The Adoption of Electric Buses in Transit; A Multi-Criteria Analysis of Transit Providers' Preference

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Abstract

Transit is always considered a suitable target to considerably decarbonize the transportation sector. The nature of bus transit operation, with fixed routes and timely schedules, offers a suitable setting to utilize electric powertrain technology. However, it is evident in the literature that there is a lack of research that investigates the willingness, or lack thereof, of service providers to adopt electric bus technology. Even though they are at the forefront of the procurement, operation, and the maintenance of e-Buses.

This study contributes to address this gap and provides evidence on the perspectives of transit providers in Canada as it relates to the implementation of the electric bus in the transit context. Toward that end, this study employs the Analytical Hierarchy Process (AHP) model to quantify the relative importance of five main categories and 20 attributes that are thought to govern the perspective of transit providers.

The initial results indicate the operational feasibility of the electric bus is the keystone for the transit providers, which is followed by the financial feasibility of the e-Bus in transit. That said, operational feasibility is by far the dominating factor for the adoption of e-Bus. In particular, the results indicate that both operational availability (range & charging time), and operational flexibility are the significant contributing attributes to the adoption of e-Bus in transit. Overall, this study provides blueprints for both policy makers and transit industry to develop a feasible business case for e-Bus adoption in transit.

Keywords

Ground Theory, Analytical Hierarchy Process, Electric Bus, Decision-making process

1 Introduction

Public transit is always considered a cornerstone in our modern society, it contributes to social inclusion and it is an indicator of social welfare and economic development in many countries (Kamruzzaman et al., 2015). However, a paradigm shift in the transportation sector is palpable, mainly with regards to the adoption of disruptive technologies in the transportation sector (Mahmoud et al., 2016). Furthermore, the role of transit in our daily activities is thought to increase as evidence of attitudinal shift towards shared mobility, smart commutes, and automated mobility are emerging. It could be argued that there is a declining desire to own a private car as a means of transport (Mahmoud and Hine, 2013; 2016; Offer, 2015; Pihlatie et al., 2014). Some might even claim that the era of privately owned vehicles is coming to an end.

On the other hand, transit is often viewed as a sustainable mobility choice. Although the transportation sector currently contributes 22% of global greenhouse gas (GHG) emissions, this share is dominated by private cars. That is said, many scholars have identified transit as a suitable target for further GHG reductions (Miles and Potter, 2014; Mohamed et al., 2017; Wanga et al., 2017; Zhou et al., 2016). The increasing technological advancements in electric powertrains provides the means to considerably decarbonize the transportation sector. In this respect, transit is considered a more suitable target for alternative powertrains technologies compared to private vehicles. In particular, the nature of bus transit operation, with fixed routes and timely schedules, offers a suitable setting to utilize electric powertrain technology (Mahmoud et al., 2016). The electrification of transit, therefore, is receiving considerable attention from academics and policy makers (Ke et al., 2016; Ribau et al., 2014; Rogge et al., 2015; Wanga et al., 2017; Zhou et al., 2016).

The adoption of the electric bus in transit has been examined in several ways. Technology review (Bayindir et al., 2011; Chan, 2007; Kühne, 2010; Mahmoud et al., 2016), battery technology (Khaligh and Li, 2010; Lu et al., 2013), life cycle cost (LCC) models (Lajunen, 2014; Pihlatie et al., 2014), environmental assessment (García Sánchez et al., 2013; Nylund and Koponen, 2012; Ribau et al., 2014; Yetano Roche et al., 2010), market demands (Frost & Sullivan, 2013), and operational feasibility (De Filippo et al., 2014; Miles and Potter, 2014) have been prominent research domains in the electric bus literature.

Although previous attempts provide sound contributions to facilitate the adoption of e-Buses in transit, additional aspects that significantly affect the electrification of bus transit are surprisingly yet to be investigated. Most notable is the lack of research quantifies the decision-making process of service providers to adopt electric bus technology, even though the they are at the forefront of the procurement, operation, and the maintenance of e-Buses.

This study contributes to address this gap and provides evidence on the impacts of several attributes on the decision making of transit providers in Canada as it relates to the implementation of the electric bus in the transit context. In a nutshell, this study aims to investigate key factors that govern the perspectives of transit providers towards the adoption of e-Bus.

After the introduction, the study is organized as follows: the methodology section describes the mixed methods research design, participants and data collection approaches. The results section illustrates the research findings. Which is followed by a discussion and concluding remarks.

2 Methodology

A mixed method approach is adopted in this study to 1) investigate the salient factors that govern the adoption of e-Buses based on transit providers perspective, and 2) quantify the contribution of these factors in the decision-making process. Namely, two analytical methods are adopted in the study in a sequential mixed method design: qualitative-based grounded theory and analytical hierarchy process (AHP). The analysis is supported by two sets of primary data. First, we conducted 11 in-depth interviews with 11 transit managers to investigate transit providers perspective towards the adoption of e-Bus in transit. Second, findings from this stage are used for an online survey to quantify the decision making process.

2.1 Grounded theory approach

Grounded Theory, advocated by Glaser and Strauss (1967), is considered a powerful inductive tool to explore complex decisions. Fundamentally, grounded theory allows the pattern of ideas to emerge from data through systematic procedures of coding (Beirão and Sarsfield Cabral, 2007). The method utilizes participants' perspective/experience to construct a theory that emerges and advances from multiple interactions between codes, concepts, and categories (Beirão and Sarsfield Cabral, 2007; Creswell, 2013).

The grounded theory is based on 11 in-depth interviews with transit providers. The interview transcript includes five themes with a total of 18 items/questions: 1) general theme of participants' attitude towards e-Buses in general, 2) decision-making process for fleet management, 3) operational and technological concerns regarding electric buses, 4) key barriers/drivers for implementing electric transit buses, and 5) transit policies in relation to the implementation of the electric bus.

The data analysis follows the typical grounded theory analytical approach advocated by Glaser and Strauss (1967). Firstly, line-by-line codes were developed, followed by focused coding to group the most frequent and significant codes. The generated categories are linked through axial codes that rebuild relationships between the extracted categories (Strauss, 1987). In the final stage, categories are linked in a theoretical coding process that outlines the emerging theory (Beirão and Sarsfield Cabral, 2007; Charmaz, 2014; Creswell, 2013).

2.2 Analytical Hierarchy process (AHP)

Since its inception by Saaty (1980), the AHP method has been used as a powerful tool to solve a wide range of multi-criteria decision problems. The creativity of the AHP method is attributed to its ability to solve multidimensional problems through pairwise comparisons that identify the relative weight of importance of sets of criteria or sub-criteria. The main different between AHP and other MCDM methods is that AHP has introduced a combination of multilayer and multidimensional approaches for problem solving (Ball and Srinivasan, 1994; Kim et al., 2012; Yuen, 2010). In addition, AHP has linked the qualitative and quantitative methods through a combination of both objective and subjective assessments in a simple and logical form. In practice, the applications of AHP method vary from solving simple decision-making problems to complex multi-discipline problems (Al Khalil, 2002). Therefore, AHP has been implemented in many disciplines including the industry, military, business, social sciences, transport, and policy (Bodin and Gass, 2003)

The AHP method is carried out in two main stages including AHP hierarchy structure and Eigenvalue Method (EM) of weight election (Saaty, 1980; 1996; Saaty and Vargas, 2000). The apex of the AHP hierarchy represents the aim of the decision under investigation. The second level represents a set of multiple objectives (often expressed as criteria) that address the multidimensionality of the overall aim. Lastly, sets of sub-criteria and alternatives are classified in the lower levels of the hierarchy. The AHP hierarchy indicates the relationships between variables and elements in the same horizontal level/layer. It also indicates the vertical relationships within each column (Al Khalil, 2002; Bhushan and Rai, 2004; Castillo and Pitfield, 2010; Saaty, 1980; 1996).

In this study, the analysis of transit providers perspectives towards the adoption of e-Buses follows the typical AHP data analysis strategy, and is carried out in six steps (Saaty, 1996):

i. Set up the ultimate goal and develop the AHP hierarchy chart
ii. Construct a matrix for pairwise comparisons (n * n) for both criteria and sub-criteria levels, and calculate the reciprocal elements
iii. Calculate Weighted Vectors (Eigenvectors), and Weighted Scores
iv. Calculate λmax and Consistency Index (CI)
v. Calculate the Consistency Ratio (CR)
vi. And lastly, repeat steps 2-5 for all possible pairwise comparisons

Both criteria and sub-criteria represent the findings of the qualitative analysis. In this respect, the AHP model is structured in two layers: the first layer includes five main criteria, while the second layer includes 20 sub-criteria. The AHP chart is detailed in Table 1.

3 Results

3.1 Insights on the decision-making process to adopt e-Bus in transit

The findings of the qualitative analysis are detailed in (Mohamed et al., In Press) and highlighted in Table 1. In a nutshell, five main criteria govern the decision-making process for the adoption of e-Buses in transit. These are the concerns over e-Bus technology, the operational feasibility of e-Buses, the financial burden of e-Buses, the environmental benefits of e-Buses, and the political support of e-Bus adoption in Transit.

Although the qualitative findings offer detailed insight on the factors that govern the decision-making process, there is no information on how each factor contributes to the decision-making process. One cannot assume that all these factors contribute to the decision-making process equally.

Table 1 AHP hierarchical chart

Goal	Main Criteria	Attributes
Decision-making process to adopt e-Buses in Transit	Concerns over Electric Bus Technology	High risk of being the first adopter "Technology Anxiety" and fear of obsolescence Health, and safety concerns Standardization of electric bus technology
	Operational Feasibility	Availability of Canadian e-Buses operational data Operational availability (range & charging time) Operational flexibility Network optimization Integration with current fleet technology Expectation of increased fleet size due to electrification
	Financial Feasibility	Cost of human resources (i.e. drivers & mechanics) Capital cost per bus Maintenance cost (i.e. battery, parts, etc.) Infrastructure cost (i.e. chargers, garage upgrade, etc.) Electricity (Hydro) rates
	Environmental Benefits	Well-To-Wheel (WTW) GHG emissions Reduction of noise & vibration Air pollution
	Political Support & Incentives	Federal financial support Municipal & provincial financial support

3.2 Quantifying the decision-making process to adopt e-Bus in transit

Based on the qualitative results, an AHP hierarchical chart was developed, Table 1, to quantify the relative weight of importance for all criteria and attributes that govern the decision-making process to adopt e-Bus in the transit context. The AHP model results are presented at two levels; local and global weights of importance. The formal quantifies the weight of importance for each attribute relative to its criterion, while the latter quantifies the global weight of importance for each attribute relative to all attributes. The relative local weights of importance for each attribute within its criterion are presented in Figures 1-5. Both. Values for both Consistency Index (*CI*) and Consistency ratio (*CR*) for all criteria are within the recommended thresholds, which indicate that the data fits the model well.

As it relates to e-Bus technology, transit providers have expressed sound concerns on adopting new technology in the transit context, they have allocated higher level of importance on developing standards for e-Bus technology as illustrated in Figure 1. In addition, the high risk of being amongst the first to adopt the technology was considered very important, it could be argued that there is a shared concern to be the first adopters. In contrast, the fear of obsolescence was regarded with a relatively lower importance.

While for the operational feasibility of e-Bus in transit, the availability of e-Bus for operation, which considers both driving range and charging time, and the operational flexibility of e-Bus are considered the key attributes for feasible e-Bus operation. In addition, network optimization under e-Bus operation is regarded relatively important. In contrast, the integration with current fleet technology, the availability of Canadian e-Bus operational data, and the expectation of increased e-Bus fleet size are not considered as equally important as highlighted in Figure 2.

The financial feasibility of e-Bus, illustrated in Figure 3, shows almost equal level of importance distributed between all attributes, with higher weight allocated to infrastructure cost, followed by hydro rates and capital cost respectively. For the environmental benefits, it is evident in Figure 4 that the reduction of noise and local air pollution are key attributes for the decision-making process, which might reflect concerns on local context rather than the overall well-to-wheel GHG emission that was regarded relatively less important. Lastly, transit managers have allocated higher importance for federal financial support compared to those of the municipalities and the provinces as detailed in Figure 5.

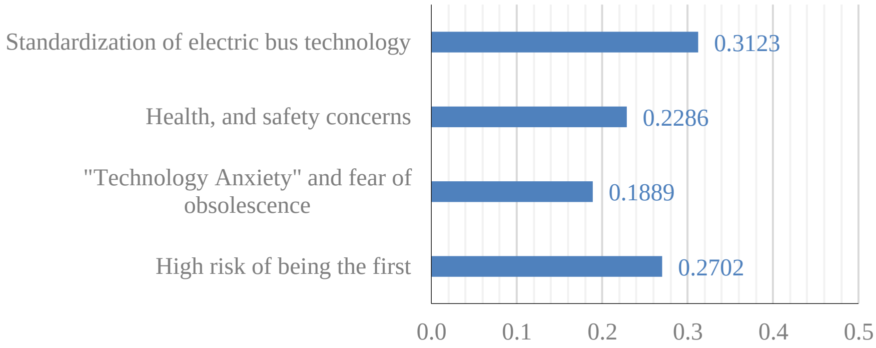

Figure 1 Local weights of importance for concerns over e-Bus technology attributes

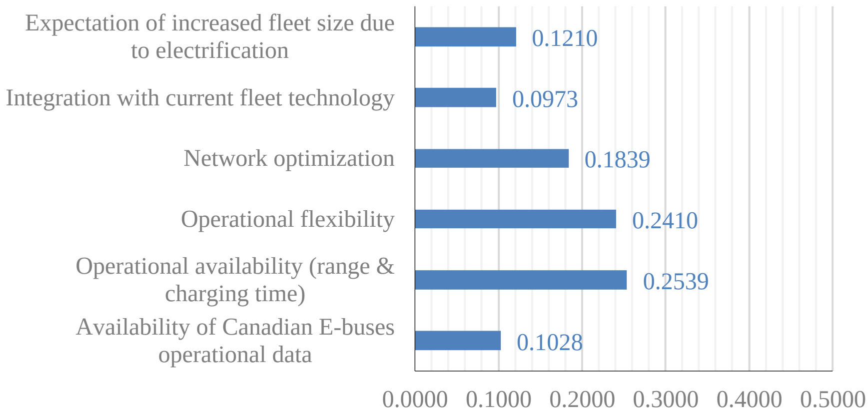

Figure 2 Local weights of importance for operational feasibility attributes

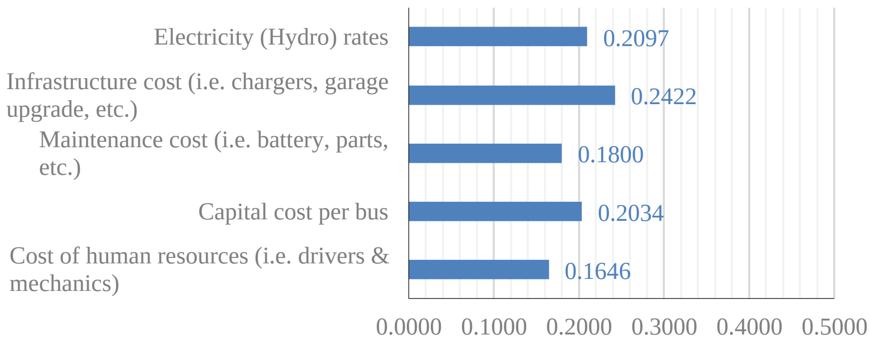

Figure 3 Local weights of importance for financial feasibility attributes

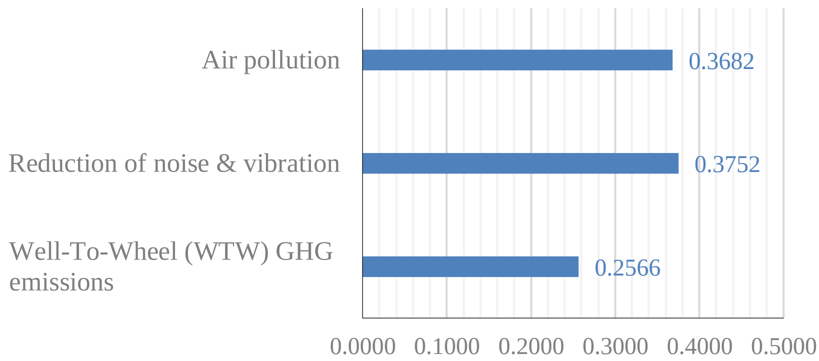

Figure 4 Local weights of importance for environmental benefits attributes

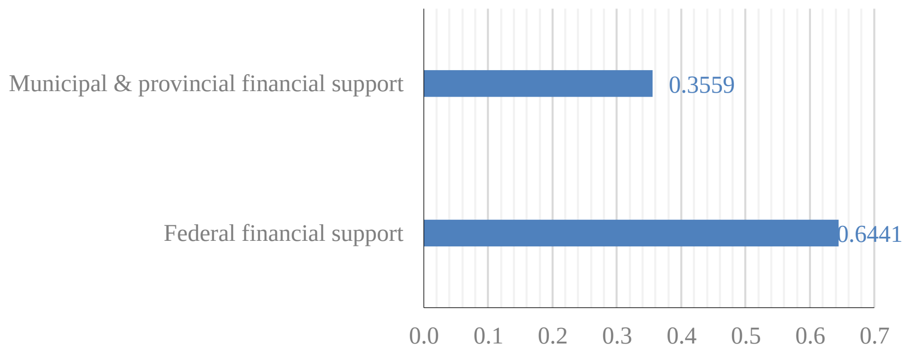

Figure 5 Local weights of importance for political supports & incentives attributes

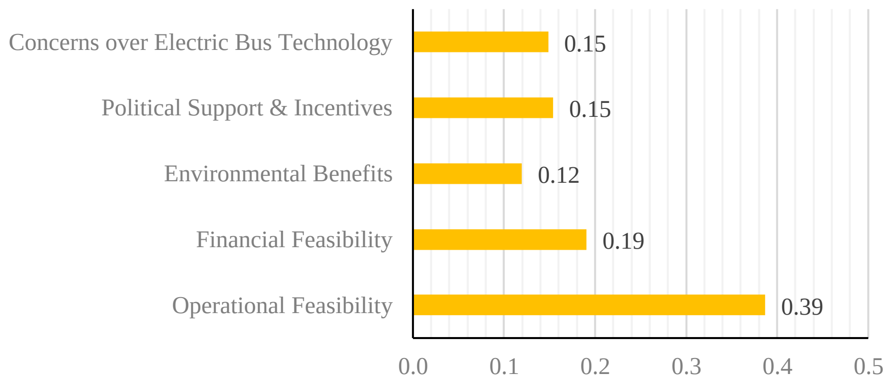

Figure 6 Relative weights of importance for contributing criteria to the adoption of e-Bus in transit

Although the local weight of importance provides detailed information on the taxonomy of the decision-making process, it only provides a partial understanding as each attribute is considered within its criterion, which does not allow for cross comparison between attributes from separate criteria.

The relative weights of importance for the contributing criteria to the decision-making process to adopt e-Bus in the transit context are illustrates in Figure 6. It is apparent that the operational feasibility of e-Bus is the key factor that governs the decision-making process. This is followed by financial feasibility of e-Bus, concerns over e-Bus technology, and political support respectively. On the other hand, the environmental benefits of e-Buses seem to have very little contribution to the decision of transit providers. It could be argued therefore, that achieving the environmental benefits of the e-Bus in transit hinges on providing feasible operation in Canadian context.

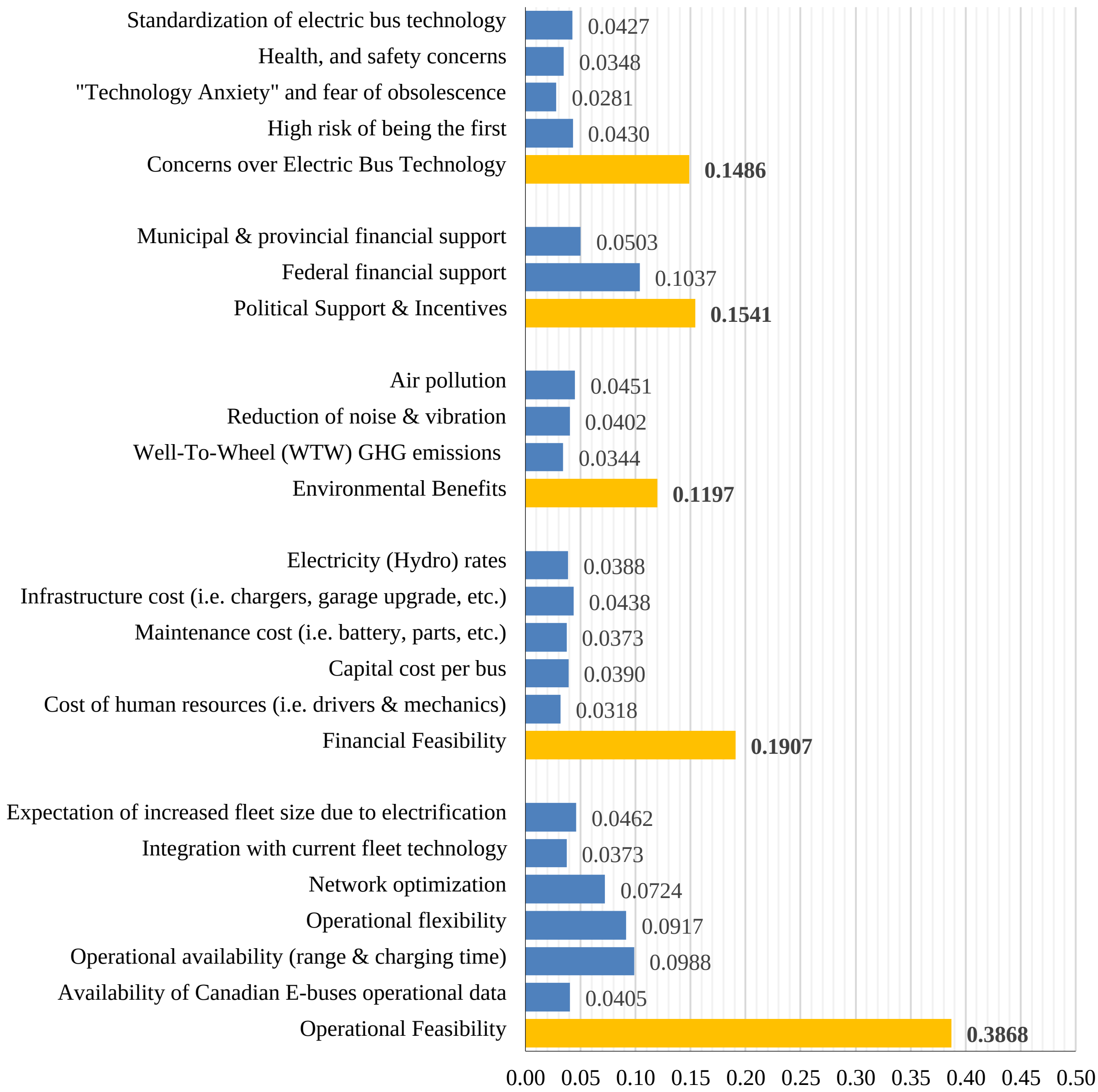

Figure 7 Relative weights of importance of key criteria contributing to the adoption of e-Bus in transit

The global weight of importance, presented in Figure 7, provides a vivid picture on the absolute level of importance for each attribute in the decision-making to adopt e-Bus in transit context. Four attributes are considered of significant importance to facilitate the adoption of e-Bus in transit. These are; federal financial support, operational availability (range & charging time) of e-Bus, operational flexibility, and network optimization under e-Bus operation. One can argue that these represent the building-blocks for promoting e-Bus in Canadian transit for many reasons. First, federal financial support is seen by transit providers as a tool to mitigate the financial burden of adopting e-Bus. While, the operational availability, flexibility, and network optimization are key ingredients for reliable transit services.

In contrast, the fear of obsolescence form technological advancements and the cost of human resources could be seen as relatively less important. That said, all attributes included in the AHP model are considered important for the decision-making process and the ranking of attributes should be carefully interpreted.

4 Concluding Remarks

This study aimed at identifying and quantifying the contributing factors for the decision making to adopt electric bus in transit. The analysis is grounded on the perspectives of transit providers as they are at the forefront of the procurement, operation, and management of transit services in Canada. The study adopted a mixed method sequential design approach that combines qualitative and quantitative methods. A grounded theory analysis was carried out based on primary data of 11 in-depth interviews. Findings from this analysis was used for an online survey based on the Analytical Hierarchy Process (AHP) method.

Overall the study identified that five main criteria govern the decision-making process to adopt e-Buses in transit. These cover multiple aspects including the concerns over e-Bus technology, operational, financial, and environmental feasibility of e-Buses as well as the political support to promote e-Bus adoption in Transit. Furthermore, the AHP model of 20 attributes, indicated that four attributes have significant contribution to the decision-making analysis including federal financial support, operational availability, flexibility, and network optimization.

Based on the AHP findings, three families of attributes are created in Table 2, these are; attributes of significant importance (four attributes), attributes of high importance (six attributes), and attributes of relatively medium importance (ten attributes). It should be noted however, that this classification is mainly objective.

Table 2 Ranking of attributes that influence the decision-making to adopt e-Bus in transit

Rank	Attribute	Global Weight	Delta global weight
1	Federal financial support	0.1037	
2	Operational availability (range & charging time)	0.0988	-0.0050
3	Operational flexibility	0.0917	-0.0071
4	Network optimization	0.0724	-0.0192
5	Municipal & provincial financial support	0.0503	-0.0221
6	Expectation of increased fleet size due to electrification	0.0462	-0.0042
7	Local Air pollution	0.0451	-0.0010
8	Infrastructure cost (i.e. chargers, garage upgrade, etc.)	0.0438	-0.0013
9	High risk of being the first	0.0430	-0.0008
10	Standardization of electric bus technology	0.0427	-0.0003
11	Availability of Canadian E-buses operational data	0.0405	-0.0022
12	Reduction of noise & vibration	0.0402	-0.0003
13	Capital cost per bus	0.0390	-0.0012
14	Electricity (Hydro) rates	0.0388	-0.0002
15	Maintenance cost (i.e. battery, parts, etc.)	0.0373	-0.0015
16	Integration with current fleet technology	0.0373	0.0000
17	Health, and safety concerns	0.0348	-0.0025
18	Well-To-Wheel (WTW) GHG emissions	0.0344	-0.0004
19	Cost of human resources (i.e. drivers & mechanics)	0.0318	-0.0026
20	"Technology Anxiety" and fear of obsolescence	0.0281	-0.0037

These findings of this study provide directed indications on the required interventions to promote the adoption of e-Buses in the Canadian transit system.

For policy makers, it is evident that the federal support through monetary and non-monetary incentives is a key building block to promote e-Bus in transit. Apparently, transit providers are not willing to take the financial risk associated with the adoption of e-Buses. In addition, financial support at both provincial and municipal levels is also deemed important. Policy makers should also seek the development of standards for the e-Bus technology, which will aid the procurement process.

For researchers, it is very clear that additional efforts are needed to offer transit providers with evidence-based research on the operational capabilities, as well as limitations, of e-Buses in transit operation. Achieving an optimized operation of e-Buses in transit is a significant factor for the adoption of the new technology. Such research should also offer information on the total cost of ownership (TCO) based on current real-world operation data.

Lastly, electric mobility in general has been always promoted on its environmental merits. However, in the transit context it is very clear that the environmental benefits of e-Buses are not seen as one of the driving forces for adoption, rather it is considered as additional gain resulting from an optimized operation that satisfied transit users.

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