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Evaluating Alternative Propulsion Systems for Urban Public Transport in Niš: A Multicriteria Decision-Making Approach

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Abstract: In the pursuit of sustainable urban development, the implementation of cleaner propulsion systems in public transportation emerges as a critical strategy to reduce urban pollution and emissions. This study focuses on the City of Niš, where conventional propulsion vehicles, predominantly buses, contribute significantly to environmental degradation. The necessity to adopt alternative propulsion systems is underscored by the myriad of limitations and uncertainties that accompany such a transition. To address this complexity, the criteria importance through intercriteria correlation (CRITIC) method was employed to derive weight coefficients, while the evaluation based on distance from average solution (EDAS) method was utilized to select optimal propulsion systems. These methodologies facilitated a comprehensive evaluation of alternatives, including buses, electric trolleybuses, and trams, for both city and suburban public transport. The integration of these multi-criteria decision-making techniques enabled a systematic analysis of each alternative against established criteria, thereby assisting in the identification of the most advantageous propulsion systems. This approach not only aids in making informed decisions that align with sustainability objectives but also contributes significantly to mitigating the environmental impact of urban transport. The findings from this study provide a foundational framework that supports decision-makers in the strategic implementation of environmentally sustainable transport solutions in urban settings.

Keywords: Urban public transport; Alternative propulsion systems; Multi-criteria decision-making; Criteria importance through intercriteria correlation (CRITIC); Evaluation based on distance from average solution (EDAS)

1 Introduction

In today's society, transportation is essential for everyone. Vehicles powered by gasoline or diesel, which contribute to pollution, are being swiftly replaced by fully electric cars. These all-electric vehicles are far more environmentally friendly as they produce no exhaust emissions. The electric vehicle market has seen significant growth in recent years, creating challenges for consumers to assess their options and raising substantial concerns. [1]. Electromobility is a major trend revolutionizing public transportation globally. Supported by international organizations like the European Union and national co-founders, public transport operators, and local authorities are making strategic choices regarding the extent and direction of fleet electrification [2, 3]. Today, the design and adoption of sustainable and more ecological transport systems are of the utmost interest. The European Commission, along with multiple EU countries, is formulating plans and programs and allocating resources to decarbonize cities and transportation by 2030.

Air pollution caused by extensive urban development and the growing use of private vehicles is a significant environmental issue, especially in cities. Urban public road transport plays a crucial role in influencing land use patterns, air quality, and overall quality of life. Therefore, it must be efficient in reducing air pollution to support sustainable urban mobility and economic growth [4].

The majority of electric buses being deployed are replacing conventional buses and, thus, typically operate on existing bus routes. Urban public transport systems need to be both economically efficient and environmentally sustainable. Decision support systems, including traditional and modern multi-criteria decision methods, help identify which public transport vehicles are suitable and which should be phased out to maintain efficient and eco-friendly cities [5].

Urban Public Passenger Transport (UPPT) is a major consumer of energy and a significant source of environmental pollution, necessitating improvements. In the City of Niš, the public mass transportation system relies solely on buses. Research conducted by the Faculty of Mechanical Engineering on the Niš public transport system, which operates on 13 routes covering a total of 134 km with 124 diesel-powered buses traveling approximately 8.8 million km annually, highlights the need for alternative energy sources in city bus fleets to reduce pollution.

Since public city transport buses are significant polluters, integrating alternative energy sources into city bus fleets is especially effective. In Serbia, there are no significant applications for alternative propulsion systems. The City of Belgrade, which is the capital of the Republic of Serbia, was established in 2016 as the first city line, on which only 5 electrically powered buses operate, and in 2022, 10 more electric buses were put into operation. In Novi Sad, the first electric buses were put into operation in 2023. In Belgrade, gas-powered buses were utilized solely for research or experimental purposes, while in Novi Sad, since 2011, six compressed natural gas buses have been in use. In the cities of Serbia, buses with EURO 0, EURO 1, and EURO 2 standards are gradually being withdrawn from operation, and new ones with EURO 4 and higher standards are being introduced. Unfortunately, due to a lack of financial resources, that process is moving too slowly.

Following the initial part, which underscores the significance and examination of alternative propulsion systems for public transport, the second section delves into a comprehensive review of the literature concerning the utilization of approaches and methodologies for employing multi-criteria decision-making techniques in UPPT. The third section gives a general procedure using multi-criteria to specify sets of input data represented as alternatives and criteria, culminating in the creation of a decision matrix. The selection of alternatives and criteria will be based on a review of foreign scientific and technical literature, as well as expert assessments provided by the authors. In the fourth section, the process of the CRITIC method for determining weighting coefficients and the EDAS method for ranking propulsion systems and fuels for buses, as well as other modes of transport like trolleybuses and trams in the City of Niš, is outlined. The paper will conclude with the primary findings and a summary of future research objectives.

2 Review of Relevant Literature

UPPT offers transportation services under predefined and well-established operating conditions accessible to all users. Public transportation plays a crucial role in cities, particularly in alleviating traffic congestion in downtown areas.

Urban transport accounts for approximately a quarter of carbon dioxide emissions from transportation. Phasing out conventionally fueled vehicles from urban regions is pivotal in reducing heavy reliance on oil, greenhouse gas emissions, pollution, and noise. Introducing new vehicles powered by appropriate alternative energy sources is essential. Given that public transportation vehicles are significant contributors to pollution, transitioning to alternative energy sources is especially impactful for city bus fleets.

The objective of study [6] is to assist public transport managers in making informed decisions regarding the composition of their bus fleets, considering economic, environmental, and social factors from a sustainability standpoint. The paper examines data pertaining to the public bus system in Madrid, employing two analytical methods, Data Envelopment Analysis (DEA) and Elimination et Choice Translating Reality (ELECTRE) III, for a comparative analysis. The findings suggest the existence of two primary categories of vehicles that could potentially contribute to a theoretical solution. The key conclusions drawn from the research indicate that plug-in and induction electric vehicles differ significantly from CNG and diesel-hybrid vehicles in terms of cost, pollution, and service. Additionally, the ELECTRE III model is found to offer more comprehensive insights for addressing this issue compared to the DEA model [6].

In recent times, there has been a noticeable shift among bus operators towards electrifying their fleets as a means to mitigate air pollution in urban areas, generating increased interest within the scientific community. The paper [7] offers a comprehensive overview of the latest advancements concerning the integration of battery electric buses (BEBs) in urban environments. It conducts an analysis of BEB powertrain configurations and charging technologies, with a specific focus on power electronics systems. Additionally, the paper provides an in-depth examination of vehicle planning, optimal charger placement, and charging management strategies. From this examination, it is evident that accurate energy consumption estimation for BEBs is crucial for bus operators. Consequently, integrating real-time, multi-objective smart charging management strategies into scheduling practices for large bus fleets, alongside synchronized charging capabilities, smart charging depots, and electric bus rapid transit, can further alleviate strain on the grid [7].

The paper [8] introduces a novel approach that combines the ELECTRE TRI multi-criteria method with the DELPHI procedure to determine the acceptability of urban public transport vehicles, considering a predefined sustainability threshold that encompasses rigorous economic and environmental criteria. The proposed model utilizes data on urban public road traffic in Madrid from 2020, sourced from the Madrid City Council, collected and assessed by the authors, and validated by a panel of 20 experts to identify the criteria and factors integrated into the model. The outcomes of this study offer valuable insights to local governments, aiding in the identification of urban public transport vehicles that should be gradually replaced with alternatives classified as both economically efficient and environmentally sustainable [8].

The research [9] originates from the perspective of Swedish regional transport authorities, focusing on the public procurement of bus transport. These authorities aim to contribute to a transition that emphasizes decreasing reliance on fossil fuels and enhancing sustainability performance. The article aims to develop a multi-criteria assessment (MCA) method to facilitate the evaluation of public bus technologies' viability. The method, established through an iterative and participatory approach, encompasses various bus technologies (alternatives) such as biodiesel, biomethane, diesel, electricity, ethanol, and natural gas, along with 12 indicators. The article provides an introduction to the problem's context and offers an overview of pertinent previous research concerning green or sustainable public procurement and sustainability assessments. Additionally, it presents and discusses the process and MCA method, emphasizing tips for conducting effective and efficient sustainability assessments [9].

The paper [10] introduces a methodological process and toolkit for determining the priority of transitioning from conventional to electric buses based on the characteristics of each route. The PROMETHEE method was employed to identify the most suitable routes based on technical, social, ecological, economic, and locational criteria. The final ranking of routes was achieved using the Visual PROMETHEE software. By processing the values assigned to each criterion and their corresponding weights, the method facilitated the prioritization of routes. Considering 23 lines and 475 bus units, the initial phase of the study determined the need for 68 electric buses across five lines to decrease fuel consumption. Key decision-making criteria included the number of passengers served, trip duration, and energy requirements for each route [10].

3 Approach to Multiple Criteria Decision Making (MCDM) and Input Data Analysis

Multi-criteria analysis, used to evaluate and compare alternatives based on multiple criteria or objectives, has indeed seen significant evolution and diversification in approaches since the 1960s [11]. Over this period, various techniques (methods) have emerged, each offering different strengths and weaknesses in addressing real-world problems requiring complex decision-making.

Indeed, methods for categorizing information can be broadly classified into two groups based on their purpose and characteristics [8]. The first group comprises methods that do not require information about the criteria, such as the domination method, MAXIMIN method, and MAXIMAX method. The second group consists of methods that necessitate specific information about the criteria, including MABAC (Multi-Attributive Border Approximation Area Comparison) [12, 13], TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) [14–17], EDAS [18–21], MAIRCA (Multi-Attributive Ideal-Real Comparative Analysis) [22], VIKOR (Višekriterijumsko kompromisno rangiranje) [15], AHP (Analytic Hierarchy Process) [12, 16, 23, 24], SAW (Simple Additive Weighting) [25], and so on.

To make a well-informed decision, it's crucial to clearly outline the options available by establishing relevant criteria. Furthermore, it is crucial to assign weight coefficients to each criterion, reflecting their relative importance in the decision-making process. These coefficients can be determined using various methods, including CRITIC [26], Entropy [17, 25], FUCOM (Full Consistency Method) [26], and so on.

Moreover, for each criterion, its nature is determined, indicating whether the criterion should be minimized or maximized when selecting an alternative [27]. Subsequently, alternatives are evaluated for each criterion based on precisely defined parameters or subjective assessments.

In evaluating alternative propulsion systems and modes of transport for public passenger transport in Niš, several solutions are being considered in light of today's technological advancements:

A_1 - Supplying the bus with conventional diesel engines (oil). Given that conventional diesel buses have historically dominated public transportation in Serbia, accounting for over 99% of cases, they have posed significant environmental challenges, particularly in urban areas where they contribute to high levels of particulate pollution and nitrogen oxide emissions [28]. In light of global energy crises and heightened awareness of the environmental impacts of diesel engines, there's a growing imperative to explore new technological solutions. These solutions revolve around alternative fuels and advancements in combustion processes aimed at reducing emissions of pollutants.

A_2 - Supplying the bus with Compressed Natural Gas (CNG) or Liquid Natural Gas (LNG). CNG technology has gained widespread commercialization globally, with approximately four million CNG vehicles in operation worldwide. This technology is particularly prevalent in countries with abundant natural gas resources. CNG vehicles emit relatively low levels of carbon dioxide and boast a high octane value, making them well-suited for public transportation. Many European cities, including Rome, Madrid, Barcelona, Torino, Porto, Lille, and Paris, have adopted CNG-powered buses in substantial numbers [28]. In Belgrade, however, the use of gas-powered buses remains largely in the realm of research and experimentation, whereas in Novi Sad, there have been efforts since 2011 to implement six buses powered by CNG. Challenges related to natural gas supply, distribution, and security persist and require improvement [29]. In countries like Japan, Italy, and Canada, a notable percentage of buses (up to 7%) are powered by LNG, and several European nations are considering the introduction of LNG vehicles as part of efforts to mitigate pollution [15].

A_3 - Supplying the bus with renewable biofuels (biodiesel). Biodiesel, derived from biomass such as oil crops' seeds, offers a liquid renewable energy source. Its properties closely resemble those of fossil diesel, with enhancements stemming from its oxygen content. This feature improves the combustion process and provides better lubrication, offsetting some of the effects of its slightly lower energy content compared to traditional diesel. Biodiesel serves as an excellent substitute for fossil diesel, requiring no significant modifications to diesel engines to accommodate its use.

A_4 - Hybrid electric bus with diesel engine. Hybrid propulsion for buses involves the integration of two power units utilizing different energy sources. This system typically comprises an internal combustion engine, an electric generator, an electric motor, power converters, and a battery. The combustion engine powers an alternator, which in turn supplies electricity to the electric motor, typically ranging from 100 to 150 kW. Any surplus electricity generated is stored in batteries, enabling the vehicle to operate independently for short distances, usually between 5 and 10 kilometers [29]. Moreover, during downhill drives, braking, and stopping, the engine continues to recharge the battery, further optimizing energy efficiency. Cities such as Berlin, Brussels, London, and Paris have initiated the deployment of buses featuring hybrid diesel-electric propulsion systems, marking a step toward more environmentally friendly and efficient public transportation solutions.

A_5 - Supplying the bus with electricity. An autonomous electric vehicle relies on electricity stored in its onboard battery for power. These electric vehicles have seen significant development by major manufacturers worldwide, with a particular focus on enhancing battery capacity. Buses equipped with electric DC motors offer favorable operating characteristics, thanks to the straightforward control of drive torque. However, a critical challenge in the operation of these vehicles lies in replenishing their electricity sources, primarily the batteries. This issue is typically addressed through two methods: recharging the depleted batteries or replacing them with fully charged ones [15]. Nevertheless, the restoration of electricity sources remains a significant drawback of this technology, posing challenges for widespread adoption and efficient operation.

A_6 - Supplying the bus with hydrogen (H_2). Fuel cells are electrochemical devices designed to directly convert the chemical energy stored in certain elements or compounds into DC electricity [28]. Typically, hydrogen is the preferred fuel stored in tanks, either in liquid or gaseous form. Despite its immense potential, the adoption of hydrogen as a fuel for buses has been limited, despite its capability to produce zero emissions of pollutants. Major vehicle manufacturers worldwide have been investing significant efforts into the development of vehicles powered by fuel cells. This technology holds promise for providing clean and sustainable energy solutions, although its widespread application in the transportation sector remains a work in progress.

A_7 - Trolleybus as subsystem of UPPT supplying with electricity. The trolleybus subsystem is a component of UPPT that closely resembles traditional buses, with the main distinction being their electric power source. These vehicles run on rubber wheels and are continuously connected to a two-wire air-contact line, drawing electricity from it.

In recent years, there has been an expansion of trolleybus systems in cities worldwide, particularly in the European Union, where it serves as a primary mode of transportation in 86 cities [30]. Athens boasts the largest trolleybus subsystem in the EU, with 315 vehicles. Countries like Italy and Switzerland lead in trolleybus technology, with 15 and 14 companies, respectively, employing cutting-edge technology in this sector. Many other countries are either reintroducing or planning to introduce trolleybus systems into their public transport networks [30].

The trolleybus subsystem offers several advantages over conventional buses. It is environmentally friendly, emitting no harmful emissions and producing the lowest noise levels among public transport options. Moreover, it is cost-effective due to its utilization of renewable energy sources, leading to a longer average lifespan compared to buses (about 15 years).

However, there are some drawbacks to trolleybus systems compared to traditional buses. They require a higher initial investment cost, typically around 10% more than conventional bus systems. Additionally, the power supply network necessitates maintenance, and trolleybuses are less flexible than buses due to their reliance on fixed overhead wires. Despite these challenges, trolleybus systems remain a viable and sustainable option for urban public transportation.

A_8 - Tram as subsystem of UPPT supplying with electricity. Electricity serves as the primary source of propulsion power in the rail subcategory of UPPT. This mode of propulsion offers exceptional dynamic performance for vehicles and ensures clean and easily maintainable engines. Environmentally friendly, it also facilitates energy recovery during braking, further enhancing its sustainability. Within the rail subsystem of UPPT, trams exemplify this form of propulsion. Trams operate along fixed routes according to set timetables, utilizing electrical energy as their source of power. This electricity is obtained through constant contact with an electric trolley, typically via a pantograph, and an overhead air contact line [30].

The evaluation of alternative propulsion systems and transport modes for public passenger transport in Niš is based on several criteria:

C_1 - Energy supply. The evaluation of this criterion, ranging from 1 to 9, is determined by factors such as the feasibility of energy provision, the cost of energy resources, infrastructure development, and the availability of supplies. This assessment draws upon information from [14], supplemented by personal evaluations specific to trolleybuses and trams.

C_2 - Energy efficiency. The evaluation is conducted with reference to data from the study [15], with a specific focus on trolleybuses and trams. In this assessment, the relationship between energy efficiency is established, equating 1 liter of diesel fuel to 3.67 kWh of energy.

C_3 - Air pollution (CO_2). The evaluation process relied on data about maximum measurements of gas emissions as outlined in literature sources [15, 29]. These measurements served as the basis for assessing air pollution levels associated with different propulsion systems and modes of transport.

C_4 - Noise [dB]. The evaluation was conducted using information derived from the study [15], supplemented by the author's personal assessment of trolleybuses and trams. This combined approach provided a comprehensive understanding of the various factors influencing the assessment of alternative propulsion systems and modes of transport.

C_5 - Technical characteristics of the vehicle (capacity, power, acceleration, braking, comfort, average speed). The evaluation process was based on data from the study [15] along with the author's personal assessment, particularly considering the higher capacity of trams compared to buses. This comprehensive approach ensured a thorough evaluation of trolleybuses and trams in terms of their technical characteristics and suitability for public transportation.

C_6 - Investment costs (price of the vehicle). The evaluation of investment costs, specifically the price of the vehicle, draws upon data from literature sources [15, 31]. This multi-source approach ensures a thorough understanding of the financial implications associated with acquiring vehicles for public transportation purposes in Niš.

C_7 - Maintenance costs [$] (parts, oil, fluids, large and small service, etc.). Assessed by consulting data from literature source [15] as well as the author's evaluation, particularly focusing on trolleybuses and trams. This combined approach facilitated a comprehensive understanding of the ongoing expenses associated with maintaining these modes of transportation in Niš.

C_8 - Inclusion the domestic industry on at the level of Serbia. The assessment of the involvement of the domestic industry at the level of Serbia was conducted solely based on the author's personal evaluation. This evaluation considered factors such as the extent of domestic manufacturing, supply chain integration, and overall contribution of Serbian industry to the production or provision of transportation vehicles for public passenger transport in Niš.

A decision matrix (Table 1) has been developed based on the adopted alternatives and criteria. This matrix aids in determining the weight coefficients assigned to each criterion, which influences the chosen alternatives. Subsequently, a multi-criteria decision-making procedure is conducted, leveraging the established weight coefficients to assess and rank the alternatives effectively.

Table 1. Quantified decision matrix

Alternative	**Criteria**							
	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
	max	max	min	max	max	min	min	max
$\mathbf{A_1}$	7	1	1700	0.42	0.79	100000	11400	7
$\mathbf{A_2}$	5	0.8	1400	0.55	0.73	300000	10410	6
$\mathbf{A_3}$	2	0.8	1.8	0.58	0.52	120000	14700	6
$\mathbf{A_4}$	5	1.5	1.1	0.58	0.67	360000	22200	5
$\mathbf{A_5}$	5	10.9	300	0.59	0.47	300000	18495	2
$\mathbf{A_6}$	1	1.9	200	0.58	0.56	600000	30720	1
$\mathbf{A_7}$	3	1.1	300	0.58	0.5	300000	10000	3
$\mathbf{A_8}$	3	1.5	100	0.5	0.8	2500000	15000	4

4 Implementation of the Approach and Discussion of the Results

In multi-criteria decision-making, conflicts between different criteria are common and are inherent to the decision-making process. When criteria are in conflict, resolving the multi-criteria problem requires employing complex procedures to select a preferred option or establish the order of alternatives. The CRITIC method, as outlined in sources [32, 33], offers an objective approach to determining the weights of criteria. It combines the standard deviation of alternative values across criteria with the correlation coefficient between criteria. This method involves analytically examining the decision matrix to ascertain the information captured by the criteria used to evaluate the alternatives.

In the first step of the process, the values of the alternatives are normalized based on the criteria or elements of the initial decision matrix. To create a normalized matrix, this normalization process involves applying Eqs. (1)-(2):

For criteria that have been maximized, the normalized values are calculated as follows:

$$r_{ij} = \frac{a_{ij} - a_i^-}{a_i^+ - a_i^-} \tag{1}$$

For criteria that have been minimized, the normalized values are calculated as follows:

$$r_{ij} = \frac{a_i^+ - a_{ij}}{a_i^+ - a_i^-} \tag{2}$$

This transformation is rooted in the concept of an ideal point. In expressions (1) and (2), a_{ij}, a_i^+, a_i^- are the elements of the initial decision matrix, where:

a_i^+- the maximum value of the observed criterion by alternatives, that is $a_i^+ = \max(x_1, x_2, \ldots, x_m)$ and a_i^-- the minimum value of the observed criterion by alternatives, that is $a_i^- = \min(x_1, x_2, \ldots, x_m)$.

The r_{ij} value shows how close some alternative is to the ideal value $a_i^+$and how far it is from the anti-ideal value a_i^-.

In the second step, a criteria vector is formed based on the value r_{ij}, where each vector has a standard deviation σ_{j} by applying Eq. (3):

$$\sigma_j = \sqrt{\frac{1}{n}\sum_{j=1}^{n} (r_{ij} - \overline{r_j})^2} \tag{3}$$

where, n represents the number of criteria, $\overline{r_j}$ represents the arithmetic mean of the elements of the normalized matrix.

In the third step, the correlation coefficient is calculated for each pair of criteria, as an indicator of their mutual dependence using Eq. (4):

$$R_{ij} = \frac{n\sum r_j r_k - \sum r_j \sum r_k}{\sqrt{n\sum r_j^2 - \left(\sum r_j\right)^2 \cdot \sqrt{n\sum r_k^2 - \left(\sum r_k\right)^2}}} \tag{4}$$

and forms an $\mathrm{n} \times \mathrm{n}$ matrix where r_j and r_k are linear correlation coefficients and n represents the number of alternatives.

To further apply the method, in the fourth step, it's necessary to calculate the measure of conflict of the j-th criterion with respect to the other criteria in the given decision matrix. This calculation is done by applying Eq. (5):

$$\sum_{k=1}^{n} (1 - R_{jk}) \tag{5}$$

In the fifth step, the amount of information is determined in relation to each criterion using Eq. (6):

$$C_j = \sigma_j \sum_{i=1}^{m} (1 - r_{ij}) \tag{6}$$

Table 2. The final values of the criteria weight coefficients

	$\mathbf{C_1}$	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_4}$	$\mathbf{C_5}$	$\mathbf{C_6}$	$\mathbf{C_7}$	$\mathbf{C_8}$
$\boldsymbol{w_j}$	0.0983	0.1208	0.1623	0.1345	0.1540	0.1093	0.1088	0.1121

Finally, in the last sixth step, the weighting coefficients of the criteria (Table 2) are determined by normalizing the value of C_j using the following expression, given in Eq. (7):

$$w_j = \frac{C_j}{\sum_{j=1}^{n} C_j}, j = 1, \ldots, n \tag{7}$$

EDAS method, developed by Ghorabee and collaborators [34], is a relatively recent addition to the field of multi-criteria analysis. According to their perspective, traditional methods often involve complex calculations and produce rigid decision-making outcomes. In contrast, the EDAS method offers both optimistic and pessimistic solutions, affording decision-makers greater flexibility in their final assessments. Ghorabaee starts from the assumption that the values of successful problem solving with the EDAS method follow a normal distribution, which makes it very applicable in various fields. This method operates by aggregating values derived from both the positive distances from the average value and the negative distances from the average value. Also, it is taken into account whether the criterion type is "max" or "min".

The goal is to conduct a multi-criteria analysis of alternative propulsion systems and fuels for buses in Niš, while also including additional subsystems of UPPT such as electric propulsion, trolleybuses, and trams. Also, the aim is to rank the adopted alternatives and identify the best option that aligns with the established criteria. The mathematical model of the EDAS method consists of six steps [34].

Step 1. Formation of the decision matrix (Table 1)

Step 2. Determining the average solution for each criterion individually based on Eq. (8):

$$AV = [AV_j]_{1\times m} = \left[\frac{\sum_{i=1}^{n} x_{i1}}{n} \frac{\sum_{i=1}^{n} x_{i2}}{n} \dots \frac{\sum_{i=1}^{n} x_{im}}{n}\right] = [x_1^*, x_2^*, \dots, x_m^*] \quad (8)$$

Step 3. Determination of the positive distance from the average solution (PDA) and the negative distance from the average solution (NDA) of the matrix based on the type of criteria (max or min) according on the following Eqs. (9)-(10):

$$PDA = [PDA_{ij}]_{n\times m} \quad (9)$$

$$NDA = [NDA_{ij}]_{n\times m} \quad (10)$$

If the j-th criterion should be maximized by Eq. (11):

$$\begin{aligned} PDA_{ij} &= \frac{\max\left(0, (x_{ij} - AV_j)\right)}{AV_j} \\ NDA_{ij} &= \frac{\max\left(0, (AV_j - x_{ij})\right)}{AV_j} \end{aligned} \quad (11)$$

and if the j-th criterion should be minimized by Eq. (12):

$$\begin{aligned} PDA_{ij} &= \frac{\max\left(0, (AV_j - x_{ij})\right)}{AV_j} \\ NDA_{ij} &= \frac{\max\left(0, (x_{ij} - AV_j)\right)}{AV_j} \end{aligned} \quad (12)$$

Step 4. Formation of one-dimensional weight matrices according to the following Eqs. (13)-(14):

$$SP_i = \sum_{j=1}^{m} w_j PDA_{ij} \quad (13)$$

$$SN_i = \sum_{j=1}^{m} w_j NDA_{ij} \quad (14)$$

where, w_j is the weight coefficient of the jth criterion.

Step 5. Normalization of SP_i and SN_i values for all alternatives according to Eqs. (15)-(16) (Table 3):

$$NSP_i = \frac{SP_i}{\max_i (SP_i)} \quad (15)$$

$$NSN_i = 1 - \frac{SN_i}{\max_i (SN_i)} \quad (16)$$

Step 6. Calculation of the mean value of AS_i for all alternatives according to Eq. (17) (Table 3):

$$AS_i = \frac{1}{2}\left(NSP_i + NSN_i\right) \tag{17}$$

where, $0 \leq AS_i \leq 1$.

In everyday real decision-making problems, there is almost no "ideal" alternative that would be the best in relation to each criterion or goal. For example, an alternative that is more useful is usually more expensive. As there is almost always a conflict of goals, the main purpose of multi-criteria decision-making is to determine a "good" compromise, that is, an alternative that meets all the set criteria to the greatest extent. According to the findings derived from the EDAS method (Table 3), the optimal alternative identified is A_5, which corresponds to the bus powered by electricity.

Table 3. Ranking of alternatives according to criteria

Alternatives	**NSP_i**	**NSN_i**	**AS_i**	**Ranking**
$\mathbf{A_1}$	0.5481	0.0000	0.2740	**8**
$\mathbf{A_2}$	0.3345	0.2442	0.2893	**7**
$\mathbf{A_3}$	0.5472	0.5868	0.5670	**4**
$\mathbf{A_4}$	0.4669	0.8587	0.6628	**2**
$\mathbf{A_5}$	1.0000	0.7556	0.8778	**1**
$\mathbf{A_6}$	0.1832	0.6714	0.4273	**6**
$\mathbf{A_7}$	0.2926	0.5965	0.4445	**5**
$\mathbf{A_8}$	0.3164	0.8417	0.5791	**3**

Also, the worst evaluated is a bus powered by a conventional diesel engine (oil). Alternative solutions, A_4-Hybrid electric bus with diesel engine, and A_8 - Tram as subsystems of UPPT supplying with electricity, are deemed to be viable options based on the evaluation. To achieve better air quality in the city of Nis, the obtained results could be used as guidelines for improving current and future traffic development strategies.

5 Conclusions

Understanding the complexity of urban transportation is often lacking, leading to an underestimation of its impact in urban areas. Transportation planning should not only aim for an efficient transport system but also the creation of modern cities with high-quality living standards, including clean air. Introducing new vehicles with suitable alternative energy sources is crucial for achieving this goal, especially considering the significant pollution generated by public city transport vehicles, making the transition particularly effective in city bus fleets.

UPPT offers transport services under predetermined and known operating conditions, playing a crucial role in addressing traffic congestion, especially in central city areas. The bus subsystem of UPPT is the most prevalent technology in passenger transport, typically powered by conventional fossil fuels or alternative sources such as natural gas, renewable biofuels, and hydrogen.

The bus subsystem encompasses a diverse range of vehicles with varying capacities and performance characteristics, including propulsion energy type, engine, transmission, ergonomic elements, and body, tailored to meet specific transport requirements, city morphology, route type, and desired service quality.

This paper conducts a multi-criteria analysis of various UPPT subsystems, including buses with conventional diesel engines and alternative propulsion systems, as well as trolleybuses and trams. Alternative bus propulsion options considered include natural gas, biofuels, diesel-electric hybrids, electric, and hydrogen. Evaluation criteria include energy supply, efficiency, noise, technical characteristics, investment and maintenance costs, domestic industry involvement, and air pollution, with the EDAS method identifying electric-powered buses as the most favorable option. However, due to technical limitations such as the need for frequent recharging, alternative solutions like hybrid buses and trams hold significant importance for immediate solutions.

Since the White Paper recommends gradually removing vehicles with conventional fuels from urban areas, the results of the research can help decision-makers at the local level when choosing adequate technology for buses to achieve sustainable development and sustainable traffic. Future research directions will be focused on defining and taking into account more complex criteria, as well as the use and comparative analysis of a larger number of multi-criteria methods.

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Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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