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Evaluating the appropriate fuel-based bus technology in Indian context by integrating Fuzzy AHP-Fuzzy TOPSIS

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Abstract

According to WHO, India's transportation sector accounts for 11% of its CO_2 emissions. Sustainable energy-based bus transportation systems are a necessity in Indian context. However, factors like capital cost, refueling infrastructure, etc. are also important as most State Road Transport Undertakings (SRTUs) are operating in severe losses. This study evaluates the most effective fuel-based bus transport system in the Indian context through the comparative analysis of electric buses, hydrogen fuel cell buses, compressed natural gas (CNG) buses, and conventional diesel buses. Multiple criteria decision making (MCDM) approach was employed through the use of Fuzzy AHP-Fuzzy TOPSIS tool. Electric buses were found to be the best alternative, and the stakeholders placed less importance on noise levels and rated the initial cost of buying a bus, tailpipe emissions, and operating costs as major determining parameters. The findings may help national and state-level decision-making agencies in planning for the future sustainable bus systems.

Keywords: Fuel based bus system; MCDM; Fuzzy AHP; Fuzzy TOPSIS; Emissions.

1. Introduction

The efficiency of an economy's transportation system determines its ability to operate. The dependence on petroleum in transport sector poses significant environmental concerns (Sharma and Chandel, 2020). To achieve the sustainable development goals (SDGs), India is focusing heavily on sustainable urban transportation. At present, the transport sector accounts for almost 11% of India's CO_2 emissions (Singh, 2019). To reduce such externalities, alternative and suitable fuel technologies must be introduced into urban transport systems. Developing an electric or hydrogen-based fuel system for India's urban bus transport is a significant and necessary step (Sontakke and Jaju, 2021). Shifting to electric or hydrogen fuel-powered buses has the major advantage of negligible tailpipe emissions. Furthermore, sustainable fuel cell buses have lower operating costs per km and are quieter than conventional diesel or CNG buses. However, there are

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challenges associated with implementing these changes. Since their capital cost and corresponding refueling infrastructure are expensive, it makes difficult for State Road Transport Undertakings (SRTUs) to adopt them fully. In the pre-COVID scenario, most of the SRTUs were suffering heavy financial losses, and the situation has further degraded during the COVID-19 pandemic. The cost of purchasing one electric or hydrogen fuel cell bus is almost three and ten times that of a CNG and a diesel-powered bus respectively (Deliali et al., 2021). To achieve Sustainable Development Goals (SDGs) and sustainable growth, an optimistic point of view needs to be taken towards electric and hydrogen buses.

With the introduction of electric and hydrogen fuel cell buses in India, fuel consumption and carbon emissions will be reduced dramatically. Hence, it is imperative to shortlist the various performance parameters, analyse their relative importance in the Indian context, and undertake a comparative study to analyse which alternative is most appropriate for the Indian scenario. In recent years, multiple-criteria decision-making (MCDM) has become one of the major tools used by researchers when tackling complex decision-making issues (Güner, 2018). Among the most common techniques for multiple criteria decision-making are Fuzzy AHP and Fuzzy TOPSIS. In this kind of decision-making research, Fuzzy Analytical Hierarchy Process (AHP) and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) may be applied. The present study attempts to compare all the four available alternatives (diesel engines, CNG fuel buses, electric buses, and hydrogen fuel cell buses) using fuzzy decision-making methods (Fuzzy AHP and Fuzzy TOPSIS) based on the viewpoints and knowledge of stakeholders from various organizations in India. The integration of Fuzzy AHP with Fuzzy TOPSIS will lead to a ranking-based assessment that will help identify fuel-based bus technology appropriate for the Indian context.

The rest of the paper is organized as follows: Section 2 deals with the review of existing studies relevant with the topic under consideration and highlights the research objectives; Section 3 emphasizes on study methodology; Section 4 presents the data analysis and outcomes obtained in the present study; Section 5 discusses the study findings and reports the key conclusions obtained from the study; and lastly, Section 6 lists out the study limitations and directions for future research.

2. Literature review

Numerous researchers have examined the viability and effectiveness of different public transportation services running on various types of fuel (Frenzel et al., 2021; Trencher and Edianto, 2021; Thorne et al., 2021; Stempien and Chan, 2017; Seki, 2017; Logan et al., 2020). A recent study found that acceptance of electric vehicles (EVs) depends on fuel usage, information about secondary effects, and long-term trends of politically supported transport innovations (Frenzel et al., 2021). Trencher and Edianto (2021) conducted a similar study in Germany to identify and compare the factors affecting the production and market penetration of privately-owned fuel cell electric passenger vehicles (FCEVs) and fuel cell electric buses (FCEBs) in public transit fleets. Based on the same study, it was found that the hydrogen mobility market, even though it has multiple drivers, faces significant challenges. Factors such as labour cost, production quantity, accessibility to refueling stations, and low demand for vehicles are impeding fuel cell electric passenger vehicles (FCEV) production in Germany (Trencher and Edianto, 2021). Further, Thorne et al. (2021) investigated the factors affecting the adoption of electric buses in Norway. The study concluded that while the private sector is willing to support innovation, the role played by government authorities in planning and facilitating fast-charging infrastructure is crucial (Thorne et al., 2021). Moreover, Stempien and Chan (2017) compared hydrogen fuel cell buses and fuel cell electric buses with internal combustion diesel buses, natural gas buses, and battery hybrid electric buses. Their findings indicated that CNG and Hybrid electric buses are the cheapest alternatives in terms of cost of ownership. Another comparative study by Seki (2017) concluded that electric buses have low life cycle costs and high environmental benefits when compared to conventional diesel buses, diesel hybrid electric buses, CNG and LPG buses. Furthermore, Logan et al. (2020) investigated the possibility of introducing hydrogen and electric fuel cells in the United Kingdom (UK) and found that electric buses emit lower levels of cumulative carbon dioxide emissions than hydrogen buses and suggested promoting an integrated electric bus system for reducing carbon footprints in the UK.

The Government of India (GoI) has announced several initiatives to promote the use of electric vehicles (EVs) (Kumar and Chakraborty, 2020) and a few studies have considered the impact of introducing electric buses. SIAM (2019) analysed the growth pattern and impact of alternate fuel cell buses in India with the goal of reducing energy intensity by 35% by 2030, a goal set by the Government of India, and suggested diversification fuel along with fleet electrification. Sheth and Sarkar (2021) conducted a Social Benefit-Cost Analysis (SBCA) in Ahmedabad and found that the electric bus rapid transit system (e-BRTS) offers tangible societal benefits. Saini and Sarkar (2018) explored the feasibility of introducing electric buses in Delhi and suggested strategies for promoting e-buses, such as electricity subsidization, bus cost reduction initiatives, fare increases, and solar charging. Based on their study, Singh et al. (2021) concluded that electric vehicles can reduce air pollution and carbon emissions significantly, and suggested EV adoption will be driven by charging infrastructure, local battery production facilities, and Indian policy. Sharma and Chandel (2020) concluded that EVs may reduce air pollution most when they operate on more efficient batteries charged from renewable energy sources, as CO_2 emissions drop by at least 29% across all vehicle classes additionally, and concluded that by 2050, EVs could achieve CO_2 emission reductions of 14–100% if the electricity is generated from renewable resources significantly. Yet, based on the available literature, it is evident that none of the existing studies has included hydrogen fuel cell buses and compared them to their counterparts within the context of India. The present study attempts to compare all four available alternatives (diesel engines, CNG fuel buses, electric buses, and hydrogen fuel cell buses) using fuzzy decision-making methods (Fuzzy AHP and Fuzzy TOPSIS) based on the viewpoints and knowledge of stakeholders from various organizations, which is a major contribution to the state-of-the-art.

The application of integrating Fuzzy AHP-Fuzzy TOPSIS has been quite extensively used in various performance evaluation models (Güner, 2018; Kishore and Padmanabhan, 2016; Soltani et al., 2013). Güner (2018) employed a two-stage analysis model incorporating an Analytic Hierarchy Process (AHP) and a Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for assessing the quality of public transportation. Kishore and Padmanabhan (2016) applied the same approach for selecting the most optimal logistics service provider for transportation-related and prioritizing road maintenance. In another study, Soltani et al. (2013) evaluated bus route performance using the same technique.

2.1 Research gaps and contributions

Decarbonisation or urban transport system in India is imperative in order to achieve the sustainable development goals. In last few years, city authorities and urban planning experts in India have emphasized on vehicles operating from alternate fuels like electric vehicles. In this regard, a lot of studies on Indian context have been performed to assess the viability and benefits of switching towards electric vehicles. However, majority of the studies have only focussed on decarbonisation of private transportation and passenger modes have been left out. However, urban bus transport system in Indian cities have significant mode share and also contribute to air pollution, especially when they are stuck in traffic jams because of high congestion. To mitigate this, it is imperative to shift urban bus transport system from fossil fuel dependent to renewable energy dependent.

Yet, before deciding, it is prudent also consider and evaluate the performance factors of the urban bus transport system in India in order to determine whether or not they are ideal substitutes. The present study is the first of its kind that intends to fill this gap by performing a comparative study on four types of fuel cell buses (ICE engine buses, CNG engine buses, Electric fuel cell buses, and Hydrogen fuel cell buses) based on the performance parameters of urban bus transport system in India. The study findings can be useful for city bus authorities and STUs to determine which type of fuel-based bus technology to adopt based on resources and needs and can assist policymakers in developing a framework to promote the use of sustainable fuel technology-based buses in India.

From the comprehensive literature review, it can be concluded that several researchers have attempted to analyze the effectiveness of different public transportation services running on various types of fuel in global context, however, there is a dearth of similar studies in context of developing countries like India. Additionally, the application of MCDM approach has been extensively applied and found to be quite effective in the field of transport planning. The present study attempts to fill a gap in the literature by assessing the relative importance of parameters affecting the performance of buses operating on different fuel technologies in India, and identifying the most appropriate fuel technology for bus transportation using MCDM approach.

3. Method

The present study follows a systematic methodology for ranking the alternatives based on the chosen parameters (Figure 1). The primary step for approaching such studies is the selection of attributes or parameters. An extensive literature review was conducted to identify the factors that determine bus performance in urban areas. The State Road Transport Undertaking reports of India, published by the Central Institute of Road Transport (CIRT) specify occupancy, capital cost, operating cost as major performance parameters governing the performance of urban bus transport system. Gadepalli and Rayaprolu (2020) identified driving range, seating capacity, and capital cost as major parameters influencing the bus transport performance. Whereas, Zhu et al. (2016) weighed on environmental parameters (noise pollution, air pollution) and suggested them as a key determinant as performance measure parameters.

After the identification of factors, stakeholder discussions were conducted to obtain the data of pairwise relative importance for each of the selected parameters against the other parameters (Barabino et al., 2011). A total of 37 stakeholders from concerned authorities were asked to participate in the data collection process, but only 28 of them responded. After the construction of pair-wise comparison matrix for determining the weight of each criterion or parameter, estimation of fuzzy geometric mean and weight determination of criteria was carried out. The results from the Fuzzy-AHP indicated the stakeholder have highly weighted capital cost and tailpipe emissions for the selection of optimal fuel-based bus transport system, while noise pollution and occupancy have the least weight assigned. To rank the four selected alternatives using Fuzzy-TOPSIS, the initial step was to construct decision matrices. For constructing a combined decision matrix, stakeholders were asked to assign the rank to all four alternatives from ‘very low’ to ‘very high’ on a five-point scale based on their knowledge and perception of how well each of the four alternatives performs with regard to selected parameters. The obtained decision matrix for all the 28 stakeholders was then combined to form a combined decision matrix. The combined decision matrix was then standardized, and the weights obtained by performing Fuzzy-AHP were assigned which were then used for the construction of the ideal positive and negative solutions. With the use of ideal positive and negative solutions, calculation of closeness coefficients was carried out and finally, all the four alternatives were ranked. Figure 1 illustrates the stated method, where steps indicated in orange color are a part of Fuzzy AHP while steps in yellow are a part of Fuzzy TOPSIS technique. Additionally, in order to check the consistency in opinion and agreement among stakeholders, Kendall’s concordance test was performed.

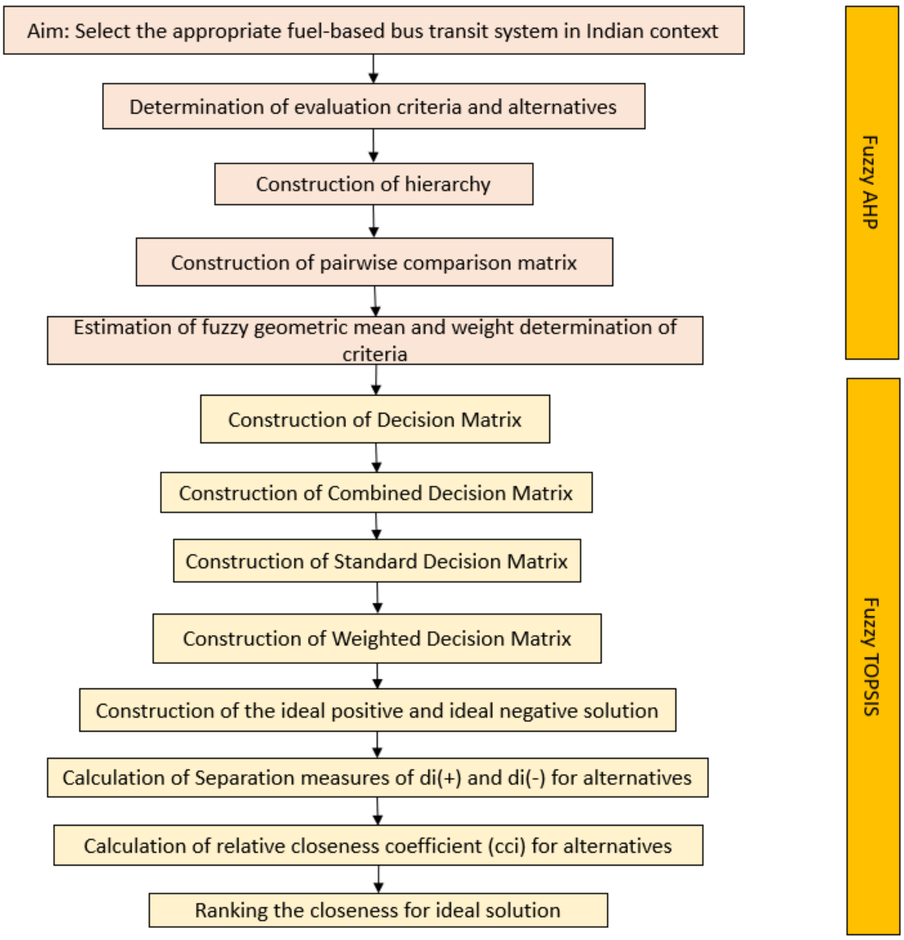

Figure 1: Study methodology

The Kendall coefficient of concordance (W) measures the degree of agreement among multiple expert groups non-parametrically (Dobrovolskienė & Tamošiūnienė, 2016). Kendall's concordance test is calculated as (Patel & Patel, 2020).

$$W = \frac{12\,S}{m^3(n^3-n)} \quad (1)$$

where W represents Kendall's coefficient of concordance, S is the sum of deviation of rank mean, m is the number of experts and n is the number of criteria. The standard values for testing the agreement of decision makers in Kendall's Concordance test is given as (0: No agreement ; 0.1: Weak agreement ; 0.3: Moderate agreement; 0.6: Strong agreement; and 1: Perfect Agreement) (Duleba & Moslem, 2018; Patel & Patel, 2020).

4. Analysis and results

4.1 Fuzzy-AHP

The analytic hierarchy process was proposed by Saaty (1990). While AHP is one of the widely used MCDM techniques, it only considers crisp numbers (e.g., 1–10), which is one of its major limitations (Helmy, 2021). For overcoming such a problem, Fuzzy AHP was developed in which Experts adopt natural linguistic terms (e.g., equally important, weakly important) to express their judgments in fuzzy AHP (Dang et al., 2019). The Fuzzy AHP method using geometric mean was proposed by Buckley in 1985. The performance and deciding parameters were finalized based on the discussion with the stakeholders. The stakeholders were considered from Bhopal city link limited (BCLL), other SRTUs, City Municipal Corporations, Academicians, and Scholars. A nine-rating scale of relative importance was used to fuzz the responses. The experts were asked to respond in linguistic terms (equal importance, strong importance, etc.), as depicted in Table 1.

Table 1: Scale of relative importance

Scale of relative Importance		Fuzzy Triangular Scale
1	Equal Importance	(1,1,1)
3	Moderate Importance	(2,3,4)
5	Strong Importance	(4,5,6)
7	Very Strong Importance	(6,7,8)
9	Extreme Importance	(9,9,9)
2, 4, 6, 8	Intermediate Values	(1,2,3), (3,4,5), (5,6,7), (7,8,9)
1/3, 1/5, 1/7, 1/9	Values for Inverse Comparison	

The following steps were performed to estimate the weight of parameters using fuzzy logic:

Step 1: Determination of evaluation criteria and alternatives

As deciding performance parameters, approximate refueling time in minutes (P1), approximate range in km (P2), cost of operation in cost/km (P3), Occupancy rate (P4), Average capital cost of one unit in lakhs (P5), Noise levels in terms of acceleration and deceleration sound in dB (P6), and tailpipe emissions (P7) were adopted from stakeholder discussions. Four alternatives were finalized namely, electric bus, hydrogen fuel cell bus, CNG engine bus, and diesel bus.

Step 2: Construction of hierarchy

Under this step, a hierarchy was constructed for establishing the relationship between chosen parameters with different alternatives (Figure 2).

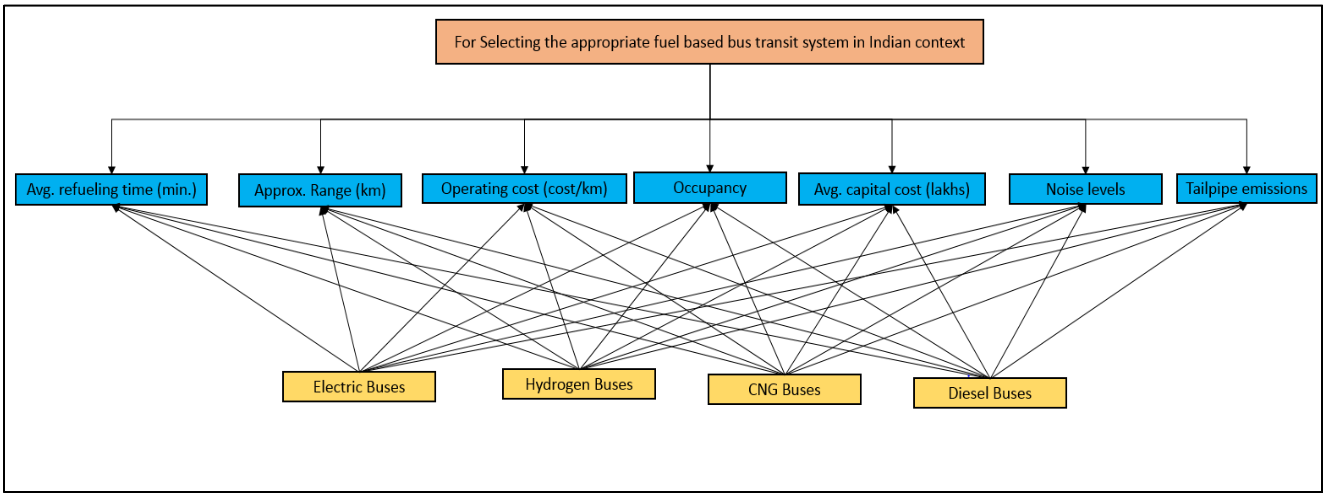

Figure 2: Bus transit transport deciding performance parameters

Step 3: Construction of pairwise comparison matrix

In this step, the fuzzy importance level is determined for linguistic variables, as shown in Table 2. The criteria are compared in a pairwise manner with the help of linguistic variables. The importance of one criterion over the other was unanimously determined after the stakeholder's discussion. The pairwise matrix helps in understanding the priority sensitivity for changes in consideration (Dang, 2019). The equation used for creating pairwise comparison matric is as follows:

$$\widetilde{A}^{k} = \begin{bmatrix} \widetilde{d_{11}}^{k} & \widetilde{d_{12}}^{k} & \cdots & \widetilde{d_{ij}}^{k} & \widetilde{d_{1n}}^{k} \\ \vdots & & \ddots & \vdots & \\ \widetilde{d_{n1}}^{k} & \widetilde{d_{n2}}^{k} & \cdots & \widetilde{d_{in}}^{k} & \widetilde{d_{nn}}^{k} \end{bmatrix} \tag{2}$$

Here, $\tilde{d}_{ij}{}^{k}$ represents the kth decision maker prefers criterion i over criterion j. A pairwise comparison matrix for all criteria based on several decision makers is shown as follows:

$$\widetilde{A} = \begin{bmatrix} \tilde{d}_{11} & \cdots & \tilde{d}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{d}_{n1} & \cdots & \tilde{d}_{nn} \end{bmatrix} \tag{3}$$

$$\text{where } \tilde{d}_{ij} = \frac{\Sigma_{k=1}^{k} \tilde{d}_{ij}^{k}}{K} \tag{4}$$

Table 2: Pairwise comparison matrix

Parameters	P1	P2	P3	P4	P5	P6	P7
P1	(1,1,1)	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1,2,3)	(1/8, 1/7, 1/6)	(2,3,4)	(1/7, 1/6, 1/5)
P2	(2,3,4)	(1,1,1)	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1/7, 1/6, 1/5)	(3,4,5)	(1/6, 1/5, 1/4)
P3	(1,2,3)	(2,3,4)	(1,1,1)	(2,3,4)	(1/6, 1/5, 1/4)	(4,5,6)	(1,1,1)
P4	(1/3, 1/2, 1)	(1,2,3)	(1/4, 1/3, 1/2)	(1,1,1)	(1/5, 1/4, 1/3)	(4,5,6)	(1/3, 1/2, 1)
P5	(6,7,8)	(5,6,7)	(4,5,6)	(3,4,5)	(1,1,1)	(9,9,9)	(2,3,4)
P6	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1/9, 1/9, 1/9)	(1,1,1)	(1/6, 1/5, 1/4)
P7	(5,6,7)	(4,5,6)	(1,1,1)	(1,2,3)	(1/4, 1/3, 1/2)	(4,5,6)	(1,1,1)

Step 4: Estimation of fuzzy geometric mean and weight determination of criteria

In this step, the fuzzy geometrical means are created and fuzzy weights for each criterion are evaluated using the geometrical mean technique (Dang et al., 2019):

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{1/n}, i = 1,2, \dots \dots, n \quad (5)$$

Here, $\tilde{r}_i$ represents the fuzzy geometrical mean, and $\tilde{d}_{ij}$ signifies the decision makers' preference for the *i*th over the *j*th criteria. To evaluate the fuzzy weights, the following formula is adopted (Dang et al., 2019):

$$\widetilde{w}_i = \tilde{r}_i \times (\tilde{r}_1 + \tilde{r}_2 + \cdots + \tilde{r}_n)^{-1} \quad (6)$$

where $\widetilde{w}_i$ depicts the fuzzy weight of the criteria.

The estimated fuzzy weights are being applied in Fuzzy TOPSIS for ranking of alternatives. The geometric means of the selected parameters and their fuzzy weights are depicted in Table 3.

Table 3: Geometric mean and fuzzy weight of selected parameters

Parameters	Fuzzy Geometric Mean	Fuzzy Weights
Approximate Refueling Time	(0.43, 0.53, 0.79)	(0.034, 0.053, 0.099)
Approximate Range	(0.50, 0.64, 0.90)	(0.039, 0.065, 0.110)
Cost of Operation/km	(1.15, 1.51, 1.84)	(0.091, 0.153, 0.232)
Occupancy	(0.58, 0.79, 1.16)	(0.046, 0.080, 0.146)
Average Capital Cost of One Unit	(3.50, 4.19, 4.82)	(0.270, 0.425, 0.609)
Noise Levels	(0.22, 0.25, 0.31)	(0.017, 0.025, 0.035)
Tailpipe Emissions	(1.53, 1.93, 2.73)	(0.121, 0.196, 0.345)

4.2 Kendall’s Concordance Test

As the significance value for Kendall's W test was less than 5%, the null hypothesis was rejected. Moreover, Kendall's coefficient of concordance (W) was above 0.6, indicating a high degree of agreement between the experts. The proximate value obtained from Kendall’s W test was 0.642.

4.3 Fuzzy TOPSIS

Developed by Hwang and Yoon in 1981, TOPSIS works on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS). As the parameters or criteria are often of incongruous dimensions in multi-criteria problems it may create problems in evaluation. To avoid this issue, a Fuzzy system is necessary. For ranking different alternatives based on shortest and farthest distances from positive ideal and negative ideal solutions, Fuzzy TOPSIS is used. Fuzzy TOPSIS works based on the following steps:

Step 1 & 2: Construction of decision matrix and combined decision matrix

In the present study, there are 4 alternatives and 7 criteria that were ranked by using fuzzy TOPSIS. A total of 28 stakeholders were considered for the construction of the combined decision matrix. Each of the stakeholders responded on the relative importance of each parameter against one another in linguistic terms. A five-point linguistic scale (from very low to very high) was used as a reference used to convert linguistic terms into fuzzy values, as depicted in Table 4.

Table 4: Conversion scale of linguistic terms to fuzzy numbers

Scale	Fuzzy Number
Very Low	1,1,3
Low	1,3,5
Moderate	3,5,7
High	5,7,9
Very High	7,9,9

After collecting the responses from each of the 28 stakeholders, a combined decision matrix was constructed. Equal importance was given to each decision-maker as illustrated in Table 5.

Table 5: Combine decision matrix

Alternatives	P1	P2	P3	P4	P5	P6	P7
Hydrogen Fuel Cell Buses	(1, 3, 5)	(5, 7, 9)	(1, 3.4, 7)	(1, 4.6, 7)	(7,9,9)	(1,1,3)	(1,1,3)
Electric Battery Buses	(5, 8.2, 9)	(1, 4.6, 7)	(1, 1, 3)	(3, 5, 7)	(3, 6.6, 9)	(1,1,3)	(1,1,3)
CNG Buses	(1, 3, 5)	(3, 5.4, 9)	(3, 5.4, 9)	(3, 5, 7)	(3, 5, 7)	(5, 8.2, 9)	(5, 5.4, 9)
Diesel Buses	(1, 3, 5)	(5, 7.4, 9)	(5, 7.4, 9)	(3, 5, 7)	(3, 5, 7)	(7,9,9)	(7,9,9)

Step 3: Construction of standard decision matrix

After the construction of the combined decision matrix, normalized matrix construction was the next step, as shown in Table 6. The parameters were categorized into beneficial

and non-beneficial categories for further calculation. Approximate refueling time, Cost of operation (Cost/km), Average capital cost of one unit, Noise levels and Tailpipe emissions (CO_2) were classified as non-beneficial criteria (a_{j-}), while Approximate range (km) and Occupancy was classified as beneficial criteria (c_{j*}).
A standard decision matrix was constructed with the help of the following equations (Ansari et al., 2020):

$$R_{ij} = \left(\frac{a_{ij}}{c_{j*}}, \frac{b_{ij}}{c_{j*}} \dots\dots\right);\ c_{j*} = \max i\ c_{ij};\ \text{Positive ideal solution} \quad (7)$$

$$R_{ij} = \left(\frac{a_{j-}}{c_{ij}}, \frac{a_{j-}}{b_{ij}} \dots\dots\right);\ a_{j-} = \min i\ a_{ij};\ \text{Negative ideal solution} \quad (8)$$

Table 6: Value of beneficial and non-beneficial criteria

Alternatives	P1	P2	P3	P4	P5	P6	P7
Hydrogen Fuel Cell Buses	(1/5, 1/3, 1)	(5/9, 7/9, 9/9)	(1/7, 1/3.4, 1)	(1/9, 4.6/9, 7/9)	(3/9, 3/9, 3/7)	(1/3, 1 ,1)	(1/3, 1, 1)
Electric Battery Buses	(1/9, 1/8.2, 1/5)	(1/9, 4.6/9, 7/9)	(1/3, 1, 1)	(3/9, 5/9, 7/9)	(3/9, 3/6.6, 1)	(1/3, 1, 1)	(1/3, 1, 1)
CNG Buses	(1/5,1/3,1)	(3/9, 5.4/9, 9/9)	(1/9, 1/5.4, 1/3)	(3/9, 5/9, 7/9)	(3/7, 3/5, 1)	(1/9, 1/8.2, 1/5)	(1/9, 1/5.4, 1/5)
Diesel Buses	(1/5,1/3,1)	(5/9, 7.4/9, 9/9)	(1/9, 1/7.4, 1/4)	(3/9, 5/9, 7/9)	(3/7, 3/5, 1)	(1/9, 1/9, 1/7)	(1/9, 1/9, 1/7)
	Aj- = 1	Cj*= 9	Aj- = 1	Cj*= 9	Aj- = 3	Aj- = 1	Aj- = 1

Step 4, 5, and 6: Construction of weighted decision matrix, construction of weighted decision matrix for fuzzy positive and negative ideal solution

The weighted decision matrix was formed using the weighted obtained from Fuzzy AHP, as depicted in Table 7. The formula for construction of weighted matrix is as follows:

$$v_{ij} = r_{ij^*} \times w_{ij} \quad (9)$$

where w_{ij} represents the weight of criteria c_j.

Table 7: Weighted decision matrix

Alternatives	P1	P2	P3	P4	P5	P6	P7
Hydrogen Fuel Cell Buses	(0.0068, 0.017, 0.099)	(0.021, 0.053, 0.11)	(0.012, 0.043, 0.23)	(0.005, 0.044, 0.112)	(0.089, 0.140, 0.255)	(0.0056, 0.025, 0.035)	(0.039, 0.196, 0.345)
Electric Battery Buses	(0.0037, 0.0063, 0.019)	(0.0042, 0.033, 0.084)	(0.030, 0.15, 0.23)	(0.015, 0.044, 0.112)	(0.089, 0.19, 0.609)	(0.0056, 0.025, 0.035)	(0.039, 0.196, 0.345)
CNG Buses	(0.0068, 0.017, 0.099)	(0.012, 0.053, 0.11)	(0.012, 0.027, 0.076)	(0.015, 0.044, 0.112)	(0.11, 0.255, 0.609)	(0.0018, 0.003, 0.007)	(0.013, 0.035, 0.069)
Diesel Buses	(0.0068, 0.017, 0.099)	(0.021, 0.053, 0.11)	(0.012, 0.019, 0.057)	(0.015, 0.044, 0.112)	(0.11, 0.255, 0.609)	(0.0018, 0.0027, 0.0049)	(0.013, 0.021, 0.048)
Fuzzy Positive Ideal Solution	(0.0068, 0.017, 0.099)	(0.021, 0.053, 0.11)	(0.03, 0.15, 0.23)	(0.015, 0.044, 0.112)	(0.11, 0.255, 0.609)	(0.0056, 0.025, 0.035)	(0.039, 0.196, 0.345)

Alternatives	P1	P2	P3	P4	P5	P6	P7
Fuzzy Negative Ideal Solution	(0.0037, 0.0063, 0.019)	(0.0042, 0.033, 0.084)	(0.012, 0.019, 0.057)	(0.005, 0.044, 0.112)	(0.089, 0.140, 0.255)	(0.0018, 0.0027, 0.0049)	(0.013, 0.021, 0.048)

The FPIS and FNIS of the alternatives can be defined as follows:

$$A^* = \{v_{1^*}, v_{2^*}, \dots \dots \dots, v_{n^*}\} = \{(max_j\ v_{ij}\ \ , i\ \varepsilon\ B), (min_j\ v_{ij}, i\ \varepsilon\ C)\} \quad (10)$$

$$A^- = \{v_{1^-}, v_{2^-}, \dots \dots \dots, v_{n^-}\} = \{(max_j\ v_{ij}\ \ , i\ \varepsilon\ B), (min_j\ v_{ij}, i\ \varepsilon\ C)\} \quad (11)$$

where v_i* is the max value of i for all the alternatives and v_1^- is the min value of i for all the alternatives. B and C represent the positive and negative ideal solutions, respectively, as depicted in Table 8 and Table 9.

Table 8: Weighted decision matrix for fuzzy positive ideal solution

Alternatives	P1	P2	P3	P4	P5	P6	P7	Di+
Hydrogen Fuel Cell Buses	0	0	0.062	0.0057	0.21	0	0	0.2777
Electric Battery Buses	0.045	0.02	0	0	0.036	0	0	0.101
CNG Buses	0	0.0051	0.018	0	0	0.02	0.19	0.2331
Diesel Buses	0	0	0.12	0	0	0.021	0.19	0.331

Table 9: Weighted decision matrix for fuzzy negative ideal solution

Alternatives	P1	P2	P3	P4	P5	P6	P7	Di-
Hydrogen Fuel cell buses	0.046	0.018	0.1	0	0	0.2	0.19	0.554
Electric Battery Buses	0	0	0.12	0.011	0.2	0.2	0.19	0.721
CNG Buses	0.046	0.019	0.01	0.011	0.21	0.0012	0.014	0.3112
Diesel Buses	0.046	0.019	0	0.011	0.21	0	0	0.286

Step 7 & 8: Calculation of relative coefficient and ranking for alternatives and ranking the closeness

As shown in Table 10, the distance between each alternative and FPIS and the distance between each alternative and FNIS are respectively calculated as follows:

$$S_{i^*} = \Sigma_{j=1}^{n}\ d\left(v_{ij}, v_{j^*}\right)\ i = 1,2, \dots \dots, m \quad (12)$$

$$S_{i^-} = \Sigma_{j=1}^{n}\ d\left(v_{ij}, v_{j^-}\right)\ i = 1,2, \dots \dots, m \quad (13)$$

where d is the distance between two fuzzy numbers. With given two triangular fuzzy numbers (a1, b1, c1) and (a2, b2, c2), the distance between the two can be calculated as follows:

$$d_y(M1, M2) = Sq.root\,\{\tfrac{1}{3}\ [a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]\} \quad (14)$$

where d(v_{ij}, v_j*) and d(v_{ij}, v_j^-) are crisp numbers.
The closeness coefficient of each alternative can be calculated as follows:

$$CC_i = \frac{S_i-}{S_i+ \ + \ S_i-} \tag{15}$$

where S_i- is the negative closeness coefficient and S_i+ is the positive closeness coefficient.

Table 7: Calculation of relative coefficient and ranking of alternatives

`	Di+	Di-	CC_i	Rank
Hydrogen Fuel Cell Buses	0.277	0.554	0.67	2
Electric Battery Buses	**0.101**	**0.721**	**0.88**	**1**
CNG Buses	0.233	0.311	0.57	3
Diesel Buses	0.331	0.286	0.46	4

5. Discussion and conclusions

The present study aimed to find out the most suitable or optimal fuel technology for buses in Indian cities. In response to the viewpoints of several stakeholders, weights were given to all selected 7 parameters based on a fuzzy AHP and fuzzy TOPSIS methodology, and then the 4 alternatives were ranked based on how well they matched the parameters. The results obtained from the presents study will aid the policy makers and urban planners in determine the physical performance parameters that needs to be evaluated for identifying the most appreciate fuel based bus system a concerned city, which type of fuel buses are most appropriate of Indian context based on the existing scenario, and what are the issues and lacunas that need to be addressed in case a city authority is interested to introduce electric buses. Even though, several researchers have studied the viability of introducing alternate fuel cell buses, most of these studies have been performed in the case of developed countries. Additionally, the present study is first of its kind to perform a comparative analysis among hydrogen fuel cell, electric battery, CNG and Diesel buses to assess their appropriateness for various parameters.

While analyzing the results of the Fuzzy AHP, it was found that stakeholders placed more weight on capital costs, tailpipe emissions, and operating costs. The observations drawn from the stakeholders' responses are well aligned with research done by various researchers suggesting that more emphasis should be placed on reducing vehicular pollution. According to NITI AAYOG, buses account for 65% of all vehicle pollution in major Indian cities (Sharma, 2018). This makes reducing carbon emissions from the transport sector crucial. Moreover, the reduction of carbon footprints is paramount for the urban bus transport systems (Quarmby, 2019). Several other researchers have emphasized the importance of capital cost and operating cost of buses for evaluating their performance measures (Gadepalli and Rayarprolu, 2020). Moreover, as per the annual statistical handbook published by the government of India, operating cost and capital cost are deterministic parameters for assessing the performance of the bus system (CIRT, 2017-18).

As determined through Fuzzy TOPSIS, electric buses proved to be the best alternative. When compared to diesel and biogas powered buses, electric buses offer significant savings in societal cost and total cost of ownership, mainly due to decreased noise, no emissions while in use, and decreased energy costs (Borén, 2020). The shift towards electrification for passage and freight transportation has been emphasized by various researchers around the world (Dhonde & Patel, 2020; Doundoulakis et al., 2022; Fistola et al., 2021; Borghetti et al., 2022). In the study by Sharma and Chandel (2020), they concluded that EVs may reduce air pollution most when they operate on more efficient batteries charged from renewable energy sources, as CO_2 emissions will drop by at least 29% across all vehicle classes additionally, and by 2050, EVs could achieve CO_2 emission reductions of 14–100% if the electricity is generated from renewable resources significantly. Furthermore, Todorut et al. (2020) found that replacing diesel buses with electric buses would result in 2.6 times less CO_2 production. In another study performed in Italy for identifying and selecting key sustainable parameters for the monitoring of e-powered micro personal mobility vehicles, charging infrastructure was found to be most critical aspect of electric vehicle (Carrara et al., 2021).

Although, high charging time, mediocre range, lack of charging infrastructure, and high initial cost are some of the major issues related to their efficient implementation in the Indian context, the other parameters such as low noise and tailpipe emissions, very low operating cost due to low maintenance with significantly less moving parts, are some of the advantages it has over CNG or diesel engine buses, while in the case of hydrogen fuel cell buses, the initial cost can be as much as 10 times more than a CNG or Diesel bus and 4-5 times more than an electric bus. Presently, the Indian government has policies under the Faster Adoption and Manufacturing of (Strong) Hybrid and Electric Vehicles (FAME) scheme, which provides a subsidy of 60% of purchase cost or INR 85 lakhs (whichever is lower) to SRTUs on the purchase of electric buses, while there is no such incentive for operating hydrogen fuel cell buses (Inclusion of e-bus in fame India scheme 2017). The future of India appears to be electric vehicles, and for a smooth shift to them, the issues like charging infrastructure, travel range, and capacity building need to be addressed. Moreover, the source of generating electricity needs to be given a thought as currently most of the electricity in the Indian context is fossil fuel driven.

6. Limitations and future research scope

In the present study, an attempt was made to identify the influence of selected parameters on the performance evaluation of bus systems and to determine the appropriate fuel technology-based bus system in the Indian context. Since this is a qualitative study, a total of 37 stakeholders or experts were approached, and 28 of their responses were positive. Considering that the bus system in India is a matter of concern for various experts and the public, future studies including a higher number of stakeholders will improve the generalizability of the study findings. Moreover, the present study evaluated the performance of bus technology based on seven parameters gathered from the state-of-the-art and stakeholder discussions. Nevertheless, there can be more physical and financial factors that may influence the feasibility and choice of which fuel-based bus technology is best to be used. Additionally, in the present study, equal weightage was given to each stakeholder for the development of the combined decision matrix. However, in the real world, the experience, knowledge, and awareness of each expert may vary. Furthermore, future studies can also adopt various other service performance parameters such as service reliability, route characteristics, driver’s behavior, and on-board comfort for comparative assessment (Carrara et al., 2021). Future works can also focus on utilizing the application of Électre family based multi-criteria decision analysis (MCDA) methods for considering the inclusion of quantitative parameters (value of investments for each fuel alternative, values of operation costs, etc.) for assessment.

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