eight enterprises belonging to TKİ (Turkish Coal Enterprises) between 2008 and 2012. In the study where seven criteria were weighted with AHP, MULTIMOORA and COPRAS methods were used in performance ranking. In Aytekin's (2016) study, eight criteria that are effective in patients' hospital selection were addressed. Firstly, the criteria were weighted according to the answers given through the questionnaire, and then eight different alternatives, three public and five private hospitals in Eskişehir city center, were ranked with MULTIMOORA. Onat et al. (2016) used the Fuzzy TOPSIS method for the selection of hybrid and electric vehicle technologies for sustainable transportation. 16 different criteria classified as economic, environmental and social were discussed in line with the opinions of 3 experts. In Kılıç and Çerçioğlu's (2016) study, priority ranking was made for the railway connection planned for 78 locations such as organized industrial zones, plants, factories, etc. with high load carrying capacity, where an interconnection line is considered by TCDD. CRITIC, SD and MW techniques were used for weighting and TOPSIS and VIKOR methods were used for ranking the alternatives. Ömürbek and Aksoy (2017) used the MULTIMOORA technique in their study in which they aimed to evaluate the performance of thirty-two different manufacturing sub-sectors constituting the manufacturing sector between 2005 and 2015. Prakash and Mohanty (2017) evaluated the performance of 50 passenger cars with Data Envelopment Analysis (DEA). Emissions, braking, ride quality, acceleration, turning circle and trunk capacity were selected as inputs, while torque and miles per gallon were determined as outputs. An output-oriented BCC model was selected. They concluded that 27 of the models analyzed were efficient.

Biswas and Das (2019) evaluated EV performance with the MABAC method. Energy consumption, price, top speed, acceleration and range were used as evaluation criteria. Hyundai Ioniq was found to be the best-performing EV. Ulutaş and Karaköy (2019) aimed to rank G20 countries according to their LPI values with a multi-criteria decision-making model consisting of SD and WASPAS methods. Koşaroğlu (2020) aimed to measure the performance of deposit banks whose shares are traded in BIST by using SD and Evaluation based on Distance from Average Solution (EDAS), which are multi-criteria decision-making techniques. In Işık and Koşaroğlu's (2020) study, it was aimed to measure and evaluate the performance of oil companies listed on BIST based on market indicators for a 10-year period covering 2010-2019. SD and Multi-Attribute Utility Theory (MAUT) methods were used to measure the performances.

In the study conducted by Gavcar and Kara (2020), ENTROPY and TOPSIS methods were used for electric car selection. 11 different alternatives were evaluated, and the 5 criteria determined were battery capacity, vehicle horsepower, aerodynamic coefficient, range with full charge and sales price. According to the criterion weights obtained by ENTROPY, the two most important criteria were the horsepower and price of the vehicle, while the least important criterion was found to be the aerodynamic coefficient. In the ranking of alternatives, 2 electric vehicle models of the Tesla brand rank first and second. Khan et al. (2020) used the fuzzy TOPSIS method for sustainable commercial taxi selection. 7 different electric vehicle alternatives from Honda and Toyota; 10 different criteria classified as economic, environmental and social are listed in line with expert opinions.

In Babacan's (2020) study, 22 automobile alternatives that middle-income individuals can purchase were analyzed under 8 criteria. AHP was used to obtain criterion weights and VIKOR was used to rank the alternatives. In the study of Alakaş et al. (2021), it was tried to determine which of the public transportation vehicles is more suitable. The weights of six main criteria (internal volume, external volume, fuel type, cost, performance, passenger demands) and 24 sub-criteria were determined by AHP method. 3 different alternatives were ranked by TOPSIS method. Maheshwari, et al. (2021) examined and analyzed the variables in the design of brake discs using finite element analysis and multi-criteria decision-making approach. 32 alternatives with 7 variables (performance parameters) were ranked using EDAS, Complex Proportional Assessment (COPRAS), TOPSIS and Additive Ratio Assessment (ARAS) methods and SD method was used for criteria weighting.

Ecer (2021) evaluated the performance of electric vehicles with different MCDM techniques, taking into account acceleration, price, battery and driving range. According to the study, Tesla Model S was determined as the best alternative among the EV evaluated. Sonar and Kulkarni (2021) evaluated electric vehicles sold in India using an integrated technique. For performance evaluation, they chose driving range, battery capacity, price, torque, seating capacity and charging time. They used the MABAC method integrated with AHP to evaluate electric vehicle models. They concluded that Hyundai Kona is the best electric vehicle in India. Öztayşi et al. (2021) used the Fuzzy KEMIRA method for electric vehicle selection. For 5 alternative vehicles, 6 criteria, 3 for cost and 3 for benefit purposes, are the sales price of the vehicle, transportation cost for 100 km, maintenance cost, maximum range with full charge, comfort and maximum speed. Ziemba (2021) evaluated the electric vehicle market in Poland. They determined acceleration, battery capacity, charging time, energy consumption, price, torque, maximum speed and cargo volume as criteria. They concluded that Volkswagen ID 3 and Nissan Leaf are the best-performing electric vehicles in Poland.

Taş et al. (2021) developed a solution proposal for the location selection of a logistics facility, which is critical for the continuation of operational activities in the fight against migration in the Aegean Region, with AHP and MULTIMOORA techniques. Rani et al. (2021) integrated SVNSs (Single-valued neutrosophic clusters), CRITIC and MULTIMOORA methods for the selection of the most appropriate food waste treatment method among a number of alternative methods.

In the study conducted by Çoşkun (2022a), SD was used as the weighting method in electric car selection and MULTIMOORA was used to rank the alternatives. According to the findings, the torque of the vehicle is the most important criterion, and the maximum speed of the vehicle is the least important criterion. Among the alternatives determined under various constraints, the Hyundai Kona 150 kW model was found to be the best alternative. In another study conducted by Çoşkun (2022b), 8 criteria that determine the performance of electric vehicles were examined with multi-criteria decision-making techniques. In criterion weighting or prioritization, ENTROPI and CRITIC methods were used as objective techniques, and AHP and WINGS methods were used as subjective techniques. In the findings obtained in the study, the most important criterion was found to be the price criterion, using 4 different methods. The least important criterion was found to be the efficiency rate criterion with ENROPI and AHP. The same criterion was found in the penultimate row in the WINGS method. Approximately the same results were obtained with 3 methods in terms of the least important criterion, and with 4 methods in terms of the most important criterion.

Gökgöz and Yalçın (2022) measured the performance of the top 10 best-selling EVs with the TODIM method. Accordingly, Tesla Model 3 is the best-performing electric vehicle. Small-sized hatchbacks were found to perform relatively worse compared to other EVs. In addition, range was found to be the most effective criterion for choosing an electric vehicle. Aydın (2024) aimed to evaluate the performance of electric buses produced and sold in Türkiye used in public transportation. For this, he used WASPAS and Entropy methods from multi-criteria decision-making techniques.

As can be understood from the literature, it is seen that multi-criteria decision-making techniques are used in electric vehicle selection and the issue is discussed from various perspectives. The importance rankings of the criteria differ depending on the objective or subjective approaches used in evaluating the criteria or the criteria selected. In this study, the criteria to be used when measuring the performance of electric vehicles were selected based on the literature (Khan et al., 2020; Ecer, 2021; Sonar & Kulkarni, 2021; Öztayşi et al., 2021; Ziemba, 2021; Çoşkun, 2022a; Çoşkun, 2022b, Aydın, 2024). In this study, Entropy, WASPAS and MOORA methods, which are objective weighting techniques, were preferred and, unlike other studies, the optimal lambda value was also calculated for WASPAS method to reveal whether the performance ranking had changed.

3. METHOD AND ANALYSIS

In the study, the performance of the 11 best-selling fully electric cars in Türkiye as of October 2023 by the Automotive Distributors and Mobility Association was measured with the help of 12 different criteria, using Entropy, WASPAS and MOORA methods, which are among the multi-criteria decision-making techniques. The criteria used within the scope of the study were weighted with the Entropy method, and then the performance ranking was performed for the fully electric cars subject to analysis with the selected Multi Criteria Decision Making methods. Also, the equally weighted results are presented.

3.1. Research Method

Within the scope of the study, the weights of the criteria were determined with the Entropy method, one of the multi-criteria decision-making techniques, and then the performance levels of the fully electric cars in question were tried to be determined with the selected Multi-Criteria Decision-Making methods.

3.1.1. Entropy Method

The concept of entropy was used by Rudolph Clausius (1865) to describe chaos within the system. (Zhang et al. 2012, p. 344). Today, the concept of entropy was developed by Shannon (1948) for use in information technologies. The entropy method was developed to measure the amount of useful information. The most important feature of the method is that it can be applied to the entire structure. However, the method has an objective nature. The entropy method consists of 5 steps (Aydın et al. 2018, p. 1129).

Step 1: Normalization of the decision matrix is performed. Criteria are normalized by taking into account benefit and cost structures.

$$r_{ij} = \{x_{ij} | max_{ij}\} (i = 1 \ldots \ldots . m; J = 1 \ldots \ldots . . n) \quad (1)$$

$$r_{ij} = \{x_{ij} | min_{ij}\} (i = 1 \ldots \ldots . m; J = 1 \ldots \ldots . . n) \quad (2)$$

Step 2: P_{ij} value is calculated by normalization.

$$P_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}}; \forall_j \quad (3)$$

i = alternatives

j = criteria

P_{ij} = normalized values

Step 3: Calculating the entropy of E_j

$$E_j = -k \sum_{i=1}^{m} \left[P_{ij} \ln P_{ij} \right]; \forall_j \quad (4)$$

$k = (\ln(n))^{(-1)}$

k = Entropy coefficient

E_j = entropy value

P_{ij} = normalized values

Step 4: Calculation of d_j uncertainty

$$d_j = 1 - E_j; \forall_j \quad (5)$$

Step 5: w_j weight values are calculated to determine the importance of criterion j.

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}; \forall_j \quad (6)$$

3.1.2. WASPAS Method

WASPAS Method was developed by Zavadskas et al. in 2012. The method consists of the combination of WSM (Weighted Sum Model) and WPM (Weighted Product Model). The aim of the method is to increase ranking accuracy (Zavadskas et al., 2013, p. 3).

WASPAS method consists of 6 steps. The steps in question can be listed as follows: (Chakraborty & Zavadskas, 2014, p. 2-3; Zavadskas et al., 2012, p. 3).

Step 1: Creating the Decision Matrix:

$$x = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{7}$$

Above; m is the number of candidate alternatives, n is the number of evaluation criteria. x_{ij} is the performance of the ith alternative considering the jth criterion.

Step 2: Creating the Normalized Decision Matrix:

In the WASPAS method, which is an equal combination of two separate MCDM approaches, linear normalization is performed using the following two equations.

Equality to be used for benefit criteria;

$$\bar{x}_{ij} = x_{ij} / \max_i x_{ij} \tag{8}$$

The equation to be used for cost criteria;

$$\bar{x}_{ij} = \min_i x_{ij} / x_{ij} \tag{9}$$

Normalization is done using these equations. Above x_{ij} value is the normalized version of x_{ij} value.

Step 3: Based on Weighted Sum Model (WSM). Calculating the overall relative importance of the alternative:

In the WASPAS method, a simultaneous optimism criterion is sought based on two equality criteria. The total relative value importance is calculated by multiplying the ith alternative value by the weight value of each criterion and then adding each alternative value respectively as follows.

$$Q_i^{(1)} = \sum_{j=1}^{n} \bar{x}_{ij} . w_j \tag{10}$$

Step 4: Based on Weighted Product Model (WPM). Calculating the overall relative importance of the alternative:

In this step, the total relative importance values according to WPM are calculated with the help of the formula below. For the value of each alternative criterion over the normalized decision matrix, the power of the relevant criterion weight is taken and the value is calculated by multiplying the found values for each alternative respectively.

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(\bar{x}_{ij} \right)^{w_j} \tag{11}$$

Step 5: Calculation of the weighted common general criterion value for Weighted Sum and Weighted Multiplication Models:

$$Q_i = 0.5Q_i^{(1)} + 0.5Q_i^{(2)} = 0.5\sum_{j=1}^{n} \bar{x}_{ij}.w_j + 0.5\prod_{j=1}^{n} \left(\bar{x}_{ij}\right)^{w_j} \tag{12}$$

Step 6: Calculating the Total Relative Importance of the Alternatives:

Within the scope of the WASPAS method for the ranking of the decision-making process, a general model has been developed to determine the total relative importance of the alternatives.

$$Q_i = \lambda Q_i^{(1)} + \left(1-\lambda\right)Q_i^{(2)} = \lambda\sum_{j=1}^{n} \bar{x}_{ij}.w_j + \left(1-\lambda\right)\prod_{j=1}^{n} \left(\bar{x}_{ij}\right)^{w_j} \quad \left(\lambda = 0, 0.1, 0.2, \ldots, 1\right) \tag{13}$$

The identified alternatives are ranked according to the Q value, that is, the best alternative must have the highest Q value. When λ=0, the WASPAS method turns into WPM, and when λ=1, it turns into WSM.

In addition, the variance of the WASPAS method seen in equation (13) is estimated based on WSM and WPM and is shown with the coefficient λ. Accordingly, the optimal λ value in the study was calculated with the help of the following formula (Zavadskas et. al. 2012, p. 4)

$$\lambda = \frac{\sigma^2\left(Q_i^{(2)}\right)}{\sigma^2\left(Q_i^{(1)}\right) + \sigma^2\left(Q_i^{(2)}\right)} \tag{14}$$

3.1.3. MOORA Method

The MOORA method, first introduced by Brauers (2004) can be successfully applied to solve various types of complex decision making problems in manufacturing. The MOORA method starts with a decision matrix showing the performance of different alternatives with respect to various attributes (Brauers & Zavadskas, 2006). When MOORA method is compared with other multi-criteria decision making methods, it is found that it has some advantages. As a matter of fact, the MOORA method provides more reliable results with fewer calculations, using the least mathematical operations. Different approaches such as MOORA-Ratio Method, MOORA-Reference Point Theory, MOORA-Full Product Form, Multi-MOORA have been developed in the literature (Brauers & Zavadskas, 2012; Altın, 2022, p. 374). The MOORA-Ratio method consists of 3 steps.

Step 1: Constructing the decision matrix of the problem: The decision matrix shows the performance of different alternatives with respect to the various criteria. x_{ij} is the performance measure of i^{th} alternative on j^{th} criterion, m is the number of alternatives and n is the number of criteria.

$$x = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (15)$$

Step 2: Creating the Normalized Decision Matrix: The matrix is normalized by dividing the performance value (x_{ij}) of each alternative according to each criterion by the square root of the sum of the squares of the performance values. Linear normalization is performed using the following formula.

$$Nx_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}} \quad (16)$$

Here, $j = 1, 2, \ldots, m$ where m is the number of alternatives, $i = 1, 2, \ldots, n$ where n is the number of evaluation criteria, x_{ij} is the value of the performance of alternative i according to criterion j and Nx_{ij} is the normalized value of x_{ij}, i.e. the normalized performance value of alternative i according to criterion j. This value can be in the range [0;1].

Step 3: Calculating Differences for Optimization: For optimization, the normalized sum of maximized performance values $\left(\sum_{i=1}^{i=g} Nx_{ij}\right)$ minus the sum of minimized performance values $\left(\sum_{i=g+1}^{i=n} Nx_{ij}\right)$.

$$Ny_j = \sum_{i=1}^{i=g} Nx_{ij} - \sum_{i=g+1}^{i=n} Nx_{ij} \quad (17)$$

Where g is the number of attributes to be maximized, (n−g) is the number of attributes to be minimized, and Ny_j is the normalized assessment value of i^{th} alternative with respect to all the attributes. In this formula linearity concerns dimensionless measures in the interval [0;1]. The Ny_j values are ranked in descending order to arrive at a performance ranking.

The second part of MOORA method is the Reference Point Theory. In the reference point theory, in addition to the ratio method, for each criterion, the highest value if the objective is maximization and the smallest value if the objective is minimization are determined as reference points (r_i). Then, the distances of these points from the normalized value of x_{ij} (Nx_{ij}) are found.

$$D_j = \left(r_i - Nx_{ij}\right) \quad (18)$$

Then, the maximum values are selected for each i. alternative. This time, the selected values are ranked from smallest to largest to arrive at the performance ranking (Stanujkic et al., 2012).

Brauers and Zavadskas developed the full-multiplicative form of the MOORA method in 2010. Here, $j = 1, 2, \ldots, m$ where m is the number of alternatives, $i = 1, 2, \ldots, n$ where n is the number of evaluation criteria, x_{ij} is the value of the performance of alternative i according to criterion j, and U_j is the suitability of alternative j for the objective (Brauers & Zavadskas, 2010, p. 13-14).

$$U_j = \prod_{i=1}^{n} x_{ij} \tag{19}$$

In this approach, for each alternative j, the product of maximized criteria A_j is divided by the product of minimized criteria B_j.

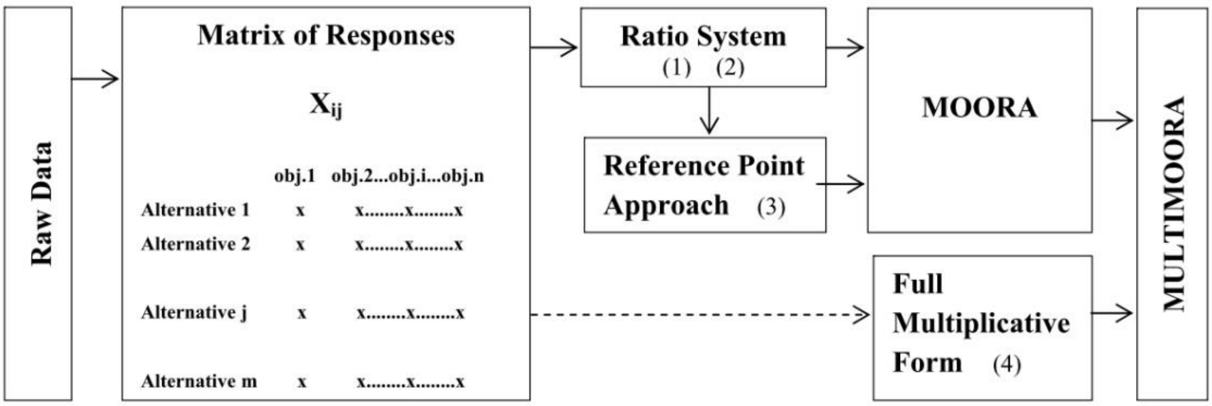
$$A_j = \prod_{g=1}^{i} x_{gi} \quad ; \quad B_j = \prod_{k=i+1}^{n} x_{kj} \quad ; \quad U_j^{'} = \frac{A_j}{B_j} \tag{20}$$

Finally, the $U_j^{'}$ values are ranked from largest to smallest to arrive at the performance ranking.

MULTIMOORA, which is the combined result of these methods, is not a method in itself. It provides re-evaluation of the rankings made as a result of different MOORA approaches according to their dominance and concentration. In this way, it increases the reliability of research.

The diagram below shows the relationship structure between MULTIMOORA decision matrix, ratio method, reference point theory and full-multiplicative form. Thus, MULTIMOORA becomes the most robust system of multi-criteria optimization (Brauers & Zavadskas, 2012, p. 8-11).

Figure 1. Diagram of MULTIMOORA



3.2. Analysis of Results

In the study, the performances of the best-selling fully electric cars in Türkiye as of October 2023 by the Automotive Distributors and Mobility Association were measured with the help of 12 different criteria. Data regarding the fully electric cars and performance criteria included in the study are given in Table 1, and the impact aspects of the criteria on performance are given in Table 2.

Table 1. Full Electric Cars and Performance Criteria

	Average Consumption (100 km) (kWh)	Range Average (WLTP Estimated)	Battery Capacity (kWh)	Fast Charging Time (10-80% with 50 kW DC fast charging)	Power (HP)	Torque (Nm)
Tesla Y Long Range RWD (4x2)	16.70	455.00	57.50	30 min.	299.00	350.00
TOGG T10X V2 Long Range	16.90	523.00	88.50	28 min.	218.00	350.00
Renault Zoe e-Tech R135	17.70	386.00	52.00	65 min.	135.00	245.00
MG4 Luxury	16.60	435.00	64.00	40 min.	204.00	250.00
Skywell ET5	17.00	489.00	86.00	38 min.	204.00	320.00
Opel Mokka-e	16.20	327.00	50.00	30 min.	136.00	260.00
Renault Megane E-Tech iconic	15.30	450.00	60.00	30 min.	220.00	300.00
Volvo XC40 RWD (Single Motor)	16.90	567.00	79.00	27 min.	252.00	420.00
Dacia Spring e	13.00	220.00	26.80	56 min.	65.00	113.00
MG ZS EV	17.80	440.00	72.60	40 min.	156.00	280.00
New Opel Corsa Edition / GS	16.10	354.00	50.00	40 min.	136.00	260.00

	Price (Thousand TL)	Aerodynamic (Driction) Coefficient (Cd)	Standard Luggage Volume (Lt)	Acceleration (0-100 km/sec)	Efficiency Rate (Battery Capacity/ Average Range) (kWh/Km)	Maximum Speed (Km/h)
Tesla Y Long Range RWD (4x2)	2,207.90	0.23	363.00	6.90	0.13	217.00
TOGG T10X V2 Long Range	1,563.50	0.28	441.00	7.80	0.17	185.00
Renault Zoe e-Tech R135	1,348.90	0.24	338.00	9.50	0.13	140.00
MG4 Luxury	1,499.00	0.25	363.00	7.90	0.15	160.00
Skywell ET5	1,655.00	0.35	467.00	7.90	0.18	150.00
Opel Mokka-e	1,493.90	0.36	310.00	9.20	0.15	150.00
Renault Megane E-Tech iconic	1,599.00	0.33	440.00	7.40	0.13	160.00
Volvo XC40 RWD (Single Motor)	2,411.00	0.32	419.00	7.30	0.14	180.00
Dacia Spring e	969.00	0.36	290.00	13.70	0.12	125.00
MG ZS EV	1,649.00	0.31	448.00	8.60	0.17	175.00
New Opel Corsa Edition / GS	1,175.90	0.29	267.00	8.20	0.14	150.00

Table 2. Criteria Used in the Analysis and Their Effects on Performance

Criterion	Direction of Effect
Average Consumption (100 km) (kWh)	Negative
Range Average (WLTP Estimated)	Positive
Battery Capacity (kWh/h)	Positive
Fast Charging Time (10-80% with 50 kW DC fast charging)	Negative
Power (HP)	Positive
Torque (Nm)	Positive
Price (Thousand TL)	Negative
Aerodynamic (Driction) Coefficient (Cd)	Negative
Standard Luggage Volume (Lt)	Positive
Acceleration (0-100 km/sec)	Negative
Efficiency Rate (Battery Capacity/ Average Range) (kWh/Km)	Negative
Maximum Speed (Km/h)	Positive

While 6 of the 12 criteria used in the analysis have a positive effect on performance, 6 of them have a negative effect. The weights of the criteria were calculated by the Entropy method. Table 3 shows the Entropy criterion weight values (w_j) for each criterion and their order of importance when listed from largest to smallest. Accordingly, for the fully electric cars subject to analysis; the first three most important performance criteria are;

- Power (HP)
- Fast Charging Time (10-80% with 50 kW DC fast charging)
- Battery Capacity (kWh/h)

On the other hand, the last three lowest performance criteria are;

- Maximum Speed (km/h)
- Efficiency Rate (Battery Capacity/ Average Range) (kWh/Km)
- Average Consumption (100 km) (kWh)

Table 3. Entropy Weights and Importance Ranks of the Criteria Used in the Analysis

Criterion	Entropy Weight	Order Quantity
Average Consumption (100 km) (kWh)	0.066816	12
Range Average (WLTP Estimated)	0.083532	6
Battery Capacity (kWh/h)	0.095212	3
Fast Charging Time (10-80% with 50 kW DC fast charging)	0.095407	2
Power (HP)	0.110056	1
Torque (Nm)	0.092556	4
Price (Thousand TL)	0.086350	5
Aerodynamic (Driction) Coefficient (Cd)	0.073009	9
Standard Luggage Volume (Lt)	0.076395	8
Acceleration (0-100 km/sec)	0.078835	7
Efficiency Rate (Battery Capacity/ Average Range) (kWh/Km)	0.069463	11
Maximum Speed (Km/h)	0.072369	10

In the study, although Entropy weights were considered, the performance ranking that would be obtained when the criteria were given equal weight (1/12 = 0.0833) was also examined and the fully electric cars subject to analysis were ranked by performing a performance evaluation with the WASPAS method. In addition to the entropy weights, the results obtained when equal weights are taken into account are also presented.

Table 4. Total Relative Importance Values Based on WSM and WPM

Fully Electric Cars	**by Entropy Weights**			**by Equal Weights**		
	WSM $Q_i^{(1)}$	**WPM** $Q_i^{(2)}$	Q_i	**WSM** $Q_i^{(1)}$	**WPM** $Q_i^{(2)}$	Q_i
Tesla Y Long Range RWD (4x2)	0.842409	0.822005	0.832207	0.845341	0.825472	0.835407
TOGG T10X V2 Long Range	0.840102	0.832366	0.836234	0.838409	0.831036	0.834723
Renault Zoe e-Tech R135	0.659248	0.640905	0.650077	0.677437	0.659631	0.668534
MG4 Luxury	0.741945	0.736559	0.739252	0.750705	0.745266	0.747986
Skywell ET5	0.770979	0.761365	0.766172	0.771130	0.761608	0.766369
Opel Mokka-e	0.666664	0.655231	0.660948	0.675611	0.665364	0.670487
Renault Megane E-Tech iconic	0.786097	0.778680	0.782388	0.791660	0.784156	0.787908
Volvo XC40 RWD (Single Motor)	0.851640	0.830630	0.841135	0.847632	0.827319	0.837476
Dacia Spring e	0.554177	0.489199	0.521688	0.583248	0.518936	0.551092
MG ZS EV	0.726345	0.717097	0.721721	0.735504	0.727032	0.731268
New Opel Corsa Edition / GS	0.687144	0.673033	0.680088	0.702231	0.688604	0.695418

Total relative importance values based on weighted sum method (WSM) and weighted product method (WPM) are presented in Table 4. Volvo XC40 RWD (Single Motor) achieved the highest score in terms of WSM and WPM values calculated based on entropy and equal weights. Accordingly, it has been understood that it has the highest performance among fully electric cars.

In the WASPAS method, after calculating the $Q_i^{(1)}$ and $Q_i^{(2)}$ values within the scope of WSM and WPM, the Weighted Common General Criterion Values Q_i were calculated and then the performance ranking was made. Ranking values are in Table 5.

Table 5. Performance Ranking Based on WASPAS Method

Performance Order	**by Entropy Weights**	**by Equal Weights**
1	Volvo XC40 RWD (Single Motor)	Volvo XC40 RWD (Single Motor)
2	TOGG T10X V2 Long Range	Tesla Y Long Range RWD (4x2)
3	Tesla Y Long Range RWD (4x2)	TOGG T10X V2 Long Range
4	Renault Megane E-Tech iconic	Renault Megane E-Tech iconic
5	Skywell ET5	Skywell ET5
6	MG4 Luxury	MG4 Luxury
7	MG ZS EV	MG ZS EV
8	New Opel Corsa Edition / GS	New Opel Corsa Edition / GS
9	Opel Mokka-e	Opel Mokka-e
10	Renault Zoe e-Tech R135	Renault Zoe e-Tech R135
11	Dacia Spring e	Dacia Spring e

Considering the entropy weights in Table 5; the top three highest performing fully electric cars are Volvo XC40 RWD (Single Engine), TOGG T10X V2 Long Range and Tesla Y Long Range RWD (4x2). In addition, considering that the criteria are given equal weights; the top three highest performing fully electric cars are Volvo XC40 RWD (Single Motor), Tesla Y Long Range RWD (4x2) and TOGG T10X V2 Long Range. The best-performing fully electric car in both alternative calculations was the Volvo.

In the WASPAS method, the lambda (λ) effect is examined in order to increase the ranking accuracy and efficiency of the decision-making process. The λ effect on the ranking, which is a more general step to determine the total relative importance of the alternatives, was calculated and the λ coefficient was found to be 0.555068 ≅ 0.60. The WASPAS method basically gives a weight of 0.50 each for WSM and WPM. Considering the optimal λ, WSM is given 0.60 weight and WPM is given 0.40 weight. According to the analysis results, there was no performance ranking change when the performance ranking was made considering equal λ (0.50) and optimal λ (0.60). Since the optimal λ value is close to 0.50, it can be said that there is no change in the ranking.

MULTIMOORA is not a method in itself. It ranks the rankings obtained as a result of different MOORA approaches such as the ratio approach, reference point approach and full product form, according to the dominance/concentration status among the alternatives. MULTIMOORA results, which provide a final ranking based on the findings of different MOORA approaches applied using both entropy and equal weights, are presented in Table 6.

Table 6. Performance Ranking Based on MULTIMOORA Method

Performance Order	by Entropy Weights	by Equal Weights
1	TOGG T10X V2 Long Range	TOGG T10X V2 Long Range
2	Volvo XC40 RWD (Single Motor)	Volvo XC40 RWD (Single Motor)
3	Tesla Y Long Range RWD (4x2)	Tesla Y Long Range RWD (4x2)
4	Renault Megane E-Tech iconic	Renault Megane E-Tech iconic
5	Skywell ET5	Skywell ET5
6	MG4 Luxury	MG4 Luxury
7	MG ZS EV	MG ZS EV
8	New Opel Corsa Edition / GS	New Opel Corsa Edition / GS
9	Opel Mokka-e	Opel Mokka-e
10	Renault Zoe e-Tech R135	Renault Zoe e-Tech R135
11	Dacia Spring e	Dacia Spring e

As can be seen from Table 6, using equal weights or entropy weights in the MULTIMOORA method did not have an effect on the performance ranking, and the ranking results were the same. As a matter of fact, the first three fully electric cars in the MULTIMOORA method are determined as TOGG T10X V2 Long Range, Volvo XC40 RWD (Single Motor) and Tesla Y Long Range RWD (4x2). Accordingly, as in the WASPAS method, the cars in the top three ranks among the highest performance fully electric cars in the MULTIMOORA method have not changed. However, the ranking values differed. Interestingly, the cars from fourth to eleventh places were ranked exactly the same in both the WASPAS and MULTIMOORA methods. In fact, when the entropy weights for both methods are taken into account, the fully electric cars in the third to eleventh places are in exactly the same order, and only the fully electric cars in the first two rows have changed places. Accordingly, since the ranking results are the same even though the weights change in the MULTIMOORA method, it may be considered more practical and useful to perform performance ranking directly with the MULTIMOORA method instead of the combination of entropy and WASPAS. It should be noted that the results are based on the fully electric cars included in the analysis and the criteria used.

4. CONCLUSION AND RECOMMENDATIONS

In the study, the performances of the best-selling fully electric cars in Türkiye as of October 2023 by the Automotive Distributors and Mobility Association were measured with the help of 12 different criteria. The top three performance criteria for fully electric cars subject to analysis are Power (HP), Fast Charging Time (10-80% with 50 kW DC fast charging) and Battery Capacity (kWh/h). The last three lowest performance criteria are Maximum Speed (km/h), Efficiency Rate (Battery Capacity / Average Range) (kWh/Km) and Average Consumption (100 km) (kWh). The first three most important performance criteria obtained in the study are identical to the findings of Gavcar and Kara (2020), Ecer (2021), Sonar and Kulkarni (2021) and Ziemba (2021) from the literature. On the other hand, Biswas and Das (2019), Öztayşi et al. (2021), Çoşkun (2022b), Gökgöz and Yalçın (2022) differ from their studies. In these studies, price and the range of the vehicle stand out as the most important criteria.

In the study, it was concluded that the best performing fully electric car among the fully electric cars subject to analysis, considering both entropy weights and equal weight, is the Volvo XC40 RWD (Single Engine). The worst-performing vehicles are the Dacia Spring e and Renault Zoe e-Tech R135 models, respectively. In the study, unlike other studies, the results did not change in the WASPAS performance ranking based on the optimal lambda value.

On the other hand, using equal weights or entropy weights in the MULTIMOORA method did not have an effect on the performance ranking, and the ranking results were the same. As a matter of fact, the first three fully electric cars in the MULTIMOORA method are determined as TOGG T10X V2 Long Range, Volvo XC40 RWD (Single Motor) and Tesla Y Long Range RWD (4x2). Accordingly, as in the WASPAS method, the cars in the top three ranks among the highest performance fully electric cars in the MULTIMOORA method have not changed. However, the ranking values differed.

In the literature, Biswas and Das (2019), Gavcar and Kara (2020), Khan et al. (2020), Ecer (2021), Sonar and Kulkarni (2021), Çoşkun (2022a), Gökgöz and Yalçın (2022) found that the performance of different models of Tesla and Hyundai was higher. Obtaining different results is a natural result of performance analysis. Because it should not be forgotten that the ranking is carried out in terms of the selected criteria, and the ranking may differ when the criteria and the fully electric cars subject to analysis are changed. The inclusion of TOGG, a domestic and national electric vehicle, which was not included in previous studies, may be a reason for this difference.

On the other hand, small hatchbacks such as the Dacia Spring e and Renault Zoe e-Tech R135 have relatively lower power (hp), battery capacity, range and torque values. These low values of small electric vehicles negatively affect their performance. These results suggest that if consumers want performance-oriented vehicles, they should avoid purchasing these small-scale electric vehicles. In this context, consumers should determine their priorities when purchasing an electric vehicle, as the superior features of the models may differ significantly. EV sellers increasing power (HP), range and battery capacity, while reducing fast charging time and average electricity consumption could lead to a large increase in sales.

The following suggestions can be made for future studies on the subjects and methods analyzed in this study, in which the performances of the best-selling fully electric cars in Türkiye as of October 2023 are measured; By increasing the diversity of EA models considered, comparison of EAs in the same segment can be made. In addition, both quantitative and qualitative data can be used together by interviewing expert opinions on EA and conscious EA consumers and identifying and weighting the subjective factors that affect consumers' EA preference. More optimal results can be obtained by using different multi-criteria decision-making techniques and comparing the results with sensitivity analysis.

The study does not necessitate Ethics Committee permission.

The study has been crafted in adherence to the principles of research and publication ethics.

The authors declare that there exists no financial conflict of interest involving any institution, organization, or individual(s) associated with the article. Furthermore, there are no conflicts of interest among the authors themselves.

The authors contributed equally to the entire process of the research.

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