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Araştırma Makalesi / Research Article

MEASURING THE PERFORMANCE OF ELECTRIC BUSES DEVELOPED FOR THE PUBLIC TRANSPORTATION SYSTEM USING ENTROPY AND WASPAS METHODS

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Abstract
The study aimed to assess the performance of electric buses that are used in public transportation, and produced and sold in Türkiye. To achieve this, multi-criteria decision-making techniques, the Entropy and WASPAS methods, were employed. The Entropy method was used to calculate the weights of the criteria, and the WASPAS method was used to rank the performance of the electric buses. During the analysis, the most important performance criteria were identified to be maximum torque and battery capacity, while the lowest performance criterion was found to be maximum speed. According to the results, the Otokar Kent Electra was the highest performing electric bus in terms of entropy weights, and the Temsa MD9 ElectriCITY was the best performer according to equal weights. On the other hand, the Otokar Doruk Electra was found to be the worst performing bus in both weight calculations.
Keywords: Electric Bus, Performance measurement, Public transportation Systems, Entropy method, WASPAS method.
JEL Codes: C61, C30, D24, D25.

TOPLU ULAŞIM SİSTEMİ İÇİN GELİŞTİRİLEN ELEKTRİKLİ OTOBÜSLERİN ENTROPİ VE WASPAS YÖNTEMLERİYLE PERFORMANSLARININ ÖLÇÜMÜ

Öz
Bu çalışma, toplu taşımada kullanılan ve Türkiye'de üretilen ve satılan elektrikli otobüslerin performansını değerlendirmeyi amaçlamıştır. Bunu için çok kriterli karar verme tekniklerinden WASPAS ve Entropi yöntemleri kullanılmıştır. Kriterlerin ağırlıkları Entropi metoduyla hesaplanmıştır. Ardından, WASPAS metoduyla performans değerlendirmesi yapılarak elektrikli otobüslerin performansı sıralanmıştır. Çalışmada, en önemli performans kriterleri azami tork ve batarya kapasitesi iken en düşük performans kriteri azami hız bulunmuştur. Analiz dönemi içinde en yüksek performans gösteren elektrikli otobüs entropi ağırlıklarına göre Otokar Kent Electra, eşit ağırlığa göre ise Temsa MD9 ElectriCITY'dir. Buna karşın, en kötü performans gösteren otobüs ise her iki ağırlıkta da Otokar Doruk Electra'dır.
Anahtar Kelimeler: Elektrikli Otobüs, Performans ölçümü, Toplu ulaşım sistemleri, Entropi yöntemi, WASPAS yöntemi.
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Introduction

The industrial revolution led to rapid urbanization, causing people from rural areas to move to cities in search of new opportunities. However, the increasing population density in cities has created a need for new infrastructure. The emergence of automobiles has led to public transportation services and an increase in the number of vehicles in big cities (Yaliz et al. 2011:887). This has caused a decrease in travel speed, irregularity of public transport, and significant loss of time for urban passengers. Due to congestion, access to destinations in the city center is threatened. Other challenges are road safety, increasing air pollution, traffic noise, and global warming (Banister, 2005). Therefore, it's important to prioritize sustainable investments for current transportation, the environment, and future generations. Sustainable transportation is defined as transport that meets mobility needs while protecting and improving human and ecosystem health, economic progress, and social justice, now and in the future (Deakin et al. 2002: 173).

Türkiye has committed to reducing emissions by 21% in line with the base scenario determined from 2021 to 2030 within the scope of the United Nations Framework Convention on Climate Change (Ministry of Environment and Urbanization, 2022). In a study covering 30 cities with metropolitan status, road-related greenhouse gas emissions for the years 2010 and 2019 were calculated. The total amount of greenhouse gas emissions in 2010 was 43,403 Gg CO2, which increased by approximately 62% to 70,271 Gg in 2019. The annual increase was reported to be 3.82%. However, 10.88% of the total greenhouse gas emissions in Türkiye in 2010 resulted from road transportation in big cities (Dündar, 2021). These data indicate that the amount of road-related greenhouse gas emissions in Türkiye is constantly increasing and has a significant share in the total amount of emissions.

Air pollution is the world's biggest problem, according to the World Health Organization. Air pollution is recorded as the fourth highest cause of death after high blood pressure, malnutrition, and smoking (WHO, 2022). This situation has led to some restrictive new regulations on both a global and local scale. Some prioritizations are made regarding transportation concepts by the relevant administrations to make cities more livable, and existing transportation strategies are reviewed (Topal, 2023: 296).

More than 50% of the world's population lives in cities, and it is estimated that this rate will reach 70% by 2050 (Cao et al., 2022). Population growth in cities brings with it more mobility and therefore more transportation needs. More than 50% of transportation-related emissions (NOx emissions), which are one of the main causes of climate change on a global scale, originate from transportation systems throughout Europe, according to the data of the European Energy Agency. Thus, increasing transportation-related emissions greatly increases environmental awareness (Genç, 2021).

In this context, it is important to reveal the relative environmental characteristics of various fuel technologies to understand transportation-related emissions. Table 1 below shows selected emissions measurements for various fuel types.

Table 1: *Alternative Fuels – Emissions Comparison*

	Diesel (Euro VI)	Natural Gas (CNG)	Biofuel (HVO)	Diesel Plug-in hybrid (PHB)	Battery Electric (BEB)	Hydrogen (FCB)
Local emissions (NOx PM)	Baseline	Euro VI compliance		↓	Zero	Zero
Global emissions (CO_2) WTT	Baseline	↑	↓	↑	↑	↑
Global emissions (CO_2) TTW	Baseline	→	→	↓	Zero	Zero
Global emissions (CO_2) WTW	Baseline	→	↓	↓	↓	↘
↑ **Much lower emissions vs Diesel** ↘ **Lower emissions vs Diesel** → **Same/similar emissions vs Diesel** ↓ **Much higher emissions vs Diesel**					WTW: Depending on Electricity Source (Arrows equal to average EU electricity 295g CO2/kWh - source: EEA)	

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Battery electric vehicles are a promising alternative to conventional transportation systems that rely on fossil fuels. They offer energy-efficient, flexible, and reliable solutions with recycling technologies. Research into electric vehicle technologies is growing, and different approaches are being explored for sustainable transportation.

Electric vehicles are one of the most popular options for the future that can be used instead of vehicles with internal conventional systems. Public vehicles with internal combustion engines create greenhouse gas emissions and noise, which negatively affect the quality of human life in metropolitan areas. Electric vehicle systems have the potential to provide solutions to these problems thanks to their silence, low emission values, and operational financial advantages. Electric buses are particularly important in metropolitan cities with heavy traffic, as they offer advantageous elements such as fuel economy and an innovative approach to raising awareness about sustainability in transportation (Topal, 2019: 156).

Investments and studies for the development of public transportation are of great importance in solving the transportation and traffic problem. Sustainable, livable cities can be created by making significant contributions to the economy, environment, and social life through the efficient use of existing resources. Many solutions are being put forward, such as re-planning of public transportation lines, opening new lines, arranging transfer points, improvements to the existing public transportation system, non-motorized vehicles, supporting bicycle transportation, focusing on rail systems, increasing the parking capacity, increasing the speed of the transportation system, creating special public transportation options, and organizing new ring services. Public transportation is a dynamic system that must be planned by taking into account constantly changing environmental conditions, demographic structure, technology, the quality of human resources, and changes in demand. The constant differentiation of these factors and the measures that can be taken against them will ensure sustainability (Hamurcu & Eren, 2018:2-3).

Decision-making in public transportation, especially regarding electric buses, is a complex process that involves the design and operation of multiple economic, environmental, and urban passenger transportation systems. Therefore, multi-criteria decision-making techniques are used to measure the performance of electric buses that affect their selection. The Entropy method and WASPAS (Weighted Aggregated Sum Product Assessment) method are used to measure the performances of electric buses sold in Türkiye with the help of 11 criteria. In the study, the optimal lambda value was calculated, and the performance ranking was investigated. The study includes a literature review, an explanation of the Entropy and WASPAS methods, analyses of the results, and general evaluation and policy recommendations.

1. Literature Review

The vehicle selection problem is among the topics that have received intense attention in the literature recently. 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. In the literature, it is possible to examine vehicle selection in three groups: individual automobile selection, logistics and transportation activities and public transportation activities.

Car selection; Apak et al. (2012) used the AHP method for the luxury car selection problem. Soba (2012) carried out the most suitable car selection with the PROMETHEE method. Yavaş et al. (2014) used AHP and AAS methods for automobile selection, taking into account fuel, cost, design, service facilities, engine power and equipment factors. Patil et al. (2017) carried out the selection of the most suitable car by using fuzzy AHP and Gray Relationship analysis, taking into account external appearance, interior appearance, additional features, road reliability and after-sales criteria. Yaykaşlı and Ecemiş (2018) examined the automobile selection problem by taking into account nine sub-criteria belonging to three main criteria: before purchase, during purchase and after purchase. After obtaining the criterion weights with the AHP method, the alternatives were ranked using Multi MOORA and Gray Relationship analysis. Singh and Avikal (2019) examined the choice of sedan cars in India with fuzzy AHP and TOPSIS methods. Babacan (2020) examined the automobile selection problem of individuals in the middle income group with the VİKOR method, taking into account the differences in income levels.

Vehicle selection problem is among the very important problems in the logistics and transportation industry. Due to the nature of the activity, the vehicle to be used is among the main cost elements. For this reason, the vehicle selection problem in the logistics sector is an important selection problem in the literature. In their study, Kabak and Uyar (2013) selected the most suitable heavy commercial vehicle using AAS and PROMETHEE methods, taking into account economy, performance, equipment after-sales services, image and prestige criteria. Dogan et al. (2017) selected the most appropriate vehicle for the logistics industry with the COPRAS-G method, taking into account similar criteria. Ömürbek et al. (2014) used AHP and PROMETHEE methods in their study to select light commercial vehicles planned to be purchased for use in white goods service activities. Arslan (2017) selected heavy commercial vehicles in the logistics sector using AHP and ARAS (Additive Ratio Assessment) methods, taking into account the warranty period, price, fuel consumption and power criteria. Demirci (2020) determined the most suitable alternative among seven alternatives using TOPSIS and VIKOR methods, taking into account price, fuel, engine life, after-sales support and second-hand opportunities.

Studies examining the selection of public transportation vehicles: Tzeng (2005) carried out the selection of the most suitable alternative fuel buses for public transportation with multi-criteria decision-making methods. Şengül et al. (2012) examined the public transportation vehicle selection of municipalities in Erzurum province. In this context, eight criteria and five alternatives were determined in the study and the most suitable alternative was selected using the fuzzy AHP method. Babakan et al. (2013) carried out public transportation vehicle selection in urban transportation using AAS, TOPSIS and Geographic Information Systems methods. Shafabakhsh et al. (2014) carried out the selection of the most appropriate public transportation system for transportation to an international airport using fuzzy AHP and TOPSIS methods. Aydın and Kahraman (2014) examined the alternative fuel bus selection problem for public transportation in Ankara with multi-criteria decision-making methods. In the study, considering the economic, social and technology main criteria and sixteen sub-criteria, the criteria weights were obtained with the fuzzy AHP method, and then the alternatives were ranked with the fuzzy VIKOR method. Akpınar (2016) selected the most suitable ring vehicle at a university in Izmir with the AHP method. Akman and Alkan (2016) made a selection using AHP and Axiomatic Design methods in order to determine the best alternative for a route where public transportation is used intensively within the borders of Izmit municipality. In the study, cost, transportation line features, vehicle features, environmental sensitivity and customer satisfaction criteria were taken into account to evaluate the alternatives. Hamurcu and Eren (2017) carried out the selection of monorail technology in public transportation with multi-criteria decision-making methods. In the study, seven main criteria and fifteen sub-criteria were determined and the most suitable alternative was determined using the AHP and TOPSIS methods. Büyüközkan et al. (2018) examined the selection of alternatives for sustainable city transportation with multi-criteria decision-making methods. In their study, Hamurcu and Eren (2018) made a public transportation system selection consisting of three alternatives with three main criteria, namely technological, economic and environmental criteria, and a total of 12 sub-criteria. In the study, after obtaining the criterion weights with the AHP method, the selection of alternatives was carried out with the AAS method. Varol et al. (2018) on the operation of electric vehicles using electric motors instead of internal combustion engines, which is thought to make a great contribution to the reduction of transportation-related, environmentally harmful gases in Istanbul, included scenarios where it is assumed that electric vehicle systems will be used in public transportation in the future. In the envisaged final scenario, it is assumed that 100% of commercial taxis, 70% of buses and 30% of minibuses will be converted to electric vehicles, and it is stated that the transition to electric vehicle systems will reduce emissions. Stating that road transportation has a large share in many countries and cities, Hamurcu and Eren (2018) stated that the interest in electric vehicles has increased and electric vehicles have come to the fore as an alternative solution in the transportation sector. Using multi-criteria decision-making methods within the criteria determined in the study, high-capacity electric buses were evaluated to improve urban transportation, and it was stated that electric buses would be an important step towards sustainability in environmental and urban transportation by providing comfort and safety in public transportation within the municipality approach. Cuma et al. (2016) included the charging station infrastructure for electric vehicles planned to be used at Çukurova University and the studies on the integration of this infrastructure into the existing system and the simulation results obtained. Çelikoğlu and Hülagü (2018) stated that although electric vehicles are a relatively environmentally friendly option compared to fossil-derived fuel vehicles in the use of both private and public transportation with developing technology, their limitations, especially within the scope of battery technology, were examined in terms of both their intended use and road network features emphasized the importance of planning and evaluation of infrastructure. He stated that it would be appropriate to evaluate the priority application areas on the subject specifically in urban public transportation systems. Milk et al. (2019) conducted a study on the selection of ring vehicles at Kırıkkale University within the scope of green transportation. In the study, five different bus technology alternatives that can be evaluated within the scope of green transportation were examined. In the evaluation of the alternatives, a total of twelve sub-criteria, eight of which were the main criteria, were determined and the most suitable alternative was selected using the AHP and TOPSIS methods. In their study where they examined the selection of electric buses with multi-criteria decision-making methods for green transportation, Hamurcu and Eren (2020) determined the most appropriate vehicle selection by determining six criteria consisting of speed, passenger capacity, transportation network and technical features of the vehicle. In his study, Topal (2019) revealed in detail the current situation regarding electric buses used in Türkiye's public transportation system. Alakaş et al. (2020) made the vehicle type selection in public transportation systems using the Kırkale campus line example. Criterion weights were obtained with the Analytical Hierarchy Process method and alternatives were ranked with the TOPSIS method using the weights found. Önçağ et al. (2021) made a comparative evaluation of electric buses through Izmir urban field analysis. Finally, Topal (2023) evaluated different business models for the supply of electric buses for public transportation systems in Türkiye.

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. In this study, the criteria to be used when measuring the performance of electric buses were selected based on the literature. In the study, Entropy and WASPAS methods were preferred and, unlike other studies, the optimal lambda value was also calculated to reveal whether the performance ranking had changed.

2. Method and Analysis

The aim of the study is to determine the efficiency levels of electric buses used in the public transportation system in Türkiye by ranking their performance in terms of selected criteria. However, another aim of the study is to explain Entropy and WASPAS methods, which are multi-criteria decision-making techniques, and discuss their usability in performance ranking. The criteria used within the scope of the study were weighted with the Entropy method, and then the performance was ranked using the WASPAS method.

2.1. 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 electric buses in question were tried to be determined with the WASPAS method.

Entropy Method

The concept of entropy was used by Rudolph Clausius (1865) to describe chaos within the system (Zhang et al. 2012:344). 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 stages (Aydın et al. 2018: 1129).

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

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

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

Stage 2: P_{if} value is calculated by normalization.

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

$\dot{I}$ = alternatives

j = criteria

P_{ij} = normalized values

Stage 3: Calculation of the entropy of E_j;

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

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

k = Entopia coefficient

E_j = Entopia value

P_{ij} = normalized values

Stage 4: calculation of *dj* uncertainty;

$$d_j = 1 - E_j;\forall_{\mathrm{j}} \tag{5}$$

Stage 5: w_j weight values are calculated to determine the importance of criterion J.

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

WASPAS Method

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

WASPAS method consists of 6 stages. These stages can be listed as follows: (Zavadskas et al., 2012:3).

Stage 1: Creating the Decision Matrix:

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

Here; m is the number of candidate alternatives, n is the number of evaluation criteria. *xij* is the performance of the ith alternative considering the jth criterion.

Stage 2: Creating the Normalized Decision Matrix:

In the application of 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;

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

The equation to be used for cost criteria;

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

Normalization is done using these equations. Here *xij* value is the normalized version of *xij* value.

Stage 3: Based on Weighted Sum Model (WSM) i. 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.

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

Stage 4: Based on the Weighted Product Model (WPM) i. 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 on the normalized decision matrix, the power of the relevant criterion weight is taken and the Qi (2) value is calculated by multiplying the values respectively for each alternative.

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

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

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

Stage 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.

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

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 λ coefficient. Accordingly, the optimal λ value in the study was calculated with the help of the following formula (Zavadskas et. al. 2012: 4).

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

2.2. Analysis Results

In the automotive industry in our country, buses, unlike the automobile class, are offered for sale by the relevant vehicle manufacturers through domestic production. As in many other branches of industry, developments and domestic designs initially made in the military fields are later integrated into the transportation segment and put into use. Major conventional motor bus manufacturers in Türkiye, namely Otokar, Karsan, BMC, Anadolu Isuzu and Temsa, are gradually adding electric buses to their product ranges and continuing their research and development activities on this subject.

Within the framework of increasing environmental awareness and smart urbanism principles, local governments advancing towards the main goal of zero-emission sustainable public transportation are forcing bus manufacturers to produce transportation vehicles that have zero carbon emissions and protect the environment with electric traction systems. Thanks to the absence of an internal combustion engine in the electric vehicle concept and high-torque electric motors that do not require a transmission, it operates silently and offers innovations that are beneficial in significantly reducing noise pollution.

At this point, although the expectations in urban transportation are for environmentally friendly vehicles, there is also an expectation from these vehicles that diversify with the developing technology. With electric traction systems, high reliability, low maintenance costs and infrastructure and initial investment costs, high efficiency in terms of energy per passenger, quiet and safe journey, strong but softer acceleration and braking, high journey quality, mechanical reliability and efficiency, high maneuverability; it is desired to meet objectives such as capability, long service life, high acceleration and climbing performance, and low energy consumption cost (Hamurcu and Eren, 2018: 5). In this context, 10 alternative high-capacity electric vehicles produced and offered for sale in Türkiye were determined for evaluation. Currently, electric buses in Türkiye are produced in 2 main categories. The first is the battery electric bus concept, models with different charging technologies for public transportation systems, ranging from 5.8 m to 26 m, with different charging infrastructure requirements; In the other category, the production and sale of trolleybuses, which are electric buses of 24m - 25m that generally receive their power from an electric line suspended along the road, are also produced and sold. In this study, electric buses produced and sold in Türkiye, which are in the first category, were evaluated.

In addition, based on the literature detailed above, 10 evaluation criteria were determined in line with the features of the vehicles. Data regarding the criteria were received as of September 2023. The data was compiled from the official web addresses of the relevant brand and model. The electric buses and evaluation criteria evaluated are shown in Table 2. Among the criteria, average consumption is expected to be low, charging time is short and efficiency ratio, defined as battery capacity per average range, is expected to be low. On the other hand, it is desired that the range, battery capacity, engine power, torque, seat capacity and climbing ability be high.

Table 2: *Buses Considered and Evaluation Criteria*

Electric Bus Brands-Models	Criteria	Criteria Evaluation
Bozankaya E Bus 10	K1: Average Consumption (kWh per 100 km)	Min.
Temsa Avenue Electron – Avenue EV	K2: Range Average (WLTP Estimated)	Max.
Karsan e-ATA 12	K3: Battery Capacity (kWh)	Max.
Bozankaya E Bus Sileo s12	K4: Fast Charging Time (hours with 150 kW DC fast charging)	Min.
Karsan e-ATAK	K5: Engine Power (kW)	Max.
Otokar Kent Electra E Kent C	K6: Maximum Torque (Nm)	Max.
Temsa MD9 ElectriCITY	K7: Seat Capacity	Max.
BMC Neocity Electric	K8: Climbing Ability	Max.
Anadolu Isuzu NovoCiti Volt	K9: Efficiency Rate (Battery capacity/average range) (wh/km)	Min.
Otokar Doruk Electra	K10: Maximum Speed (kmh)	Max.

The weights of the performance criteria were calculated with the Entropy method. Calculated Entropy criterion weight values (wj) are shown in Table 3. Accordingly, the first two most important performance criteria are maximum torque (K6) and battery capacity (K3). The lowest performance criteria are; efficiency ratio (K9) and maximum speed (K10). Since the 10 criteria used in the analysis will receive an equal weight of 10% each, the criteria with an Entropy weight of more than 10% are highlighted in the Table.

Table 3: *Entropy and Equal Weights of the Criteria Used in the Analysis*

	K1	**K2**	**K3**	**K4**	**K5**	**K6**	**K7**	**K8**	**K9**	**K10**	**Total Weight**
Entropy Weights (Wj)	0,047	0,079	0,176	0,131	0,163	0,236	0,065	0,054	0,043	0,005	1
Entropy Weight Cardinality	8	5	2	4	3	1	6	7	9	10	
Equal Weight	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	1

Then, the performance of the buses was evaluated using the WASPAS method and they were ranked. After calculating the Qi $^{(1)}$ and Qi $^{(2)}$ values within the scope of WSM and WPM, the Weighted Common General Criterion Values Qi were calculated and then the ranking was made. 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 was also calculated, which is a more general step to determine the overall relative importance of the alternatives. Qi, ranking values and Optimal λ Values are shown in Table 4.

Table 4: *Ranking According to Weighted Common General Criteria and λ Values*

Electric Bus Brands-Models	By Entropy Weight			By Equal Weight		
	Qi	W	λ	Qi	W	λ
Otokar Kent Electra E Kent C	0,810	1	1	0,803	2	2
Temsa MD9 ElectriCITY	0,766	2	2	0,807	1	1
Temsa Avenue Electron – Avenue EV	0,763	3	3	0,783	4	4
Karsan e-ATA 12	0,757	4	4	0,758	5	5
Anadolu Isuzu NovoCiti Volt	0,738	5	5	0,787	3	3
BMC Neocity Electric	0,689	6	6	0,711	8	8
Bozankaya E Bus Sileo s12	0,667	7	7	0,735	6	6
Karsan e-ATAK	0,667	8	8	0,728	7	7
Bozankaya E Bus 10	0,630	9	9	0,709	9	9
Otokar Doruk Electra	0,409	10	10	0,628	10	10
Optimal Lambda Value	0,569			0,657		
Qi: Weighted Common General Criterion Value						
λ : Sorting According to Optimal Lambda Values						
W: Sorting by WASPAS Result Values						

According to Table 4; The best performing electric bus is Otokar Kent Electra according to entropy weights, while it is Temsa MD9 ElectriCITY according to equal weights. On the other hand, the worst performing buses are Otokar Doruk Electra and Bozankaya E Bus 10 in both weights, respectively. 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 ranking, which is a more general step to determine the overall relative importance of the alternatives, was calculated and given in Table 4.

As can be seen in Table 4, since the Optimal λ values are above 50 percent, both W and L rankings are the same. In this case, when the effect of optimal λ on the ranking was examined, the same result was achieved as the Qi ranking, and there was no performance ranking change.

3. Conclusion

In the study, the performance of electric buses used in the Turkish public transportation system and produced and sold in Türkiye was measured using entropy and waspas methods, taking into account ten criteria. The first two most important performance criteria are maximum torque (K6) and battery capacity, while the lowest performance criteria are efficiency rate (K9) and maximum speed (K10).

In the study, the highest performing electric bus for the analysis period is Otokar Kent Electra according to entropy weights, and Temsa MD9 ElectriCITY according to equal weights. On the other hand, the worst performing bus is Otokar Doruk Electra in both weights. In the study, unlike other studies, the results did not change in the WASPAS performance ranking based on the optimal lambda value. However, 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 analyzed periods are changed.

Electric buses, on the other hand, are still less common. Currently, the reliability of electric buses is still significantly below that of conventional internal combustion engines. It leads to additional investment costs as more electric buses are required to meet the same peak service level. In addition, maintenance and operating costs, which should theoretically be lower than conventional engines, are higher in practice due to less availability of spare parts, higher spare parts costs and longer repair times. Battery costs are still very high and batteries have a limited lifespan. These problems are typical for new technologies. Electric buses are therefore not yet considered financially viable compared to conventional units, even with carbon financing. However, various options are being tried to solve the range, battery weight and battery cost issues. Electric vehicle technologies and investments are progressing very rapidly. As a result of this rapid development, it is predicted that the cost of electric buses will decrease, and while costs will decrease, battery capacity and efficiency will increase. As a result, such systems can be a good alternative to buses with internal combustion engines. On the other hand, it should be taken into account that the need for electrical energy will increase, especially within the framework of the acceptances made for the transition of public transportation vehicles to electric systems. If the electrical energy production facilities used in the current method of supplying this energy continue to be used as they are, there may be a deficit in energy supply. In this way, electrical energy production should be increased, and while doing this, renewable resources should be given priority whenever possible.

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