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APPLICATION OF THE AHP-PROMETHEE METHOD FOR SELECTING THE OPTIMAL ELECTRIC VEHICLE FOR URBAN TRANSPORT

Ivana Ilić[1]*,
[0000-0001-7364-8236]

Dejan Ilić[2],
[0000-0001-8966-9955]

Ines Ilić[3],
[0009-0002-1037-0382]

Aleksandar Mihajlović[4]
[0009-0001-0777-2308]

[1]Faculty of Information Technology and Engineering, Belgrade, Serbia

[2]Faculty of Business Studies and Law, Belgrade, Serbia

[3]Faculty of Information Technology and Engineering, Belgrade, Serbia

[4]Singidunum University, Belgrade, Serbia

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Abstract:

This study elucidates the findings derived from the implementation of the integrated AHP-PROMETHEE multi-criteria decision-making method aimed at selecting the most suitable electric vehicle for urban transport. The AHP methodology facilitated the identification of critical criteria influencing the selection of an electric vehicle for urban use, including factors such as price, battery warranty, charging speed, acceleration to 100 km/h, maximum speed, engine power, efficiency, battery performance, and mileage. The subsequent application of the PROMETHEE method allowed for the ranking of nine electric vehicles based on these established criteria. Each vehicle alternative was assessed regarding its capacity to fulfill the specified requirements and preferences of the decision-makers. The analysis revealed that the Mini Cooper E emerged as the model that most effectively aligns with the prioritized criteria. This vehicle is deemed the optimal selection for urban transport needs, considering all pertinent factors. The decision to select a specific electric vehicle is expected to influence the efficiency, sustainability, and economic viability of the urban transportation system. Furthermore, it is advisable to maintain ongoing surveillance of advancements in electric vehicle technology and charging infrastructure to ensure that the selected model continues to represent the best option in the future.

Keywords:

integrated AHP-PROMETHEE method, criteria, ranking, electric vehicles, technology.

JEL Classification:

D7, D91, R4

INTRODUCTION

Electric vehicles signify a pivotal advancement within the automotive sector, facilitating the realization of sustainable transportation and the mitigation of harmful emissions. Unlike conventional vehicles that rely on internal combustion engines fueled by gasoline or diesel, electric vehicles operate on electricity (Rifkin, 2011). They utilize batteries that can be recharged through various means, including residential outlets, public charging stations, or rapid charging facilities. This advanced propulsion technology positions electric

*E-mail: ivana.ilic@fiti.edu.rs

vehicles as a more environmentally friendly alternative to traditional combustion engine vehicles. The popularity of electric vehicles has surged, attributable to their numerous benefits (Sperling, 2009). Beyond the reduction of greenhouse gas emissions (Shehu, 2020), they provide a quieter driving experience, lower maintenance expenses, and enhanced energy efficiency relative to their conventional counterparts (Davis, C. & Boundy, R.G., 2022). However, in 2021 the Union of Concerned Scientists (UCS) identified several challenges faced by electric vehicles, including limited battery range, insufficient charging infrastructure, and elevated initial costs. Nevertheless, ongoing advancements in battery technology, the proliferation of fast charging options, and an expanding network of charging stations are poised to address these challenges. The integration of modern technological innovations, such as electric vehicles, is essential in the global endeavor to decrease greenhouse gas emissions and transition towards sustainable energy solutions (Taiebat *et al.,* 2018). By fostering further development and widespread adoption of these technologies, the way for a cleaner, more sustainable future can be paved.

The contemporary electric vehicle market presents an expanding array of options, each characterized by distinct features that vary according to their intended use and classification. Consequently, prospective buyers face significant challenges when selecting an appropriate vehicle. To facilitate the decision-making process regarding the acquisition of an electric vehicle, the application of the integrated AHP-PROMETHEE multi-criteria decision-making method can prove invaluable. Specifically, the PROMETHEE and AHP methodologies are widely recognized for their utility in decision-making across diverse domains, including the selection of electric vehicles. These approaches offer a systematic method for assessing and prioritizing various alternatives based on a range of criteria and individual preferences. The AHP technique is employed to establish weight coefficients, which are subsequently utilized in the PROMETHEE method to achieve a conclusive ranking of electric vehicles suitable for urban transportation. Finaly, it should be noted that the results shown in this paper present a part of the graduation thesis written by the student, coauthor of this paper.

LITERATURE REVIEW

Contemporary technologies are profoundly influencing the automotive sector, reshaping the processes of vehicle design, production, and utilization. The rise of electric vehicles (EVs) is attributed to their eco-friendliness and lower emissions. Furthermore, advancements in autonomous driving technology enable vehicles to operate and make decisions autonomously, potentially revolutionizing travel and transportation methods (Venkatraman, 2021). Vehicles are increasingly integrated with the Internet, facilitating data exchange among vehicles, infrastructure, and users. This connectivity enhances driving efficiency, safety, and passenger comfort (Kinsey, 2020). Technologies such as adaptive cruise control, blind spot detection, and automatic braking contribute to safer driving experiences and greater vehicle control for operators (MacGregor, 2022). The incorporation of advanced materials like carbon fiber enables the creation of vehicles that are both lighter and stronger, thereby enhancing performance and fuel efficiency (Lee, 2018). Sophisticated energy management systems in electric vehicles optimize energy usage, thereby extending driving range and enhancing battery performance (Wood, 2021). Finaly, digital innovations empower consumers to personalize and purchase vehicles online, while vehicle maintenance can be enhanced through predictive diagnostics and maintenance facilitated by IoT technologies (Baumann, 2023).

The advancements in automotive technologies not only enhance vehicle performance and safety but also revolutionize the user experience associated with automobiles. The automotive sector remains a leader in technological innovation, aiming to enhance mobility while minimizing the environmental footprint of transportation. This industry serves as a nexus for creative thinkers within both technological and industrial domains, fostering the development of distinctive and inventive solutions. Amid the global trend towards digitization, the automotive field is poised for substantial change. Over the last decade, the industry has navigated various challenges and opportunities. Nevertheless, the incorporation of cutting-edge technology across different sectors allows the automotive industry to progress, offering manufacturers increased revenue potential and consumers novel driving experiences. As forecasted by McKinsey in 2016, the automotive landscape is gradually transitioning towards a future where manufacturers can achieve greater profitability and users can access groundbreaking driving innovations (Singh & Deshpande, 2022). The past ten years have seen significant volatility within this sector. The year 2020 was particularly subdued for the automotive industry, largely due to the repercussions of the Covid-19 pandemic (Savić & Dobrijević, 2022), which led to a decline in vehicle sales. However, signs of recovery are now emerging, fostering optimism among industry stakeholders, including competitors and consumers. Vehicles have become more efficient, safer, and capable of achieving higher speeds. As the world continues to digitize rapidly, the automotive sector is gearing up for a transformative phase in the years ahead.

A notable technological progression anticipated in the automotive sector is the extensive integration of electric vehicles (EVs). As global society confronts the detrimental impacts of climate change, transitioning from conventional internal combustion engines to electric vehicles has become essential. Additionally, advancements in battery technology have markedly enhanced the range and charging efficiency of electric vehicles. The emergence of rapid charging infrastructure and more durable batteries will alleviate previous concerns regarding range limitations. The growing prevalence of electric vehicles will not only diminish our reliance on fossil fuels but will also encourage the utilization of renewable energy sources for electricity generation, thereby further decreasing our carbon emissions (Bosupeng, 2016).

The influence of automotive technology on the environment encompasses both beneficial and detrimental aspects. The positive contributions include the adoption of electric vehicles (EVs), the utilization of advanced materials and lighter designs, the implementation of smart energy management systems, and the reduction of noise pollution (Jacobson & Delucchi, 2011; Zhang & Xu, 2022; Munsi & Chaoui, 2024; Campello-Vicente *et al.*, 2017) Conversely, the negative aspects involve the production and recycling of batteries, the establishment of charging infrastructure, and challenges associated with electronic waste (Peters *et al.*, 2017;. Ma *et al.*, 2021; Costa *et al.*, 2021; Modoi & Mihai, 2022). The net environmental impact of technological advancements in the automotive sector is contingent upon the intricate interplay of these factors. Although electric vehicles offer significant advantages in terms of emission reductions, it is essential to adopt a holistic approach that addresses the adverse effects in other areas, particularly concerning battery manufacturing and the necessary infrastructure. The role of regulatory measures, technological innovations, and heightened public awareness is crucial in mitigating negative consequences while enhancing the positive contributions of automotive technology to the environment.

DATA AND METHODS

Multi-criteria decision-making (MCDM) refers to a systematic approach employed in scenarios where multiple criteria must be considered when selecting a particular alternative. Numerous methods exist within the realm of MCDM, each possessing distinct advantages and optimal contexts for application. The selection of an appropriate method is contingent upon the specific characteristics of the problem at hand, the data available, the complexity of the system, and the preferences of the decision-maker. A significant challenge inherent in multi-criteria decision-making is the need to reconcile various criteria, preferences, and conflicting interests. The primary objective is to ascertain the optimal solution, or at the very least, one of the most favorable solutions, while accommodating the diverse perspectives of the involved decision-makers. It is crucial to acknowledge that each participant may have a unique conception of the ideal solution, thereby rendering compromise an essential element of the decision-making process. To navigate this complexity, a variety of MCDM and multi-criteria decision analysis (MCDA) methodologies have been established. In this research, integrated AHP (Analytic Hierarchy Process) and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) method was used for selecting optimal electric vehicle for urban transport.

The integration of the AHP and the PROMETHEE is frequently employed in multi-criteria decision-making, particularly within the domain of urban transportation. AHP method serves to organize and prioritize criteria and alternatives in the decision-making process (Saaty, 1980), while PROMETHEE method is a methodology that facilitates the ranking of alternatives based on established criteria, and this approach involves pairwise comparisons of alternatives across each criterion to ascertain which alternatives are preferred (Brans & Mareschal, 2005). In this research AHP was used to assign weights or significance to each criterion in relation to the overall decision. Once the criteria have been prioritized and their relative importance established through AHP method, PROMETHEE method was employed to rank the alternatives, factoring in the weights of the criteria.

The research utilized Visual PROMETHEE software to compute and present the outcomes derived from the PROMETHEE method. Developed in 2012 by leading figures in the PROMETHEE/GAIA methodology, Brans and Marshall, Visual PROMETHEE is an advanced multi-criteria decision-making tool. This software is specifically crafted to offer users intuitive visual features that enhance the application of the PROMETHEE/GAIA methodology, thereby promoting a clearer comprehension and interpretation of the results (Mladenović-Ranisavljević *et al.,* 2021). Also, the Visual GAIA approach, which is integrated within the Visual PROMETHEE software tool, was used in the research, because it offers valuable insights into the conflicting attributes of the criteria and their influence on the ultimate ranking of alternatives.

RESULTS AND DISCUSSION

The study employed a decision-making approach that integrated the AHP and PROMETHEE methods to determine the most suitable electric vehicle for urban transportation. This methodological framework comprised four essential stages: data gathering, AHP analysis, PROMETHEE analysis, and final decision-making. During the data gathering stage, alternatives were identified, specifically selecting various models of electric vehicles for urban use, alongside establishing evaluation criteria and constructing a decision-making hierarchy. In the AHP analysis phase, a comparison matrix was developed, and the criteria's weighting coefficients were calculated according to the Saaty's scale of relative importance (Saaty, 1980). The PROMETHEE analysis phase involved defining the priorities for selecting an electric vehicle by establishing the preference function and its parameters. Both partial and complete rankings were conducted using the PROMETHEE I and II methods, respectively, culminating in the creation of a GAIA plane. All calculations were executed using the Visual PROMETHEE software. In the concluding decision-making phase, the electric vehicle for urban transport with the highest ranking was chosen based on the generated ranking list and the GAIA plane derived from the application of the PROMETHEE I and II methodologies.

In the course of examining the attributes of electric vehicles suitable for urban transportation, a selection of seven models from various manufacturers was undertaken, leading to the analysis of the following alternatives: A_1 - Peugeot 208 E, A_2 - Fiat 500 E, A_3 - Opel Corsa E, A_4 - Mini Cooper E, A_5 - Mazda MX-30, A_6 - BYD Dolphin, and A_7 - GWM ORA 3. The criteria that play a significant role in the selection of an electric vehicle for urban transport and that were used in the research are: C_1 - Electric vehicle price (euro), C_2 - Battery warranty (km), C_3 - Battery charging speed (min), C_4 - Acceleration up to 100 km/h (s), C_5 - Maximum speed (km/h), C_6 - Engine power (kW), C_7 - Battery efficiency (Wh/km), C_8 - Battery Usability (kWh), and C_9 - Milage (km). These criteria encompass the key factors that may impact the decision-making process regarding the choice of an electric vehicle.

The analysis conducted through the AHP method, along with the data presented in Table 1, indicates that the most significant criteria influencing the selection of an electric vehicle for urban transportation are: C_1 - the price of the electric vehicle, C_6 - engine power, C_7 - battery efficiency, and C_8 - battery usability. Furthermore, the consistency ratio calculated is 0.0734, which is below the threshold of 0.10, thereby allowing the utilization of the derived weight coefficients in subsequent decision-making processes.

Table 1. Results obtained using the AHP method

Criterion	Weight coefficients	Consistency Level (CR)
C_1	0.301	0.0734
C_2	0.054	
C_3	0.073	
C_4	0.022	
C_5	0.022	
C_6	0.181	
C_7	0.137	
C_8	0.113	
C_9	0.097	

Source: Ilić, I. (2024). Choosing an electric vehicle for urban transport using the AHP-PROMETHEE decision-making method [Graduation thesis, University Union-Nikola Tesla, Faculty of Information Technology and Engineering, Belgrade, Serbia]. (in Serbian)

To evaluate electric vehicles intended for urban transportation based on multiple criteria concerning the quality of the vehicles and their batteries, the study employed the PROMETHEE/GAIA decision support methodology. This analysis necessitated the ranking of seven alternatives, specifically seven electric vehicles designed for urban use, evaluated against nine distinct criteria. Data corresponding to these criteria for each selected electric vehicle were compiled (refer to table 2). The information utilized for the criteria was sourced from an electric vehicle database.

Table 2. Assessment scenario with selected criteria and alternatives

Parameter	C1	C2	C3	C4	C5	C6	C7	C8	C9
Single measure	Euro	km	min	s	km/h	kW	Wh/km	kWh	km
Min/Max	Min	Max	Min	Min	Max	Max	Min	Max	Max
Weight	0.301	0.054	0.073	0.022	0.022	0.181	0.137	0.113	0.097
Preference function Thresholds	Linear absolutely	Linear absolutely	Linear absolutely	Linear absolutely	Linear absolutely	Linear absolutely	Linear absolutely	Linear absolutely	Linear absolutely
Q	3,096.10	18856	7	1.4	6	16	7	6.5	37
P	6,621.82	32190	17	3.2	12	43	17	15.4	95
Alternatives									
A1	37,475.00	160000	26	9.0	150	100	160	46.3	290
A2	36,990.00	/	25	9.0	150	87	159	37.3	235
A3	34,650.00	160000	26	8.7	150	100	157	46.3	295
A4	32,900.00	160000	27	7.3	160	135	160	36.8	230
A5	35,990.00	160000	41	9.7	140	107	176	30.0	170
A6	28,000.00	200000	40	12.3	150	70	176	44.9	255
A7	38,990.00	160000	45	8.3	160	126	175	45.4	260

Source: Ilić, I. (2024). Choosing an electric vehicle for urban transport using the AHP-PROMETHEE decision-making method [Graduation thesis, University Union-Nikola Tesla, Faculty of Information Technology and Engineering, Belgrade, Serbia]. (in Serbian)

Table 3 presents the calculated values for positive (Phi+), negative (Phi-), and net (Phi net) preference flows. The findings indicate that the optimal choice is alternative A_4 - Mini Cooper E, which yields a Phi Net value of 0.2393. Conversely, the least favorable option is A_5 - Mazda MX-30, with a Phi Net value of -0.3417.

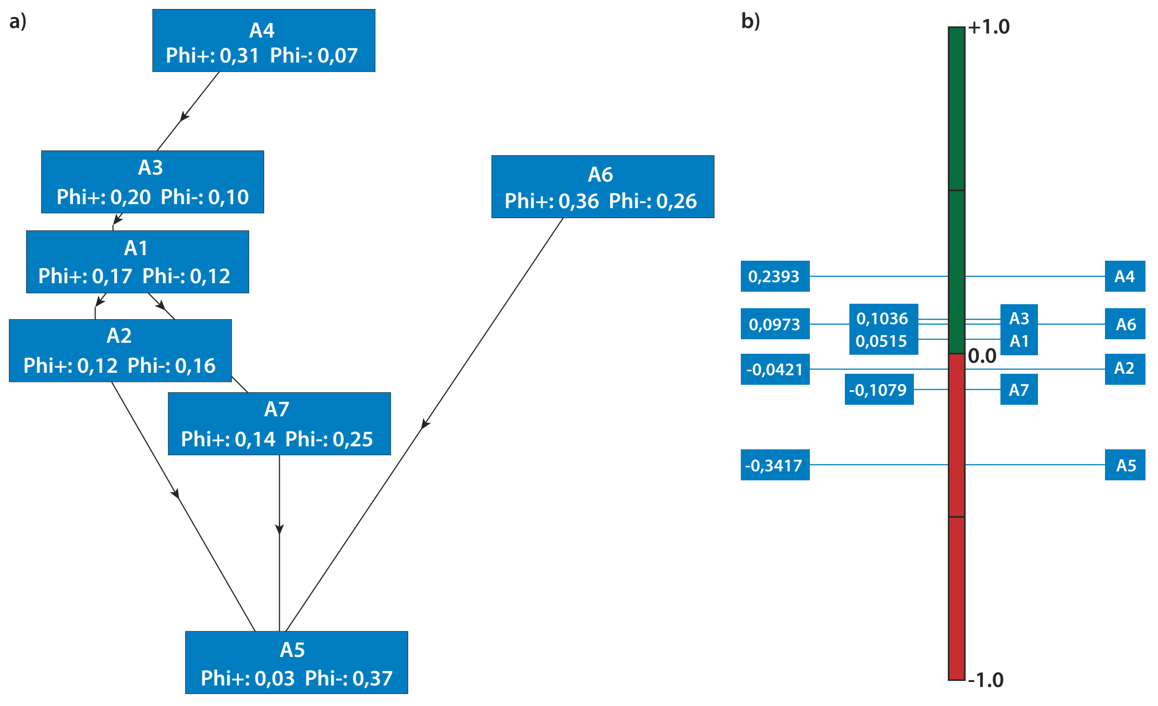
Table 3. Streams of preferences

Alternatives	*Phi+*	*Phi-*	*Phi Net*
A_1 - Peugeot 208 E	0.1696	0.1181	0.0515
A_2 - Fiat 500 E	0.1158	0.1579	-0.0421
A_3 - Opel Corsa E	0.2001	0.0965	0.1036
A_4 - Mini Cooper E	0.3087	0.0694	0.2393
A_5 - Mazda MX-30	0.0304	0.3721	-0.3417
A_6 - BYD Dolphin	0.3608	0.2635	0.0973
A_7 - GWM ORA 3	0.1401	0.2480	-0.1079

Source: Ilić, I. (2024). Choosing an electric vehicle for urban transport using the AHP-PROMETHEE decision-making method [Graduation thesis, University Union-Nikola Tesla, Faculty of Information Technology and Engineering, Belgrade, Serbia]. (in Serbian)

The analysis of data presented in Table 2 outlines a comprehensive ranking of alternatives, specifically electric vehicles intended for urban transportation, utilizing the PROMETHEE I and PROMETHEE II methodologies. These methodologies facilitate the evaluation and comparison of various options through a multi-criteria decision-making framework, which is particularly crucial when determining the most suitable vehicle for urban transport. Figure 1 illustrates the insights gained from the PROMETHEE I partial ranking, which elucidates the preferences among the different alternatives. In Figure 1a, arrows indicate the direction of preferences, effectively visualizing the interrelationships among the alternatives. This graphical representation aids in comprehending how each alternative measures up against the others and identifies which options are closer to or further from the optimal choice. Conversely, Figure 1b presents the comprehensive ranking of alternatives as determined by PROMETHEE II. It is noteworthy that alternative A_4 – Mini Cooper E emerges as the highest-rated option, boasting a Phi Net value of 0.2393. This substantial value signifies that the Mini Cooper E markedly outperforms the other alternatives evaluated. In contrast, alternative A_5 - Mazda MX-30 ranks at the bottom with a Phi Net value of -0.3417, indicating that this vehicle is not advisable for urban transportation based on the established criteria.

Figure 1. Ranking of alternatives: a) PROMETHEE I partial ranking and b) PROMETHEE II complete ranking



Source: Ilić, I. (2024). Choosing an electric vehicle for urban transport using the AHP-PROMETHEE decision-making method [Graduation thesis, University Union-Nikola Tesla, Faculty of Information Technology and Engineering, Belgrade, Serbia]. (in Serbian)

Figure 2 illustrates the GAIA plane corresponding to the specified scenario within the Visual PROMETHEE software framework. In this diagram, the alternatives are represented by turquoise squares, while the criteria utilized for ranking these alternatives are depicted as dark blue diamonds. The data quality indicated by the GAIA plane is 72.5%, surpassing the average threshold of 70%. Consequently, this representation can be deemed reliable for subsequent analyses. Through the examination of the GAIA plane, the most significant criteria influencing the quality of electric vehicles were identified. Criteria positioned in close proximity to the coordinates, such as criterion C_5, exert minimal influence on the ranking outcomes. The GAIA analysis reveals that alternatives situated near the orientation axis of each criterion tend to receive higher rankings for that specific criterion. The decision stick, marked in red within the diagram, signifies a compromise solution. Alternatives located near this decision stick are generally favorable across most criteria. Specifically, alternatives A_1, A_2, A_3, and A4 are better ranked according to criteria C_3, C_4, C_5, C_6, C_7, C_8, and C_9, as indicated in Figure 2. Alternative A1 is particularly well-ranked in relation to criterion C_8, while A_2 excels according to criterion C_3. Alternative A_3 outperforms others based on criteria C_7, C_8, and C_9, and A_4 is superior according to criteria C_4, C_5, and C_6. Additionally, alternative A_6 ranks higher than the others concerning criteria C_1 and C_2. Conversely, alternatives A_5 and A_7 are identified as the least favorable options, with A_5 performing poorly against criteria C_2, C_5, C_7, C_8, and C_9, and A_7 ranking lower in relation to criteria C_1, C_2, and C_3.

Figure 2. GAIA plane

Source: Ilić, I. (2024). Choosing an electric vehicle for urban transport using the AHP-PROMETHEE decision-making method [Graduation thesis, University Union-Nikola Tesla, Faculty of Information Technology and Engineering, Belgrade, Serbia]. (in Serbian)

CONCLUSIONS

The application of the AHP-PROMETHEE decision-making method in selecting an electric vehicle for urban transport leads to conclusions grounded in the analysis of priorities and the ranking of alternatives based on established criteria. This method enables users to gain a comprehensive understanding of the priorities and trade-offs associated with various attributes of electric vehicles, including cost, performance, range, charging efficiency, reliability, and environmental impact. By employing a systematic approach, decision-makers can pinpoint the most critical factors tailored to their specific requirements and preferences. Research utilizing the AHP-PROMETHEE framework indicates that this methodology offers a robust basis for making informed decisions regarding electric vehicles. Given the rapid technological advancements and shifts within the electric vehicle sector, ongoing refinement and adaptation of these methodologies can enhance the efficiency and precision of selecting electric vehicles that align with user needs and sustainability objectives.

Nonetheless, several challenges must be addressed when implementing the integrated AHP-PROMETHEE method. Primarily, establishing an appropriate hierarchy of criteria may be subjective and necessitate a thorough comprehension of electric vehicle features and user requirements. Additionally, obtaining reliable data for the assessment of electric vehicles can prove difficult, particularly due to the swift evolution of technology and discrepancies in testing protocols. Another challenge pertains to the interpretation of the outcomes. While PROMETHEE generates quantitative results, their interpretation can be intricate, especially in the presence of multiple criteria and alternatives. Thus, it is crucial to ensure that the results are clearly interpreted to aid in the decision-making process.

In light of the aforementioned challenges, the implementation of the AHP-PROMETHEE method serves as a valuable instrument for individuals making decisions regarding the selection of electric vehicles. Ongoing enhancements to the methodology, coupled with meticulous oversight of the decision-making process, can facilitate the resolution of these challenges, thereby ensuring the selection of an electric vehicle that aligns with user requirements and sustainability objectives. Furthermore, it is essential to recognize that the proposed methodology is applicable not only to the selection of electric vehicles intended for urban transportation but also to the acquisition of higher-class electric vehicles, as well as other categories of electric vehicles, including motorcycles, vans, buses, and trucks. It is imperative to establish the criteria for selection based on the defined alternatives, as the most pertinent criteria will vary according to the specific type of electric vehicle under consideration. Thus, the alternatives and criteria defined in the research were determined on the basis of available data. The results showed that the best choice is the A_4 alternative, *i.e.* the Mini Cooper E electric vehicle, and the worst alternative is A_5, *i.e.* the Mazda MX-30, which does not mean that the results would remain the same if some other criteria were added to rank the alternatives.

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PRIMENA AHP-PROMETHEE METODE PRI IZBORU OPTIMALNOG ELEKTRIČNOG VOZILA ZA URBANI TRANSPORT

Rezime:

Ova studija razjašnjava nalaze proistekle iz implementacije integrisane AHP-PROMETHEE višekriterijumske metode donošenja odluka u cilju odabira najpogodnijeg električnog vozila za gradski transport. AHP metodologija je olakšala identifikaciju kritičnih kriterijuma koji utiču na izbor električnog vozila za gradsku upotrebu, uključujući faktore kao što su cena, garancija baterije, brzina punjenja, ubrzanje do 100 km/h, maksimalna brzina, snaga motora, efikasnost, performanse baterije i kilometraža. Naknadna primena PROMETHEE metode je omogućila rangiranje devet električnih vozila na osnovu ovih utvrđenih kriterijuma. Svaka alternativa vozila je procenjena u pogledu njenog kapaciteta da ispuni određene zahteve i preferencije donosioca odluka. Analiza sugeriše da se Mini Cooper E pojavio kao model koji je najefikasniji u skladu sa zadatim kriterijumima. Ovo vozilo se smatra optimalnim izborom za potrebe gradskog prevoza, s obzirom na sve relevantne faktore. Očekuje se da će odluka o izboru specifičnog električnog vozila uticati na efikasnost, održivost i ekonomsku održivost gradskog transportnog sistema. Štaviše, preporučljivo je održavati stalni nadzor napretka u tehnologiji električnih vozila i infrastrukture za punjenje kako bi se osiguralo da odabrani model i dalje predstavlja najbolju opciju u budućnosti.

Ključne reči:

integrisana AHP-PROMETHEE metoda,
kriterijumi,
rangiranje,
električna vozila,
tehnologija.

JEL klasifikacija:

D7, D91, R4