CHAPTER 8

Analysing the Implications of Integration of Electric Bus Service in Urban Transit Systems

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ABSTRACT

Revolutionizing urban mobility by incorporating electric bus services is an essential advancement needed in city transit systems. Pune has become a key player in the shift towards electric mobility within its urban transportation framework. This research explores the various impacts of this integration, emphasizing sustainability, efficiency, public acceptance, infrastructure, and economic feasibility. The integration is also in terms of metro transit systems and autoicures that are there as a part of electric mobility. It is therefore essential to incorporate other aspects in terms of policies which will integrate other transportation systems with electric buses. The study identifies significant obstacles, such as technological, financial, and institutional issues, that impede the widespread adoption of electric vehicles (EVs) in urban areas. Furthermore, it examines policy structures, collaboration among stakeholders, and public attitudes. By analysing case studies from cities worldwide and utilizing simulation models, this study emphasizes the best practices and possible challenges, offering practical recommendations for policymakers and transit officials. Ultimately, a detailed framework is suggested to integrate electric mobility into Pune's urban planning and decision-making processes. This framework aims to promote collaboration among stakeholders, enhance infrastructure development, and ensure policies align with long-term sustainability goals. The findings aim to provide actionable insights for policymakers, urban planners, and stakeholders to accelerate Pune's transition toward an eco-friendly and socially equitable mobility ecosystem.

Keywords: Electric Mobility; Public Transit; Integration; Sustainability Goals; Public acceptance

1.0 Introduction

The need for transportation services to accommodate commuters has grown as cities attempt to grow due to urbanization. Integration of public transportation systems has arisen as a method to aid in navigating the challenges of urban transportation. Integration of public transportation facilitates commuters' transitions between modes, which eventually encourages a switch from personal vehicles to public transportation (ESCAP, 2024).

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By lowering overall costs through less overlap and redundancy and raising revenue through attracting more consumers, an efficient integration of the public transportation system can improve the financial sustainability of public transportation (Zimmerman & Fang, 2015). Cities need public transit, which poses a number of issues going forward. Transportation is thought to account for about 24% of the global energy demand (L. Bravo-Moncayo *et al.*, 2017). According to Woo *et al.* (2017), while the growth in the automobile fleet has benefited the economy, it has also had a negative impact on human health and natural ecosystems. A sufficient transit system that ensures user comfort is necessary to stop the indiscriminate proliferation and individual usage of private vehicles. However, internal combustion engines (ICEs), which power public buses, are generally associated with high noise levels and emissions of greenhouse gases (GHGs) (Dong *et al.*, 2014 and Lucas *et al.*, 2015). To lessen global warming, GHG emissions in particular are a crucial issue that needs to be resolved. In addition, other pollutants including NO2, SO2, and PM2.5 may cause serious health problems and lead to conditions like cancer and asthma. Particularly, areas with traffic stoppages and high-altitude cities have higher pollution levels because of the reduced motor efficiency brought on by the lower oxygen levels (Onar *et al.*, 2015).

Public transportation is undergoing a global shift to electric propulsion. In order to preserve a sustainable economic environment, cities have included battery-powered electric buses into their current fleets of buses. To preserve a sustainable economic environment, urban regions have been adding more battery-powered electric buses (EBs) to their fleets of buses in recent years (Wenz *et al.*, 2021). A key component of sustainable development is sustainable transportation. It is essential to accomplish both the Paris Climate Agreement and the 2030 Agenda for Sustainable Development, as it has implications for several Sustainable Development Goals (SDGs). "The provision of services and infrastructure for the mobility of people and goods—advancing economic and social development to benefit todays and future generations— in a manner that is safe, affordable, accessible, efficient, and resilient, while minimizing carbon and other emissions and environmental impacts" is the definition of sustainable transport given in the organization's 2016 report. Therefore, sustainable transportation is a tool to accomplish sustainable development rather than an aim in and of itself (United Nations Transportation report, 2021). With an ambitious plan to modernize its urban transportation networks by implementing electric buses on a big scale, India is moving forward. This revolutionary step, which aims to reduce carbon emissions and improve air quality, is supported by strong central government policy. India's public transportation system is making a significant effort to transition to electric vehicles with the launch of the "PM-e-Bus Sewa" programme in addition to the current Faster Adoption and Manufacturing of Electric Vehicles (FAME) frameworks (ET Energy World, 2024).

The Ministry of Urban Development (MOUD), Government of India, aims to equip every city with first- and last-mile connectivity as well as a smooth transportation system including all modes (MOUD, 2013). The future of mobility in India could be redefined by the

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merging of public and private transportation systems in the quickly changing current landscape. For commuters across the nation, this convergence heralds a profound paradigm shift that promises increased convenience, accessibility, and inclusivity. There are numerous advantages to integrating transportation networks. A new era of mobility can be unlocked with this integrated strategy, which offers more cost-effective and efficient travel options as well as smooth transitions between different means of transportation. Through interconnecting buses, trains, taxis, bike rentals, and other transportation options, commuters may experience hassle-free travel that is customized to meet their individual requirements and tastes. The amalgamation of public and private transportation networks has immense promises for transforming our modes of transportation and providing copious advantages to both commuters and the community at large. The future of mobility in India depends on the convergence of factors such as economic growth, technological innovation, improved accessibility, cost-effective travel, sustainable mobility, and cultural shift. According to Express Mobility (2024), a paradigm shift would facilitate countries' efforts toward integration and sustainability.

The goal and road map for the nation's rapid adoption of electric vehicles and their manufacture are provided under the National Electric Mobility Mission Plan (NEMMP) 2020. This plan was created to improve fuel security at the national level, offer reasonably priced, eco-friendly transportation, and help the Indian car sector become a global leader in manufacturing.

Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India) Scheme was developed in 2015 by the Department of Heavy Industry as part of the NEMMP 2020 with the goal of fostering the production of electric and hybrid vehicle technology and ensuring its sustainable growth. Buyers of electric vehicles (EVs) may take advantage of a demand incentive in the first phase of FAME, which offered a lower upfront purchase price to encourage EV adoption.

The second phase of FAME is mostly concerned with promoting the electrification of shared and public transportation. It seeks to finance the purchase of 7000 e-Buses, 5 lakh e-3 Wheelers, 55000 e-4 Wheeler Passenger Cars, and 10 lakh e-2 Wheelers through subsidies. The program will primarily apply to vehicles registered for commercial use in the e-3W, e-4W, and e-bus segments, or vehicles used for public transportation, with a focus on providing accessible and environmentally friendly public transportation options for the general public (National Electric Mobility Mission Plan, 2020, Ministry of heavy industries). With no tailpipe emissions, electric buses hold the potential to provide public transportation that is quieter, greener, and more energy efficient. However, a complex interplay of technological, financial, and logistical factors must be taken into account for their incorporation into the current urban transit frameworks. This research examines the possible advantages, difficulties, and wider effects on municipal infrastructure, environmental sustainability, and public policy of integrating electric bus services into urban public transportation networks. Stakeholders can more adeptly manage the shift to a more environmentally friendly and resilient urban transportation system by comprehending these dynamics.

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1.1 Research questions

RQ: How can an integrated urban transit system be proposed in Pune with a focus on electric buses in the transit system?

1.2 Research objectives

The following research objectives are listed below:

RO1: To assess the current state of electric buses in urban transit systems in Pune.

RO2: To identify barriers and challenges in integration of electric buses in the urban transit systems in Pune.

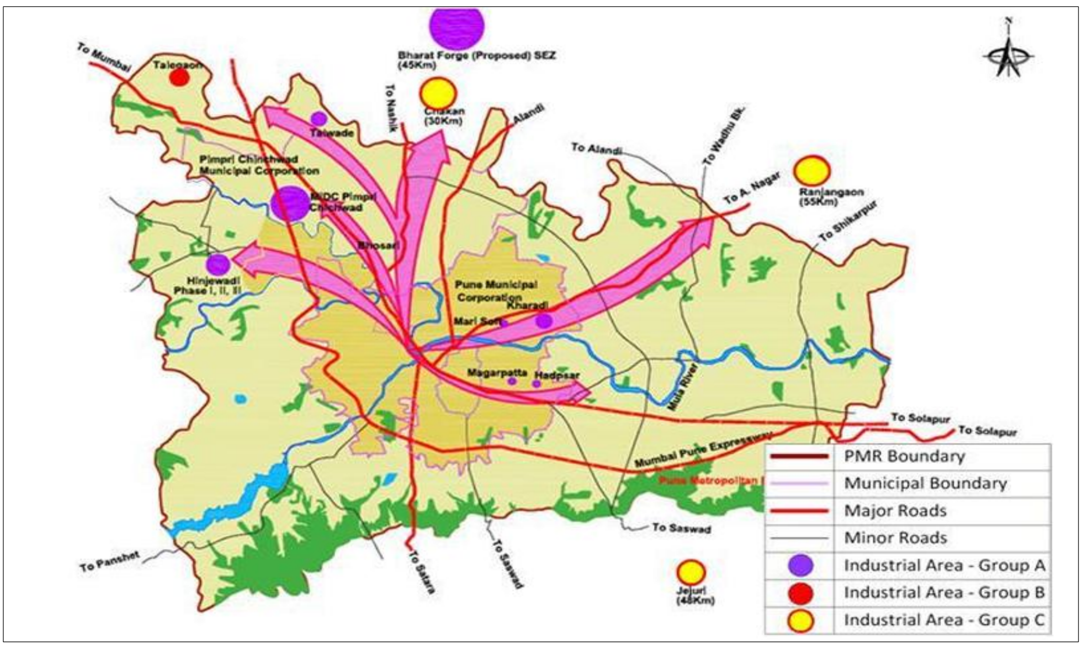
RO3: To assess the environmental and social impacts of integrating electric buses into the urban transit systems in Pune.

RO4: To develop a framework for integrating electric buses into urban transit systems in Pune.

1.3 Study area

Pune, with a 600-year history, is one of India's most culturally advanced cities. With the exception of 2009 and 2010, the number of units and jobs in the large-scale industries in the Pune region have increased throughout time. Different industrial segments are the main drivers of PMC's growth.

Figure 1: Pune Metropolitan Region Industries



Source: Comprehensive mobility plan, 2008.

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With the exception of Kharadi Knowledge Park, which is situated inside PMC boundaries, all other industries are now found outside PMC in PMR or in close proximity to PMR in the directions of North, West, and North-East. The bulk of the industrial developments are located within Pimpri Chinchwad Municipal Corporation (Pune Development Plan (DP), 2041). The traffic in and around Pune is growing quickly as a result of the city's industrial and other social expansion. Pune is crossed by a number of major thoroughfares. Both important State Highways and National Highways pass through Pune. On the other hand, traffic congestion was brought on by vehicles passing through Pune City on their way in one direction. The bus and BRT service provider in Pune and Pimpri & Chinchwad has had difficulty keeping up with the transportation needs of the city. The city's transportation system has been under pressure recently due to urban sprawl. The growth in small, medium, and heavy sectors is driving up traffic in the city at unsustainable rates. Despite their narrowness, the city's roads accommodate a range of vehicles at once.

In Pune, there are various types of public transportation available: buses, metro, and vehicles, which are used for paratransit. Urban transport policy's primary objective is to provide people with mobility; public transportation is the most efficient way to achieve this, as opposed to private automobiles. When compared to other public transportation options like the metro, tram, and monorail, the bus rapid transit system (BRTS) is the most affordable and convenient, making it the most chosen choice (Pune DP, 2041).

The Metro Rail Project made a point of highlighting the area's poor support for public transportation and rising use of private vehicles. A home interview survey result shows that 13% of people use public transportation, but at least 50% of people think this should be the case. This may have been accomplished by creating a high-carrying-capacity, effective mass transit system based on transportation technologies (Pune DP,2041). There are now two operational metro routes built by Maha Metro under Phases I and II. Puneri Metro is in charge of the building of Phase III. In order to improve last-mile connection, the city's paratransit system should be expanded to include non-motorized transportation infrastructure, including as bike lanes, sidewalks, and parking spaces close to bus stops and metro stations, which are in high demand by riders. The integration of the bus and metro is depicted on the map below, along with the locations that are and are not served by public transit. Therefore, it will assist in analyzing the city's public transportation infrastructure, feeder routes, demand and ridership factors, and overall mobility.

Pune has started offering electric bus services in order to meet the goal of sustainable transportation. PMPML Electronic Bus. To reduce pollution and save money on diesel, PMPML (Pune Mahanagar Parivahan Mahamandal Limited) has added 25 electric buses, or e-buses, to its fleet. In the first phase of the smart city program, 150 new e-buses will be added, and in the second, 350 more. On the other hand, the cost of maintaining these buses is growing. Each month, the cost of recharging the current 25 buses is 9 lakhs. Consequently, 400 more CNG buses will be added to the transportation agency's fleet, sources claim. Pune faces challenges in

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the first and last miles, especially as the population on the outskirts of the city increases, and there is a lack of coordination between many groups and projects.

Figure 2: Integrated BRT and Metro Routes

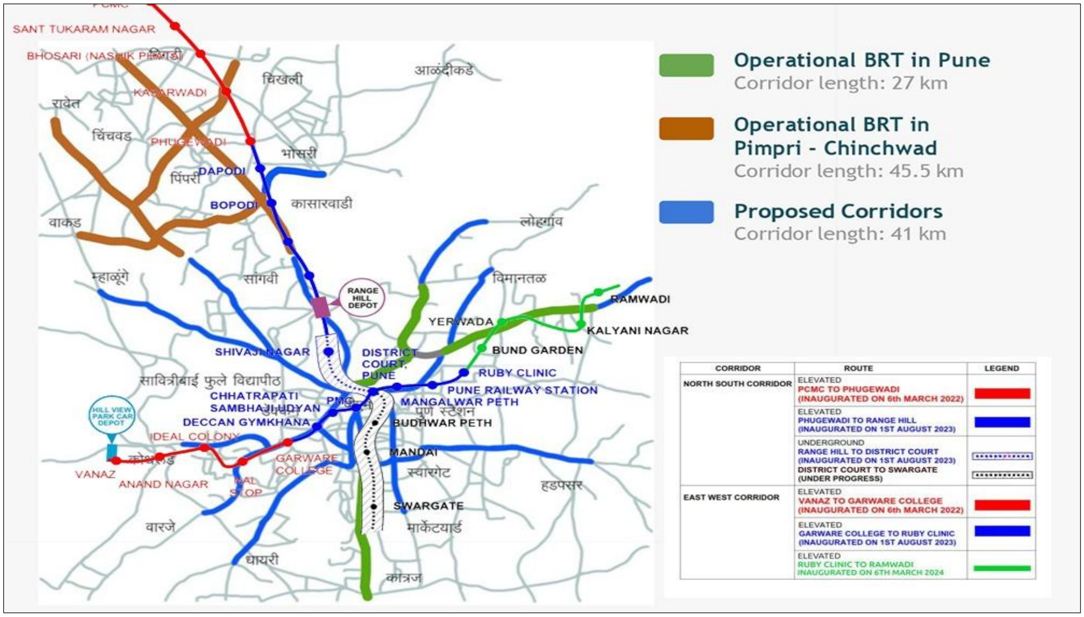
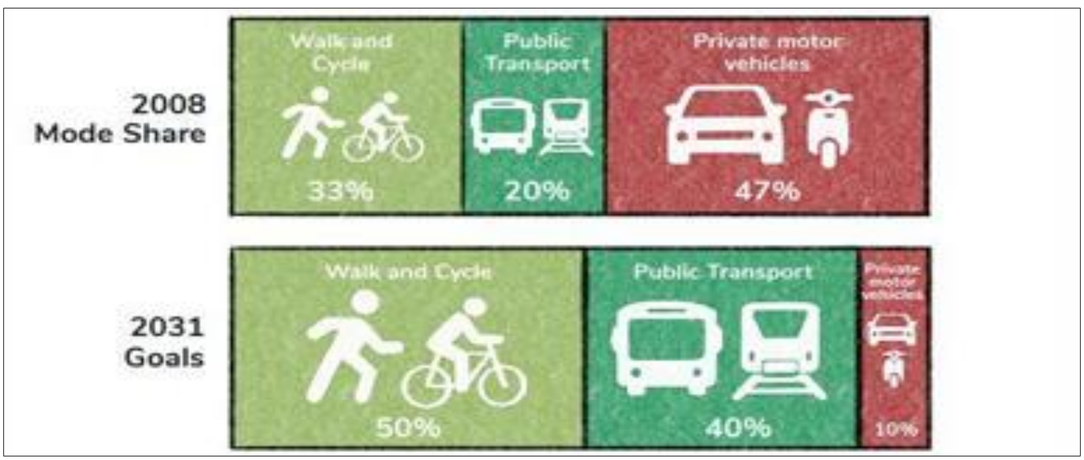


Figure 3: Sustainable Transport Policy by ITDP



Additionally, it has been noted that there is more traffic congestion. The Pune Metropolitan Region's public transportation situation is unsatisfactory (Gaikwad, 2021). This is

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evident from the fact that, in 2013, average traffic speeds were 18 mph, and projections for 2031 predict that this will drop to nine mph. (RMI & PMC, 2018). Additionally, it is said in the Comprehensive Mobility Plan for Pune Metropolitan Region (PMR) that 8% of motorized travel trips are made by bus, 12% by intermediate public transportation (IPT), and 4% by suburban railway (PMRDA, 2018).

Establishing a Sturdy and Integrated Public Transportation System in PMR is the answer to resolving this issue (Gaikwad, 2021). In order to assure a complete approach to constructing functioning and habitable streets, the ITDP (Institute for Transportation and Development Policy) report states that the city has implemented various progressive policies and programs driving the change on the ground. The purpose of Pune's Walk Smart Policy is to increase pedestrian safety in the city. It offers recommendations for narrowing traffic lanes, slowing down driving speeds, and establishing pedestrian-only areas, safe crossings, and walkways. The city of Pune established the Integrated Bicycle Plan as the main framework for distributing funds, carrying out initiatives, and assessing the outcomes in order to achieve its objectives for raising the number of people who ride bicycles.

The primary means of transportation between Pune and Pimpri Chinchwad is the regular bus service. For all Punekars, it is the most dependable form of transportation, carrying 10 to 11 lakh passengers every day. On the busiest routes between 05.30 and 12.00 am, Pune Mahanagar Parivahan Mahamandal Ltd (PMPML) buses are renowned for their punctuality and excellent service. Currently, 389 routes encompassing a 40-kilometer radius offer services that reach the PMRDA boundaries in the Pune and Pimpri-Chinchwad area. Additionally, growth plans are created, and new ones are implemented based on the recommendations that are regularly made and by researching the city's population. Today, there are roughly 1660 schedules with 21916 trips planned for daily bus travel; 96% of these operations efficiently serve customers. The World Bank, UNDP, and GEF are supporting Pune and Pimpri Chinchwad Municipal Corporation's Sustainable Urban Transport Project (SUTP), which is an initiative of the Indian Ministry of Urban Development. The PMPML E-Bus Implementation Plan called for the provision of 650 electric buses in 2022, an extra 300 electric minibuses in 2023, three operating e-bus depots, an increased number of 250 charging points, 75 charging points that are now in service, and three opportunity charging sites that are suggested (PMPML).

Table 1: Statistics of PMPML, 2023-24

Statistic	Value
Total Fleet	2066
Bus on Road per day	1658
Total Bus Depots	15
Total Bus Stops	3974
Total Routes	387
No. of trips per day (Planned)	20706

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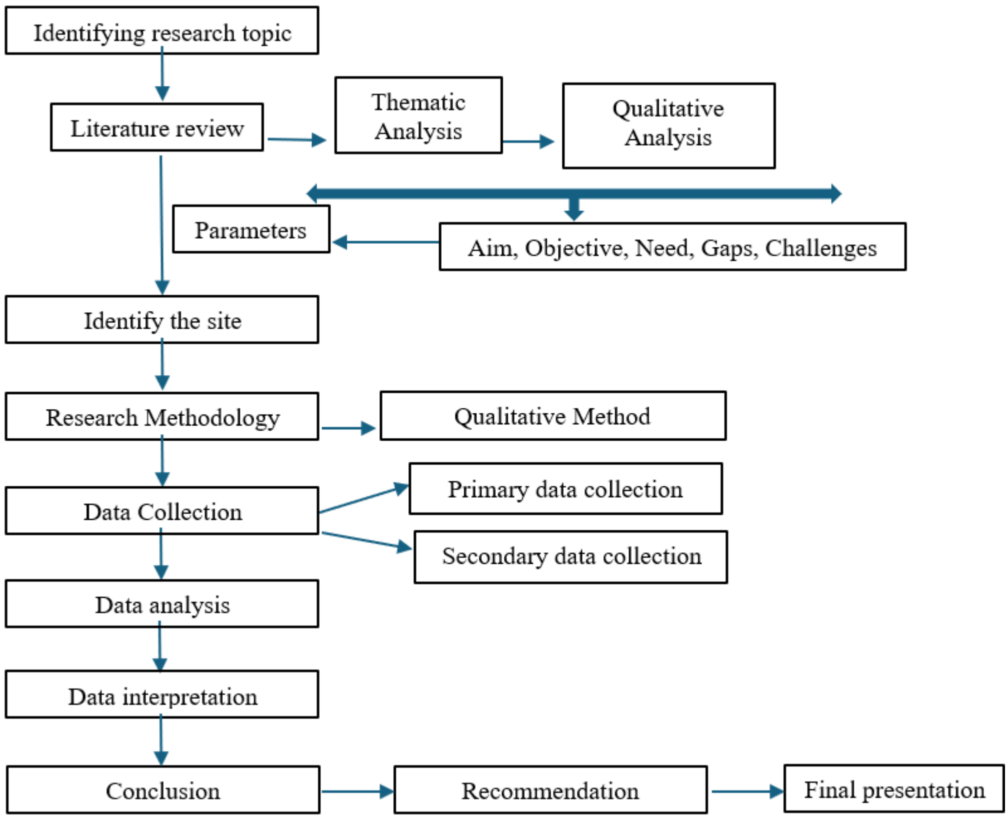
3400 buses in Pune and Pimpri-Chinchwad's fleet to guarantee public transportation for everyone. Buses near Everyone: Using the People Near Transit Analysis, increase frequency to one bus every five minutes and extend service coverage to every area of the city. Greener Buses: Include electric buses in the city to help transition to cleaner fuels. The estimated population for 2021 is used to compute the number of additional fleet units needed.

3.0 Research methodology



3.0 Literature Review

3.1 Introduction

Due to growing concerns about sustainability, air pollution, and the global shift towards renewable energy sources, the integration of electric bus services into metropolitan public transit networks has received a lot of attention. The shift to electric vehicles is a crucial part of sustainable development since urban transportation networks are important for environmental policy and municipal planning. Even though electric buses are being used extensively in many

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cities, little is known about how these changes will affect the environment and operating efficiency over the long run, especially in growing cities. Furthermore, a thorough examination of the regulations controlling the incorporation of electric buses into the current public transportation networks is still lacking. This review of the literature aims to summarize the current research on the integration of electric buses, pinpoint the main technological, financial, and policy obstacles, and emphasize the essential success elements for urban transportation networks. Important topics covered in this review include the advantages of electric buses for the environment, the difficulties in building infrastructure, user happiness, and the legislative frameworks that encourage the use of electric buses in metropolitan areas. It covers key themes such as Energy and Sustainability, BEB Technology and Infrastructure, Mobility and Transit Integration, Policy and Governance and Technology and Innovation.

3.2 Scopus search

The Scopus search was conducted to get broad number of papers that are related to the topic to have maximum number of research which can be used for review. The keywords used were integrated transit, public transit, electric bus and transport. The review is organized as follows: First, it examines the environmental and economic impacts of electric buses. Next, it explores the technological advancements and infrastructure requirements. Finally, it reviews policy initiatives and user perceptions surrounding electric bus services. The papers identified were around 1000 considering the range between the year 2000-2024. The present literature review was done for 100 papers following the thematic analysis. Considering the areas as social science, Environmental science, Decision science, Energy, Material science, Business management, Urban planning, Transportation engineering, Electric buses, Urban public transport, Sustainable transportation, Electric vehicle infrastructure, public transit policy, Bus electrification, Environmental impact of electric buses. Analysis of the literature according to the trends and patterns by filtering the data. The articles helped to analyse the integrating the integrated system and electric buses in the context of urban transit, focusing on sustainability, infrastructure.

3.3 Themes

3.3.1 Battery Electric Bus (BEB) technology and Infrastructure

The shift to Battery Electric Buses (BEBs) and their incorporation into metropolitan public transportation networks have attracted noteworthy attention owing to the technological, economic, and environmental difficulties associated with decarbonization. Numerous aspects of BEB adoption, such as their total cost of ownership (TCO), infrastructure for charging, energy management, and environmental effects, have been examined in recent research. The results of multiple important research investigations are summarized in this overview of the literature, with an emphasis on the operational difficulties, technological developments, policy implications, and economic viability of BEB implementation.

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Managing the limitations of the limited charging infrastructure and optimizing charging schedules are frequent challenges in the adoption of BEBs. A nonlinear optimization approach was put forth in Nanjing with the goal of simultaneously minimizing system costs through vehicle scheduling and charging times. System-wide and billing expenses were significantly reduced as a result of the application of this methodology (Zhang *et al.*, (2024)). To further guarantee system efficiency and lower operating costs, a number of research have concentrated on optimizing nighttime and en route charging schedules. To optimize en-route charging plans, for example, a study built a mixed-integer linear programming model and used robust optimization algorithms to address energy consumption uncertainties (Avenali *et al.*, (2024)). Research on technological advancements in energy storage and battery systems has also been quite popular. The importance of choosing the right energy storage technologies is highlighted by a study that compared Lithium Iron Phosphate (LFP) batteries and Electrochemical Recuperators (ECR) for electric buses in Finland. The study found that although the manufacturing of ECR has a higher potential to cause global warming, it performed better environmentally in bus applications (Zeng *et al.*, (2024)).

Furthermore, the next generation of BEBs is being shaped by modular trends in electric vehicle manufacturing, such as scalable units for charging and propulsion systems, which guarantee supply chain security and streamline the manufacturing process (Gnap *et al.*, (2024)). Infrastructure for Charging Electric Buses: One important area of effort for cutting carbon emissions is electrifying public transportation. When strategically placing electric bus (e-bus) charging stations, a multi-objective optimization model that makes use of the Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) successfully minimizes planning costs while optimizing traffic flow capture (Optimizing E-Bus Charging Infrastructure). Battery swapping was found to be the most effective charging technique in a comparative study of Guangzhou's Bus Rapid Transit (BRT) system, while dynamic wireless charging demonstrated higher efficiency for long routes with high service frequencies (Comparative Analysis of Charging Methods in BRT Systems). Large-scale use of BEB systems requires ensuring their operational stability. In order to make recommendations for enhancing vehicle reliability, particularly in challenging operating situations, a fatigue life evaluation of BEB bodywork was carried out (Teasdale *et al.* (2024)). Furthermore, utilizing their huge battery capacity for Vehicle-to-Grid (V2G) services, one study suggested employing BEBs to improve the resilience of urban power systems during high-impact, low-probability (HILP) disruptive events (Belloni *et al.*, (2024)).

3.3.2 Energy and sustainability

Studies reveal that electric buses (EBs) are more vulnerable to seasonal variations than diesel buses, especially when it comes to lifecycle carbon emissions. The bus body, chassis, and batteries are the main sources of emissions. When coal-based power generation is replaced with sustainable energy sources, emissions can be significantly reduced. The promotion of EBs as a practical means of lowering carbon footprints draws attention to their potential for use in

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environmentally friendly transportation systems (Zhang *et al.*, 2024). Research has shown that battery electric buses (BEBs) have certain difficulties in areas with harsh weather, like Qatar.

In comparison to gentler climes, BEBs are less efficient in high temperatures due to increased energy consumption, especially for subsystems like air conditioning (Alarrouqi *et al.*, 2024). Increased research is being called for in order to determine the possible health consequences of electromagnetic fields (EMFs) produced by electric bus batteries on both drivers and passengers. (Mazurek *et al.*, 2024). Effectively controlling energy usage is essential for BEB systems, particularly in hostile environments or for large-scale installations. One study studied energy management solutions for extended-range electric buses (EREVs), focused on improving both engine systems and air conditioning energy usage (Zhang *et al.*, (2024)).

Using a supercapacitor and battery combination, which considerably increased battery endurance, the usage of regenerative braking systems was also emphasized as an essential technology to recover energy and prolong battery life (Kepka & Minich (2024)).: Curitiba, Brazil, is a prime example of how integrated transit systems may support urban sustainability objectives. The need of switching to electric buses for attaining urban sustainability is further supported by New Energy Vehicle (NEV) programs in Chinese cities, which have demonstrated notable reductions in urban CO2 emissions. New Energy Vehicles (NEVs), such as electric buses, can dramatically cut urban CO2 emissions, according to pilot programs in Chinese cities. These reductions illustrate how NEVs might help decarbonize urban transportation, especially in developing nations, and benefit not just the cities themselves but also the surrounding areas (Cheng & Xiong, 2024). Advanced Energy Management Systems: By employing Deep Transfer Reinforcement Learning (DRL), among other novel techniques, energy management systems have increased the fuel efficiency of electric vehicles by as much as 6.78%. These solutions are particularly helpful for hydrogen-powered vehicles in urban transportation and also reduce development cycles (Huang, 2024). Deep Transfer Reinforcement Learning (DRL)-based energy management system (EMS) for electric vehicles was found to increase fuel efficiency by 6.78%, which is especially advantageous for hydrogen-powered vehicles in the urban transportation sector (Deep Reinforcement Learning for Electric Vehicle Energy Management).

Furthermore, reserve provision was shown to be more profitable than energy arbitrage in a bi-level optimization framework for managing the charging strategies of electric bus fleets, though battery degradation costs remained a concern. that high temperatures have a significant impact on energy consumption, particularly in the subsystems responsible for heating, ventilation, and air conditioning (Alarrouqi, 2024). This indicates that electric buses face particular challenges in extreme climates. BEBs have been shown to have positive environmental effects, especially when it comes to lowering greenhouse gas (GHG) emissions. The effects of widespread E-bus charging on the grid and emphasized the necessity of careful planning to guarantee grid stability and sufficient hosting capacity. An effective means of increasing electric public transportation without stressing the grid was also investigated: the implementation of In-Motion-Charging (IMC) trolleybuses (Zheng *et al.* (2024)).

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3.3.3 Policy and governance

Policies are a major factor in encouraging the use of ecologically efficient buses. A Slovakian study assessed how the EU Directive 2019/1161 affected the promotion of clean cars and found that legislative changes were necessary to promote BEB uptake in suburban regions (Alamoodi *et al.*, (2024)). Furthermore, the adoption of eco-friendly buses is strongly correlated with higher GDP per capita, with Nordic countries setting the standard due to their financial capacity to invest in environmentally friendly public transit systems.

3.3.4 Mobility and transit integration

The conversion of dispersed bus systems into integrated transit networks relies heavily on community involvement. For instance, research conducted in Bogotá reveals a "vision dissonance" between planners' objectives and user demands that might be lessened by early user engagements to match transportation improvements with community expectations (Kash, 2014).

Similarly, the effective integration of buses, ferries, and fast transit in Vancouver is a testament to the value of strategic planning and community engagement, as seen by the system's growth that overcome geographical obstacles (Glover, 1988). Innovative transit options with substantial energy savings and increased computational efficiency, such as the Modular Electrified Transit System for Urban Corridor Areas (Zou *et al.*, 2024), provide effective, flexible public transportation. MET-CA outperforms conventional Bus Rapid Transit (BRT) models by reducing energy use by 24.4% and minimizing operating expenses for the transit system (Zou *et al.*, 2024). On the other hand, poor transit accessibility outside of the city centre is revealed by an analysis of Surat's Bus Rapid Transit (BRT) system, which may account for the low ridership and mode share. The integration promotes more equitable resource distribution to close accessibility gaps in transit (Rathod, 2024). The temporal variation of accessibility, policymakers could improve service provision in underserved regions. In a similar vein, time-sensitive factors influence intermodal transfers between metro and bus services in Shanghai, highlighting the necessity for improved intermodal connection to enhance the user experience (Shi, 2023). Enhanced accessibility due to smartcard-based bus-subway integration, but unequal benefit distribution highlights equity issues and calls for more equitable public transportation regulations (Kim, 2024).

A number of studies recommend combining public transportation systems with ride sourcing services, such as those offered by Transportation Network Companies (TNCs). According to study, TNCs in the Twin Cities can enhance access and improve the quality of services provided by public transit, complementing it (Zhang, 2021). According to a University of Michigan study, ride sourcing might enhance last-mile connection, decrease wait times and possibly boost transit ridership if low-ridership bus lines are replaced. This is according to a suggested system called MTransit. Transit usage is greatly impacted by the quality and accessibility of real-time information, particularly when traveling outside of regular routes. Better information search quality and real-time availability boost transit use by enhancing

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perceived service levels and familiarity, according to a study comparing Copenhagen with Recife and Natal (Kaplan, 2017).

A model used in Florence, Italy, which separated the optimization of fare structures into two sub-problems—minimizing the costs to transit agencies and configuring zones to improve affordability—shows that optimizing transit systems requires striking a balance between operational efficiency and passenger convenience (Pratelli, 2004). Similar difficulties with network adaptation and schedule design arise when integrating autonomous and electric bus systems. The necessity of incorporating the unique needs of electric buses into future transit systems is highlighted by a study that employs adaptive large neighbourhood search optimization (Electrification and Autonomous Buses: Challenges for Sustainable Transport Networks). At signalized crossings, eco-driving tactics that make use of Vehicle-to-Everything (V2X) communication have demonstrated notable gains in both travel time and energy efficiency. By cutting energy use by more than 21%, these methods improve the overall sustainability of electric bus operations (Rodrigues *et al.*, 2024). Urban Planning and Sustainable Transit: Curitiba, Brazil, offers a well-accepted example of how to combine urban planning and public transportation. Curitiba serves as an example of the long-term advantages of coordinated urban transit planning for cities looking to establish eco-friendly transport networks by emphasizing sustainability and lowering dependency on automobiles (Zhang *et al.*, 2024).

3.3.5 Financial Viability

Numerous studies have placed a strong emphasis on the economic viability of BEBs, particularly when considering the total cost of ownership (TCO) framework. According to a study that examined actual data from Shanghai, fast-charging BEBs are typically more costly than slow-charging ones because quick charging shortens battery life and raises the cost of charging equipment (Xiao *et al.*, (2024)). Sensitivity analysis also showed that operational subsidies play a crucial role in the economic viability of BEB systems, as they have a considerable impact on the TCO, especially for slow-charging BEBs. The high upfront costs of electric buses, particularly in poor nations, continue to be a major obstacle to their broad adoption, notwithstanding the advantages they have for the environment. Around the world, many electric bus charging techniques have been compared.

While dynamic wireless charging is advantageous on long routes, particularly when infrastructure is shared with other modes of transportation, battery swapping is thought to be the most efficient method for regular services (Pei *et al.*, 2024). Furthermore, by giving reserve services priority over energy arbitrage, aggregator-supported charging schemes can lower fleet management costs even while battery degradation is still a financial concern (Miraftabzadeh, 2024). While dynamic wireless charging is advantageous on long routes, particularly when infrastructure is shared with other modes of transportation, battery swapping is thought to be the most efficient method for regular services (Pei *et al.*, 2024). Furthermore, by giving reserve services priority over energy arbitrage, aggregator-supported charging schemes can lower fleet

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management costs even while battery degradation is still a financial concern (Miraftabzadeh, 2024). The high initial prices of electric buses, however, continue to be a significant obstacle despite their positive environmental effects, particularly in developing nations where diesel buses can still be more cost-effective (Sistig *et al.*, 2024).

4.0 Conclusion

Country	City	Electric Bus Integration	Mode of Integration	Key Data/Highlights
China	Shenzhen	Full conversion of its public bus fleet to electric buses.	Integrated with metro systems and bike-sharing schemes.	Over 16,000 electric buses; 48% reduction in CO2 emissions from the transport sector.
Netherlands	Amsterdam	Electric buses operate on key routes, including airport connections and urban areas.	Integrated with trams and metro systems for seamless transfers.	258 electric buses, targeting zero-emission public transport by 2030.
India	Pune	Deployed electric buses under the FAME-II scheme, improving urban transit connectivity.	Integrated with Pune Metro and feeder services.	Over 150 electric buses, plans to expand fleet size to 1,000.
Germany	Hamburg	Electric buses used in urban routes with charging stations powered by renewable energy sources.	Integrated with metro, suburban trains, and car-sharing systems.	100+ electric buses; city targets a zero-emission bus fleet by 2030.
United States	Los Angeles	The metro bus system will be transitioning to fully electric by 2030, targeting dense urban corridors.	Integrated with light rail and subway systems.	225+ electric buses in operation; reduced GHG emissions by 36% since integration began.
United Kingdom	London	Electric double-decker buses serve major routes across the city, alongside hybrid buses.	Integrated with Underground (Tube), overground rail services, and bike-sharing schemes.	Over 850 electric buses aim to achieve a fully zero-emission bus fleet by 2034.
Chile	Santiago	Operates one of the largest electric bus fleets in Latin America, deployed in urban areas.	Integrated with the Metro system for multimodal connectivity.	Over 800 electric buses are in operation, supported by renewable energy for charging.
Norway	Oslo	Electric buses used in urban and suburban routes; charging supported by clean energy sources.	Integrated with trams, ferries, and metro systems.	Over 100 electric buses; the city aims for a fossil-free public transport fleet by 2028.
Sweden	Gothenburg	Operates electric buses in urban areas with opportunity charging at select bus stops.	Integrated with trams, suburban rail, and bike-sharing.	200+ electric buses; city has reduced transit-related emissions by 30% in recent years.
South Korea	Seoul	Electric buses deployed on high-demand urban routes; plans for large-scale deployment.	Integrated with subway systems and local taxis as part of smart mobility initiatives.	Over 100 electric buses; plans to expand to 3,000 by 2025, with significant investment in charging infrastructure.

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BEB integration offers opportunities and problems for urban public transportation systems. The research that are discussed here stress how crucial it is to improve energy management, optimize charging infrastructure, and put supportive policies in place in order to guarantee the effective deployment of BEBs. The long-term viability of BEB systems will be greatly influenced by developments in energy storage and battery technology as well as financial incentives like subsidies. In order to strengthen BEB's position in decarbonizing urban transportation, more research should be done on how their widespread use affects grid stability and environmental performance. To put it briefly, these studies highlight the significance of ride sourcing integration, real-time information, optimization strategies, user engagement, and spatial-temporal accessibility in enhancing the performance of integrated transit systems. They also highlight the complex challenges and solutions that these systems present. For those in charge of transit planning and policy, this research offers vital information.

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