Analysis of Carbon Reduction Benefits and Promotion Strategies for Fully Electrified Urban Bus Fleets

Jingyi Jia*

Faculty of Forestry, University of British Columbia, Vancouver, British Columbia, V8h 9H2, Canada

*Corresponding author: ubc0726@student.ubc.ca

Abstract. As society develops, environmental pollution has become increasingly severe. Urban air quality has deteriorated significantly. Investigations reveal that urban transportation systems emit substantial greenhouse gases, making them one of the primary sources of global greenhouse gas emissions. Among these, diesel buses account for a significant share of urban air pollution and energy consumption. To address bus emissions, protect the global environment, and achieve carbon neutrality goals, the electrification of bus fleets has emerged as a solution. A fully electrified bus system can effectively reduce exhaust emissions, enhance energy efficiency, and support the transition to renewable energy. Using London, UK, as a case study, this paper explores emission reduction and promotion strategies for electric bus systems, as well as how such systems reshape urban landscapes and transform city life. Research indicates that electrification not only drastically cuts pollutants like CO_2 and lowers operational costs but also creates quieter, healthier urban neighborhoods, thereby improving quality of life. Through a series of analytical studies, this paper proposes multiple parallel solutions: alleviating investment pressures through innovative financing models, adopting intelligent charging solutions, overcoming battery technology bottlenecks, and establishing long-term governance mechanisms. Collaborative efforts among governments, operators, manufacturers, and the public are essential to achieve emission reduction goals. The transition from fuel-powered to electric buses represents not merely a vehicle upgrade but a fundamental shift in travel patterns and habits. If executed effectively, this transformation holds critical potential for achieving synergistic benefits in climate resilience and public health.

Keywords: Electric Buses; Carbon Reduction; Urban Transportation; Charging Infrastructure; Promotion Strategies.

1. Introduction

1.1. Research Background

Urban transportation is widely recognized as one of the primary sources of global greenhouse gas (GHG) emissions, accounting for nearly 23% of all energy-related CO_2 output [1]. As the most prevalent form of public transit, buses provide convenient and affordable commuting options. However, most buses are diesel-powered vehicles that consume significant amounts of fossil fuels. This not only incurs high costs but also exacerbates local environmental degradation, degrades air quality, and increases health risks. Around congested urban corridors, concentrations of nitrogen oxides (NOx) and fine particulate matter ($PM_{2.5}$)—most traceable to diesel buses—have been directly linked to respiratory illnesses, cardiovascular disorders, and even premature death [2].

Electrifying bus fleets offers a viable pathway to decarbonization. Electric buses not only reduce tailpipe emissions but also facilitate the integration of renewable energy sources [1]. Rough estimates indicate electric buses can cut greenhouse gas emissions by nearly 75% compared to fuel-powered buses [2]. Furthermore, electric buses (e-buses) are better suited for urban environments due to their fixed routes, centralized charging stations, and relatively stable operating cycles. Compared to private electric vehicles, their fixed-route operation simplifies charging infrastructure planning. Beyond significant emissions reductions, electric buses also lower operational costs throughout their lifecycle, thereby providing robust support for the financial sustainability of public transport systems [3].

The UK has taken the lead in Europe by committing to achieve net-zero emissions by 2050. Transport for London (TfL) has proposed phasing out diesel buses by 2030 and achieving a fully zero-emission bus fleet by 2037[4]. This policy not only helps reduce carbon emissions but also generates long-term economic and social benefits. Following suit, commitments have emerged across Europe: The Netherlands aims for all new vehicles to be zero-emission by 2025, while Oslo, Norway's capital, pledges to establish a zero-emission public transport system by 2028 [5]. The benefits of electric bus systems extend beyond climate advantages, encompassing multidimensional considerations such as improving urban air quality, reducing dependence on fossil fuels, and enhancing energy security. As global action accelerates, academic and policy research institutions have delved into the impacts and insights brought by bus electrification.

1.2. Literature Review

Existing literature on electric buses can be broadly categorized into three streams: environmental impact assessments, techno-economic analyses, and policy evaluations. Several studies have examined the role of electric buses in emission reduction. Xylia and Silveira found that large-scale deployment of e-buses in European cities could reduce lifecycle emissions by up to 75% compared to diesel buses, even accounting for electricity generation mixes [6]. Wang et al. highlighted the health co-benefits of reduced particulate matter from bus electrification in London, estimating significant savings in healthcare costs due to fewer pollution-related illnesses [7]. Meanwhile, Buekers et al. analyzed lifecycle greenhouse gas reductions in Belgium, concluding that e-buses powered by increasingly renewable electricity grids are environmentally superior to diesel or natural gas alternatives [8].

In terms of challenges, Rogge et al. identified issues such as limited charging infrastructure, range limitations, and high upfront costs, which slow down fleet electrification despite long-term savings [9]. Studies also emphasize the importance of government incentives, such as the UK's Zero Emission Bus Regional Areas (ZEBRA) scheme, in accelerating adoption [4].

Comparative analyses have highlighted financial aspects. Li and Castellanos showed that despite higher upfront costs, electric buses achieve lower lifetime costs due to savings in fuel and maintenance [10]. Chen and Kockelman demonstrated that optimized charging strategies, such as opportunity charging at bus terminals, can significantly reduce operational costs and improve efficiency [3]. Wang and Zhao reported that electric buses could reduce GHG emissions by 40–50% depending on the carbon intensity of the local electricity mix [11]. These studies converge on the importance of supportive policies, adequate charging infrastructure, and financial incentives as critical success factors for scaling adoption [3].

1.3. Research Gap and Contribution

Despite the growing body of literature, most existing studies focus on either the technical performance of electric buses or the environmental outcomes. Fewer of these perspectives are combined with policy design, financing mechanisms, and implementation strategies within European urban contexts. For example, while lifecycle analyses provide strong evidence of environmental benefits, they often overlook institutional, financial, and social barriers that determine whether large-scale adoption is feasible [3,8]. Similarly, cost analyses highlight lifetime savings but rarely address issues of equity or accessibility in financing electrification projects.

Additionally, while there is extensive research on emission reductions in Asian contexts such as China, where the world's largest electric bus fleet operates in Shenzhen, fewer integrated studies focus specifically on the UK and Europe [4,6]. Given Europe's ambitious climate targets, there is a need for a holistic analysis that bridges technical, economic, and policy perspectives to guide cities through this transition.

This study fills this gap by examining London and Coventry as representative cases of large-scale electrification. London, as a global megacity with an ambitious 2037 zero-emission target, presents a pioneering case of large-scale implementation. In contrast, Coventry, with its all-electric depot model, offers insights into the challenges and solutions for high-penetration electrification in a more typical urban setting. This comparative element strengthens the study's conclusions.

It connects the carbon reduction benefits of electrification with the practical challenges faced by operators and policymakers. London, as a global megacity with an ambitious 2037 zero-emission target, presents a pioneering case of large-scale implementation. In contrast, Coventry, with its all-electric depot model, offers insights into the challenges and solutions for high-penetration electrification in a more typical urban setting. This comparative element strengthens the study's conclusions.

The research framework includes: (1) a case description of London's transition, (2) analysis of benefits and challenges, (3) targeted strategies for overcoming barriers, and (4) implications for broader adoption across Europe. Through this approach, the paper links environmental benefits with practical strategies, contributing to sustainable urban transport discourse.

1.4. Study Structure and Methodology

This paper is structured into four core sections. Section 2 tracks the evolution of bus electrification across the United Kingdom, with London and Coventry—both leading cases—receiving special focus. Section 3, next, delves into the two-sided landscape of opportunities and hurdles: it examines the benefits of carbon reduction while also addressing constraints tied to operations, finances, and infrastructure. In Section 4, the focus shifts to solutions; policy design, innovative financing, and technological progress are treated not as isolated measures but as complementary strategies to be considered in tandem. To wrap up, Section 5 pulls the discussion into focus, laying out the central findings, pinpointing the study's contributions, and highlighting directions where further research holds the greatest value.

2. Comparative Case Studies: Pathways to Electrification in London, Amsterdam, and Oslo

This section will introduce three European cities: London, Amsterdam, and Oslo. All three are leading cities in implementing public transport electrification. By comparing their differences in local policies, infrastructure planning, and energy structures, this study gains clear insight into how diverse pathways can offer guidance to other urban systems.

As the capital of the United Kingdom, London is at the forefront of global zero-emission public transport networks. Transport for London (TfL), which oversees the city's extensive public transport system, has committed to completing the transition by 2037. This pledge is bolstered by initiatives such as the Green Bus Fund, the Ultra-Low Emission Bus Scheme, and, most recently, the Zero Emission Bus Regional Areas (ZEBRA) initiative, amplifying its impact. The government has also effectively mitigated the high initial costs of electric vehicles for operators through subsidies and regulatory measures. By 2023, the city had deployed over 850 pure electric buses and more than 20 hydrogen fuel cell-powered vehicles—making London Europe's largest zero-emission bus fleet [12]. Given the scale of its transport network—among the world's most extensive, carrying millions of daily passengers—this achievement represents a critical milestone, not merely an incremental step.

Infrastructure development has played a critical role in enabling this transition. TfL has deployed multiple high-capacity charging depots strategically located across the city, while pilot projects have tested on-street rapid charging stations to improve operational flexibility [13]. Depot-based charging has proven effective for overnight recharging, while opportunity charging allows buses to top up during the day without disrupting services. Investment in charging infrastructure has required close collaboration between TfL, local authorities, and energy providers to ensure sufficient grid capacity. These investments highlight the importance of integrated planning between the transport and energy sectors.

Environmental assessments demonstrate measurable benefits. Reports estimate that London's electric bus fleet already achieves annual reductions of around 40,000 tons of CO_2 emissions compared to equivalent diesel buses [14]. This quantifiable environmental payoff helps justify the significant upfront infrastructure investments and strengthens the political case for continued expansion. In addition, tailpipe elimination has led to significant decreases in nitrogen oxides (NOx) and particulate matter ($PM_{2.5}$), improving air quality in pollution hotspots such as Oxford Street and Brixton. The public health implications are considerable, with reduced exposure to harmful emissions lowering the risk of asthma and other respiratory diseases, particularly among children and vulnerable groups.

Although upfront capital costs remain high—electric buses typically cost 50–70% more than diesel equivalents—long-term economic benefits strengthen the case for electrification. Lower operating and maintenance costs are expected to generate substantial lifetime savings. Furthermore, local bus manufacturers and technology suppliers benefit from increased demand for zero-emission vehicles, contributing to green jobs and industrial growth within the UK [15]. Beyond direct financial considerations, electrification supports London's broader climate strategy and enhances the city's reputation as a pioneer in sustainable mobility, as shown in Figure 1

In addition to London, several other European cities have committed to ambitious zero-emission bus transitions. Amsterdam, for example, aims to operate only zero-emission buses by 2025 as part of the Dutch national climate strategy [16]. The city has already deployed a significant number of electric buses and relies heavily on opportunity charging infrastructure at central hubs, such as Schiphol Airport. This stands in contrast to London's heavier reliance on depot charging, demonstrating a different infrastructural philosophy tailored to Amsterdam's dense urban geography and operational patterns. This model has allowed Amsterdam to maintain intensive service levels while gradually phasing out diesel vehicles.

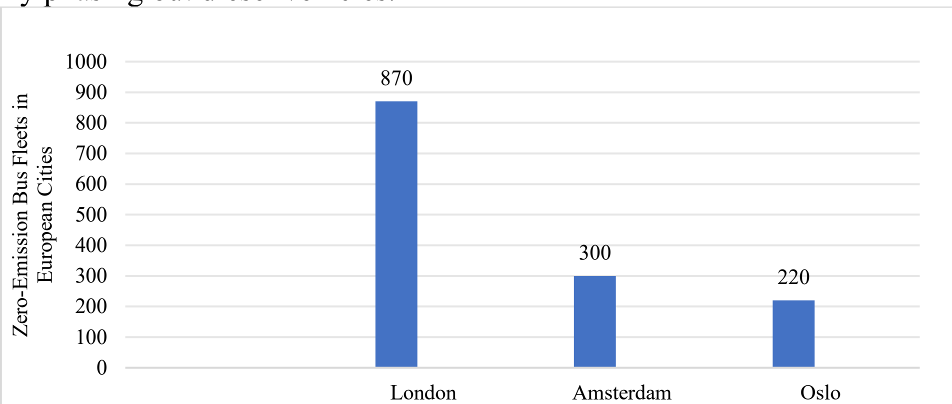

Fig. 1 Zero-Emission Bus Fleets in European Cities [12]

Similarly, Oslo, the capital of Norway, has integrated bus electrification into its broader climate action plan. By 2028, Oslo aims to operate a 100% zero-emission public transport system, including buses, trams, and ferries [17]. The city benefits from Norway's electricity grid, which is dominated by renewable hydropower, ensuring that electric buses operate with minimal lifecycle emissions. The advantages in this specific context highlight a crucial consideration: the carbon reduction benefits of electric buses depend on the cleanliness of the power grid. This factor is an indispensable part of the overall assessment. As of 2022, Oslo has deployed over 200 electric buses and plans to rapidly scale up in collaboration with public transport operator Ruter [18]. Oslo's case not only demonstrates how a clean electricity supply can maximize the climate benefits of electrification but also provides lessons on integrating e-buses with other modes of zero-emission transport.

These cases collectively validate the feasibility and sustainability of urban bus electrification across diverse scenarios. While methodologies vary, all three demonstrate that success hinges on multi-stakeholder collaboration mechanisms, requiring political commitment, robust infrastructure, and appropriate financing solutions. The London case demonstrates how policy support, financial investment, and infrastructure development drive electric bus adoption in metropolitan areas. Amsterdam highlights the synergistic effects of timely policy implementation and innovative charging strategies. Oslo reveals how renewable energy systems amplify the environmental benefits of electrification. Together, these examples provide practical guidance for global cities pursuing sustainable transportation.

3. Benefits and Challenges: A Balanced Analysis of Bus Fleet Electrification

3.1. Key Benefits and Positive Impacts

3.1.1 Significant carbon reduction

Electrified buses eliminate tailpipe emissions entirely, leading to substantial reductions in carbon dioxide (CO_2), nitrogen oxides (NOx), and particulate matter ($PM_{2.5}$). Numerous life cycle analyses demonstrate that electric buses can reduce greenhouse gas (GHG) emissions by 40–60% compared to conventional diesel buses, depending on the carbon intensity of the electricity mix, as shown in Figure 2 [6]. In London, Transport for London (TfL) reports that the current electric bus fleet reduces approximately 40,000 tons of CO_2 annually compared to diesel alternatives [14]. Similar benefits are reported in Amsterdam and Oslo, where renewable-dominated electricity grids further enhance reductions, achieving near-zero lifecycle emissions [16]. Moreover, similar emission reduction potential has been demonstrated in developing urban settings, such as Nairobi, where electric bus deployment models show significant CO_2reductions during operational lifetimes, even amid constraints in grid infrastructure [19].

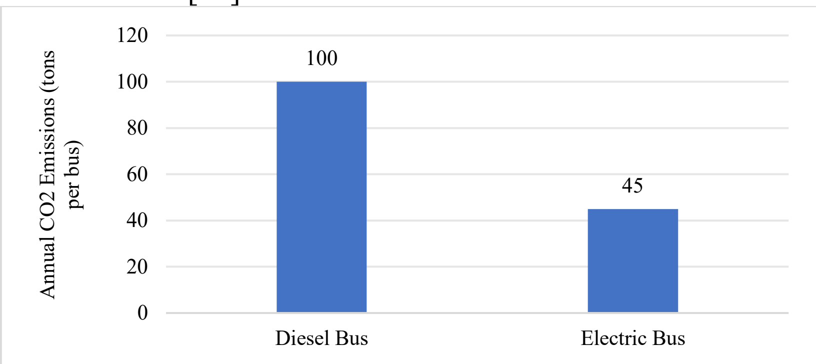

Fig. 2 Lifecycle CO_2 Emissions: Diesel vs Electric Bus [6]

The cumulative impact of widespread electrification across European cities is profound. If London, Amsterdam, and Oslo fully implement their electrification targets, combined reductions could reach several hundred thousand tons of CO_2 annually. These reductions are critical to meeting national climate targets under the UK's Net Zero Strategy and the European Union's Sustainable and Smart Mobility Strategy [5]. The replacement of diesel buses also contributes to reduced dependence on imported fossil fuels, improving long-term energy security in Europe [1].

3.1.2 Energy efficiency and long-term cost savings

Electric drivetrains are significantly more energy efficient than diesel engines. Whereas internal combustion engines convert only around 30–35% of fuel energy into useful motion, electric buses convert more than 80% of electricity into traction power [20]. This efficiency translates into lower energy use per passenger-kilometer and improved overall system sustainability.

Although the upfront purchase cost of electric buses commands a significant premium over that of their diesel counterparts, long-term operational savings are compelling. Fuel costs for electricity are typically 50–70% lower than diesel, and maintenance savings can reach up to 40% due to the reduced number of moving parts in electric drivetrains [9]. Studies in the UK estimate that the total cost of ownership (TCO) for electric buses can become competitive with diesel within 7–10 years, even without subsidies [15]. Similar findings are echoed in lifecycle assessments by Lajunen, who shows that charging strategies significantly influence TCO and optimal fleet design [21]. In Norway, where electricity prices are stable and largely renewable-based, the TCO break-even point is achieved even earlier, often within 5–6 years, as shown in Figure 3 [17].

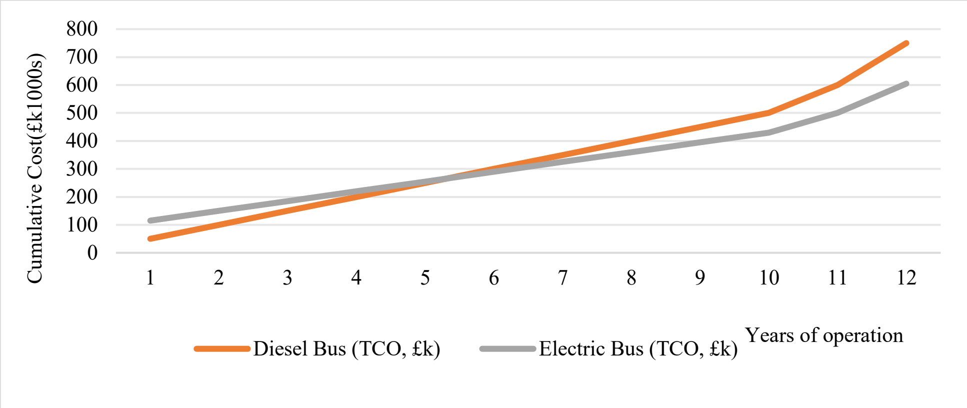

Fig. 3 Total Cost of Ownership (TCO): Diesel vs Electric Bus [18]

Furthermore, electrification provides resilience against fluctuations in global oil markets. Diesel prices are highly volatile due to geopolitical risks, while electricity, particularly from domestic renewable sources, offers a more predictable cost structure. This financial stability supports long-term planning for public transport operators and reduces vulnerability to external shocks [1].

3.1.3 Health, noise, and environmental benefits

Electrification provides substantial co-benefits for public health and the urban environment. Diesel buses are a significant source of local pollutants, including NOx and $PM_{2.5}$, both of which are associated with respiratory diseases, cardiovascular conditions, and premature mortality [2]. Electric buses eliminate these tailpipe emissions, directly improving air quality in densely populated urban centers. In London, studies found that boroughs along electrified bus routes experienced measurable declines in hospital admissions for asthma and respiratory problems [7].

Noise reduction is another key benefit. Electric buses operate much more quietly than their diesel counterparts, lowering ambient noise levels in congested streets. This contributes to improved passenger comfort, pedestrian safety, and overall urban livability [1]. Surveys conducted in the Netherlands indicate higher passenger satisfaction with electric buses, particularly in residential areas where reduced noise enhances quality of life [16].

Beyond air and noise pollution, electrification reduces the risk of oil spills and environmental hazards associated with fuel logistics. Moreover, by integrating with renewable energy, electric buses indirectly support the decarbonization of the broader energy system, fostering synergy between the transport and power sectors [8].

3.2. Persistent Barriers and Implementation Challenges

3.2.1 High initial investment costs

Despite long-term savings, the initial investment costs of electric buses remain a substantial barrier. An electric bus typically costs 50–100% more than a diesel bus, primarily due to the high cost of lithium-ion batteries [17]. For example, while a standard diesel bus may cost around £350,000, an electric equivalent can exceed £600,000. This upfront disparity creates financial strain for operators, especially in regions where subsidies are limited or declining. Similar optimization challenges related to fleet size and mix decisions are well-documented in operational research fields, including maritime transport, and provide transferable insights to public bus systems [22].

Infrastructure costs add to the challenge. Charging stations, depot retrofitting, and grid reinforcement significantly increase capital expenditure. A 2022 report estimated that installing charging infrastructure for a fleet of 100 buses in a UK city could require an additional £10–15 million investment [13]. Without long-term government grants or innovative financing models, many municipal transport authorities struggle to make the financial case for electrification, particularly in smaller cities. This creates a fundamental paradox: the technology with the lowest long-term cost faces the highest initial barrier to adoption, locking cities into more expensive and polluting diesel cycles.

3.2.2 Charging infrastructure constraints

The successful deployment of electric buses depends heavily on reliable and widespread charging infrastructure. Current limitations in charging availability and speed are major operational bottlenecks. Depot charging is suitable for overnight use but requires large amounts of space and significant upgrades to electrical connections [13]. In dense urban environments like London, securing sufficient land for charging depots is a persistent challenge.

Opportunity charging technologies, which enable buses to recharge quickly at terminals or along routes, can mitigate range anxiety but require standardized equipment and large upfront investments. Moreover, charging hundreds of buses simultaneously places considerable strain on local electricity grids, necessitating expensive grid reinforcements [23]. For example, Oslo's bus electrification project faced delays due to insufficient grid capacity at major depots, highlighting the need for coordinated planning between energy providers and transport authorities [17]. This underscores that the charging infrastructure challenge is not merely technical, but fundamentally a governance and coordination problem.

3.2.3 Battery performance and recycling issues

Battery performance remains a technological limitation. Lithium-ion batteries degrade over time, typically losing 20–30% of capacity over 8–10 years of operation [23]. This reduces range and reliability, potentially increasing fleet size requirements to maintain service levels. Cold weather conditions in Northern Europe exacerbate range limitations, requiring additional heating systems that consume energy and further shorten effective range [17].

End-of-life management of batteries presents another challenge. Recycling systems for large-format lithium-ion batteries are still underdeveloped in most European countries. While research is advancing in circular economy models, current recycling rates remain below 10% [19]. The lack of robust recycling infrastructure raises concerns over resource scarcity, environmental risks, and long-term sustainability. Valuable raw materials such as cobalt, nickel, and lithium must be recovered efficiently to ensure future supply security. Without effective recycling, widespread bus electrification risks creating new environmental problems. Therefore, developing a circular economy for batteries is not an optional add-on, but a prerequisite for the sustainable lifecycle management of the entire electric bus fleet.

3.2.4 Policy and market barriers

Policy frameworks are critical for scaling up electrification, yet uncertainty remains a major barrier. Subsidies and grants, such as the UK's ZEBRA scheme, are time-limited and subject to political shifts [6]. Operators face risks when committing to high-cost investments without assurance of long-term policy stability [4]. In addition, fragmented regulatory standards across countries and even cities hinder the development of interoperable charging systems and fleet technologies.

Market risks also complicate adoption. Government subsidies continue to shrink, coupled with persistent fluctuations in electricity prices, which have led to hidden cost increases for electric buses, diminishing their economic appeal. Small and medium-sized operators face even greater difficulties in securing financing for the transition. Meanwhile, the immaturity of battery technology forces operators to guard against technical risks [23]. Without clear long-term policy guidance from the government, the electrification of bus fleets may be hindered.

4. Strategies and Policy Recommendations for Overcoming Barriers

The analysis in Section 3 shows various challenges related to the electrification of urban bus fleets, ranging from high capital costs to infrastructure bottlenecks and policy uncertainties. To solve these problems, researchers suggest using a combination of financial, technological, and governance strategies. This module proposes a series of policy recommendations and innovative approaches aimed at facilitating the transition to electrified public transport systems in the UK and globally.

4.1. De-risking Investment: Innovative Financing and Business Models

The biggest challenge in the large-scale rollout of electric buses is the high upfront construction costs for the vehicles and their associated infrastructure. To solve these problems, this study can establish a government-operator financing model tailored to current conditions. Taking the Public-Private Partnership (PPP) model as an example, shared investment responsibilities create a win-win scenario: private enterprises provide funding for vehicles and charging facilities while securing returns through long-term service agreements [24]. Leasing arrangements also present a viable option—operators opt to lease buses or batteries rather than purchasing outright. This approach reduces upfront investment while aligning capital recovery more closely with long-term revenue streams. A further variation, the Battery-as-a-Service (BaaS) model—already piloted in several Asian markets—could be introduced in Europe to shield operators from the financial risks of battery ownership.

Beyond these operational mechanisms, cities may also turn to the financial markets. Green bonds and climate-oriented investment funds supply stable, long-term capital for sustainable transport, and Paris, as well as Copenhagen, have already demonstrated how municipal bonds can underwrite major electrification programs [25]. In parallel, carbon credits generated by reduced emissions can be sold through voluntary markets, with the proceeds reinvested in additional fleet upgrades. By diversifying funding streams in this way, operators lessen their reliance on direct government subsidy and place their transition on a more durable financial footing.

4.2. Infrastructure Optimization and Grid Integration

Developing adequate charging infrastructure is critical for operational reliability. Cities should adopt mixed charging strategies, combining overnight depot charging with on-route fast charging stations. Crucially, infrastructure planning must be integrated with urban development and renewable energy expansion plans from the outset, rather than being treated as a secondary retrofit.

Depot charging is cost-effective and allows buses to recharge during idle periods, while fast charging at strategic hubs can extend operational range without disrupting service schedules [25].

Smart charging systems that optimize charging times according to grid capacity and electricity price signals can further reduce costs and mitigate grid stress. For example, load management software can stagger charging across fleets to prevent simultaneous demand spikes. Integration with renewable energy sources, such as solar panels installed on depots, can supply buses directly with green electricity and reduce reliance on fossil-based grid power.

Grid integration strategies should also prioritize Vehicle-to-Grid (V2G) technologies, which allow buses to discharge electricity back to the grid during peak hours. Pilot projects in the Netherlands and Denmark demonstrate that V2G-enabled buses can enhance grid stability and generate revenue streams for operators [26]. By viewing buses not only as consumers but also as mobile storage assets, cities can create synergies between transport and energy systems.

4.3. Advancing Battery Technology and Recycling Systems

Battery technology remains central to the success of bus electrification. Current lithium-ion batteries face limitations related to degradation, range, and cost. Governments and industry should prioritize research and deployment of next-generation technologies such as solid-state batteries, which offer higher energy density, faster charging times, and longer lifespans [17]. Such innovations would significantly reduce operational risks and improve the total cost of ownership of electric buses.

Recycling systems must also be scaled up to address end-of-life battery challenges. The European Union has recently proposed regulations mandating higher recycling efficiency targets and material recovery for lithium, nickel, and cobalt [27]. National governments should not only comply with but proactively exceed these EU benchmarks, establishing themselves as leaders in the circular economy for batteries and creating a competitive advantage for their domestic industries.

Investment in closed-loop recycling facilities will reduce environmental impacts, enhance raw material security, and create new industrial opportunities in the circular economy. In the UK, partnerships between manufacturers, recyclers, and local authorities can ensure that the transition to electrified fleets does not create new sustainability problems.

4.4. Enabling Transition: Stable Policy Frameworks and Multi-level Governance

Stable and long-term policy frameworks are essential for giving confidence to operators and investors. Governments must establish clear zero-emission deadlines and harmonize standards across the UK and EU to ensure interoperability of technologies [27]. By reducing regulatory fragmentation, such coordination lowers risks, avoids incompatible technologies, and allows manufacturers to scale production more efficiently.

Equally important is the role of public opinion. Awareness campaigns that highlight the health gains, quieter streets, and climate contributions of e-buses can generate broader acceptance. When passengers and operators are assured of service reliability throughout the transition, resistance diminishes. Local authorities can reinforce this acceptance through practical measures: low-emission zones, congestion charges, or priority bus lanes designed for zero-emission vehicles, all of which create further incentives for electrification.

No less critical is the governance structure itself. Effective transition requires collaboration among transport operators, energy suppliers, vehicle manufacturers, and the communities they serve. Multi-level governance—in which city administrations, national governments, and EU institutions coordinate—has the potential to unlock synergies and prevent duplication of effort. While frameworks such as the EU's Green Deal and the "Fit for 55" package set the overall trajectory, local governments still carry the responsibility of tailoring these policies to regional realities if they are to succeed [24].

5. Conclusion

In conclusion, this paper demonstrates that transitioning diesel bus fleets to electric buses can significantly reduce carbon emissions, enhance operational efficiency, and improve public health. Cities like London, Amsterdam, and Oslo have achieved substantial economic and health benefits by deploying electric buses, lowering greenhouse gas emissions and air pollution while providing cleaner, more comfortable travel experiences. These benefits encourage greater public adoption of electric bus travel, further cementing electric buses as a core pillar of sustainable urban transportation and creating a virtuous cycle. Simultaneously, this lays the groundwork for achieving targets such as the UK's "Net Zero by 2050" strategy and the EU's "Green Deal."

However, the report also highlights challenges in transforming public transport systems. The high costs of vehicle procurement and charging infrastructure remain significant barriers for many city governments and operators. Infrastructure deficiencies, such as insufficient charging network coverage and limited grid capacity, severely undermine the operational reliability and sustainability of large fleets. Policy uncertainty and persistent funding gaps expose operators and investors to financial risks, slowing technological adoption. Complexities like battery performance degradation and inadequate recycling capacity further complicate the path to fully sustainable charging systems. To address these challenges and facilitate a smooth public transport transition, this paper proposes parallel solutions in finance, technology, and policy. Innovative financing mechanisms—including public-private partnerships, leasing programs, and green bonds—can achieve equitable cost-sharing and reduce reliance on subsidies. Infrastructure development strategies—such as hybrid charging solutions and smart grid integration—ensure power supply reliability while alleviating local energy constraints. Advanced battery research and robust recycling systems enhance long-term equipment performance and resource efficiency, playing a vital role in transportation systems. Finally, policy innovation, cross-regional standardization, and clear long-term governance frameworks are essential for market stability and stakeholder trust.

London's successful transition offers invaluable lessons for global urban electrification. It demonstrates that large-scale electrification of city transport systems is achievable with robust policy frameworks, sustained investment, and coordinated support from local governments, energy suppliers, and transport operators. Simultaneously, the London case highlights the importance of addressing practical constraints such as limited charging station space, lengthy charging times, and high costs. Other European city cases—including Amsterdam's tight policy deadlines and Oslo's integration of electrification with renewable energy—further underscore the necessity of aligning local strategies with broader climate and energy systems. Concurrently, London demonstrates the critical importance of addressing challenges like insufficient charging infrastructure space, prolonged charging times, and cost burdens. Other European city cases—including Amsterdam's urgent policy deadlines and Oslo's integration of electrification with renewable energy—further underscore the importance of aligning local strategies with broader climate and energy systems.

Future research should build upon these measures by collecting primary data. Through comparative analysis of grid structures and governance models across different regions, a thorough understanding of local characteristics can effectively advance the electrification process..

References

[1] International Energy Agency. Global EV outlook 2022: Securing supplies for an electric future, 2022. IEA. https://www.iea.org

[2] European Environment Agency. Air quality in Europe: 2019 report. EEA. https://www.eea.europa.eu

[3] Tao Chen, & Kara Kockelman. The electric bus as a vehicle for sustainability. Transportation Research Part C, 2015, 57, 183–198.

[4] UK Department for Transport. Zero emission bus regional areas (ZEBRA) scheme, 2021. Gov.UK. https://www.gov.uk

[5] European Commission. Sustainable and smart mobility strategy – putting European transport on track for the future, 2020. EU. https://ec.europa.eu

[6] Maria Xylia, & Semida Silveira. The role of charging technologies in upscaling the use of electric buses in public transport. Sustainable Cities and Society, 2018, 40, 397–406.

[7] Wang Meng, Roel Beelen, & Bert Brunekreef. Health benefits of transitioning to zero-emission buses in urban environments. Environmental Research, 2019, 174, 128–135.

[8] Joris Buekers, Marlies Van Holderbeke, Jos Bierkens, & Luc Int Panis. Health and environmental benefits related to electric vehicle introduction in EU countries. Transportation Research Part D, 2014, 33, 26–38.

[9] Markus Rogge, Erik van der Hurk, Allan Larsen, & Dirk Uwe Sauer. Electric bus fleet size and mix problem with optimization of charging infrastructure. Applied Energy, 2018, 211, 282–295.

[10] Li Xinyu, & Sergio Castellanos. Cost analysis of electric buses compared to conventional diesel buses. Energy Policy, 2020, 144, 111648.

[11] Wang Yong, & Zhao Hongliang. Environmental and economic assessment of electric buses in China. Journal of Cleaner Production, 2018, 172, 1559–1569.

[12] Transport for London. London's zero emission bus fleet progress report, 2023. TfL. https://tfl.gov.uk

[13] Greater London Authority. Electric bus infrastructure strategy, 2022. GLA. https://www.london.gov.uk

[14] Committee on Climate Change. Progress report on UK transport decarbonization, 2022. CCC. https://www.theccc.org.uk

[15] Li Xinyu, & Sergio Castellanos. Cost analysis of electric buses compared to conventional diesel buses. Energy Policy, 2020, 144, 111648.

[16] Gemeente Amsterdam. Clean air action plan 2025. Amsterdam Municipality, 2019. https://www.amsterdam.nl

[17] Oslo Kommune. Climate strategy for Oslo towards 2030. Oslo Municipality, 2021. https://www.oslo.kommune.no

[18] Ruter. Electrification of Oslo's bus fleet: Progress report, 2022. Ruter AS. https://www.ruter.no

[19] Mercy Chelangat Koech, & Babak Fahimi. An Energy Demand Analysis and Emission Reduction Potential of Electric Buses for Cities in Developing Economies: A Case Study of Nairobi, Kenya, 2024. Proceedings of the IEEE. https://ieeexplore.ieee.org/document/10759494

[20] Bwo-Ren Ke, Shyang-Chyuan Fang, & Jun-Hong Lai. Adjustment of bus departure time of an electric bus transportation system for reducing costs and carbon emissions: A case study in Penghu. Energy & Environment, 2022, 33(4), 728–751. https://doi.org/10.1177/0958305X211016872

[21] Antti Lajunen. Lifecycle costs and charging requirements of electric buses with different charging methods. Transportation Research Part C: Emerging Technologies, 2018, 97, 17–30.

[22] Tiziano Pantuso, Kyrre Fagerholt, & Lars Magnus Hvattum. A survey on maritime fleet size and mix problems. European Journal of Operational Research, 2014, 235(2), 341–349. https://doi.org/10.1016/j.ejor.2013.10.054

[23] Gavin Harper, Paul Sommerville, Emma Kendrick, et al. Recycling lithium-ion batteries from electric vehicles. Nature, 2019, 575, 75–86.

[24] Sandoval, J. S. O., & Gakenheimer, R. Emerging trends and innovations for electric bus adoption—a comparative case study of contracting and financing of 22 cities in the Americas, Asia-Pacific, and Europe. Research in Transportation Economics, 2017, 63, 44–56. https://doi.org/10.1016/j.retrec.2017.06.004

[25] European Investment Bank. Green bonds for sustainable transport: Case studies in European cities, 2021. EIB. https://www.eib.org

[26] João Abel Peças Lopes, Filipe Joel Soares, & Pedro Manuel Rocha Almeida. Integration of electric vehicles in the electric power system. Proceedings of the IEEE, 2011, 99(1), 168–183.

[27] Kallitsis, E., Ahmad, S., Afzal, M., & Song, M. Progress, challenges and opportunities in recycling electric vehicle batteries: A systematic review. Batteries, 2023, 11(6), 230. https://doi.org/10.3390/batteries11060230