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Original Article

Assessment of Costs and Environmental Benefits of the Transition from Conventional to Electric Buses in Hanoi

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Abstract: Hanoi is facing severe challenges of air pollution and greenhouse-gases emissions from the transportation sector, in which diesel-bus account for a substantial share. In the context of the Government of Viet Nam's commitment to achieve Net-Zero emissions by 2050, transitioning to a public transport system based on electric buses is an inevitable trend. To assess the sustainability of shifting from conventional internal-combustion engine (ICE) buses to electric buses, this study applies the DPSIR framework in combination with simulation modeling in the eMob Calculator developed by UNEP. The study simulates and compares two scenarios through 2050: i) Maintaining the current share of ICE buses; and ii) Full conversion to electric bus. The results show that the conversion scenario reduces CO_2, fine particulate matter (PM), NO_x, and energy consumption, while improving long-term operational cost efficiency. Although substantial upfront infrastructure investment is required, the cumulative economic and environmental benefits are evident. The conclusion affirms that transitioning to electric bus is necessary and consistent with national climate goals. The study recommends strengthening financial support, developing charging infrastructure, and designing policy incentives to encourage transport operators to participate in the transition.

Keywords: Electric buses, eMob Calculator, Greenhouse gas mitigation, Sustainable transport transition.

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1. Introduction

Under concurrent pressures from air pollution, traffic congestion, and carbon-neutrality goals, Hanoi is moving strongly toward "greening" public transport, in which electrifying the bus fleet is considered a key lever. With more than 8 million motorcycles and nearly 1.5 million automobiles, and with private vehicles increasing by 4–5% per year [1], the demand for road space and emissions from Hanoi's urban transport have already exceeded the city's infrastructural and environmental capacity. In terms of road-space use, each bus passenger occupies only about 1.5 m^2 of roadway, compared with 15 m^2 for a motorcycle and 47–79 m^2 for a private car. This demonstrates that public transport is far more efficient in both carrying capacity and road-space conservation [2]. Hanoi has set a target that by 2035 the entire public bus fleet will run on electricity or other clean energy sources, in parallel with increasing the public transport mode share to 50–55% [3], the transition requires major investment in vehicles and charging infrastructure. By February 2024, Hanoi had 20 of 157 routes using clean-energy buses (10 electric, 10 CNG), with 281 vehicles in total (142 electric, 139 CNG), accounting for 12.6% of the fleet-an encouraging but still modest share toward long-term goals [4].

The environmental context further underscores the urgency of the transition. The rapid growth of motorized vehicles has exacerbated urban air pollution, with "hotspots" concentrated along major traffic corridors [5]. The health burden is particularly alarming: traffic-related PM10 alone was estimated to be associated with approximately 3,200 additional deaths in Hanoi in 2009 [6]. At the vehicle-emissions level, diesel engines emit CO_2 at an emission factor of about 2.32 kg per liter; with an operating distance of 250–300 km per day, a diesel bus can emit 5.2–6.3 tons of CO_2 per month, roughly equivalent to the annual carbon uptake of about 3,000 mature trees [7]. Beyond CO_2, ICE buses are also major sources of NO_x and fine particulate matter PM2.5, especially under congested urban operating conditions and within an aging, low-efficiency fleet [8]. Certain after-treatment devices can alter the NO/NO_2 fraction within total NO_x, with implications for photochemical processes in the near-surface atmosphere [9].

"Electrifying" the bus fleet is therefore expected to deliver substantial environmental and public-health benefits alongside long-term operational efficiency gains. International studies indicate that switching to e-buses can cut CO_2 emissions at scale, for example, by 33–65% relative to diesel operation in the United States [10], and by approximately 68% in a Spain-based analysis when assessed on a full well-to-wheel basis (well-to-wheel) [11]. At the system level, reduced tailpipe emissions, lower noise, and better service quality can attract more passengers, supporting goals for higher public-transport use and more efficient land management. Meanwhile, domestic policies are expanding financial incentives, tax relief, and investment support for charging infrastructure, alongside stricter environmental standards, forming an enabling framework for the transition.

Within this context, the study quantifies and compares capital and operating costs and the environmental–social benefits of shifting from ICE to electric buses in Hanoi. It estimates system-wide reductions in CO_2, NOx, PM, and noise, and identifies barriers related to infrastructure, power supply, operations, and policy. The results provide quantitative evidence to guide policymaking, improve electrification roadmaps, and advance Hanoi's vision of green public transport.

2. Material and Methods

2.1. Data Collection

2.1.1. Socioeconomic Data

GRDP and population data for Hanoi were sourced from the annual Hanoi Statistical Yearbook issued by the Hanoi Statistical Office.

The 2000–2023 series captures long-term trends in population and economic growth. All tables were digitised and cross-checked across editions for consistency in definitions and units. Variables (year, population, nominal GRDP) were standardised, and discrepancies in units or rounding were resolved using the latest publication. This dataset outlines Hanoi's macro context of demographic and economic expansion, providing background for assessing transport demand and capacity pressures.

2.1.2. Bus System Data

Information on fleet size and composition, including vehicle numbers, fuel types (diesel, CNG, electric), route counts, and the share of clean-energy buses, was obtained from the Hanoi Public Transport Management and Operation Center and major operators such as Transerco. Data on CNG and e- bus deployment, pilot routes, and clean-vehicle shares were cross-checked with sectoral reports and public sources. The dataset spans 2015–2025, covering the diesel expansion period, the start of CNG services, and the acceleration of electrification after 2021. Indicators were compiled annually, checked for consistency, reconciled across sources, and screened for outliers before visualising fleet and fuel-mix trends.

2.1.3. Cost and Operational Data

Parameters on operating costs (fuel/electricity), maintenance and repair, and related expenditures (labor, consumables) were collated from sectoral reports and publicly available documents issued by management authorities and operators over the study period. These data support computation of total cost of ownership and the economic comparison between electric and ICE buses across the study's analysis scenarios. When source documents differed in the scope or definition of cost categories, the original classification was preserved and the coverage of each item was explicitly noted for use in the analysis.

2.1.4. Data Inputs for Transition Scenario Design

To assess the electrification pathways for the bus fleet, two scenarios were constructed based on secondary data and the existing policy–regulatory framework. Scenario 1 (Figure 1a) serves as a conservative baseline, in which the technological composition of the fleet (share of ICE buses) in 2030, 2040, and 2050 is assumed to remain unchanged from that of 2025. This approach reflects systemic inertia in the absence of additional policy interventions, while providing a counterfactual for system-scale cost–benefit and emission comparisons.

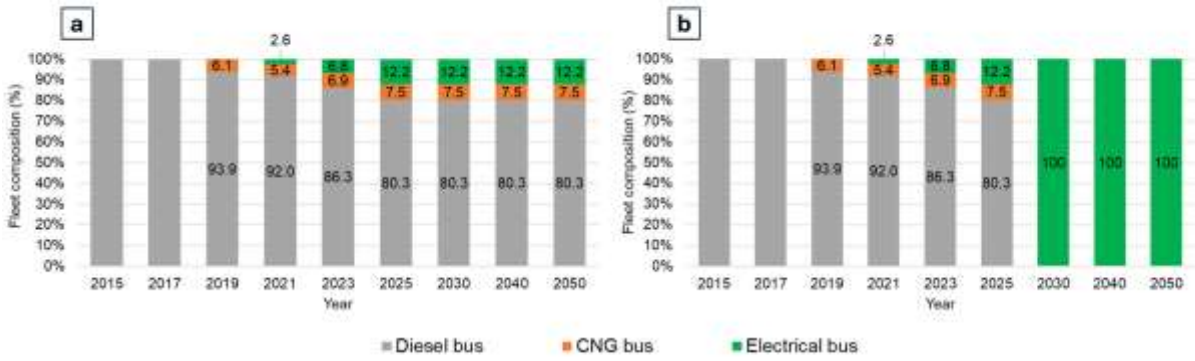

Figure 1. Transition Scenario 1 (a) and Scenario 2 (b).

Scenario 2 (Figure 1b) is formulated according to binding targets set by national and municipal policy instruments, rather than relying solely on historical trend extrapolation. Specifically, the annual shares of fleet are calibrated to comply with mandated targets:

achieving 70–90% electric or green-energy buses by 2030 as stipulated in Decision No. 6004/QĐ-UBND (2024) [3]; progressing towards full electrification during 2030–2035, with conversion to be completed before 2030 in accordance with Plan No. 149/KH-UBND (2025) [12] and the 90% green-energy bus target set by Decision No. 2066/QĐ-UBND (2025) [13]. The scenario further ensures alignment with the National Green Energy Transition Programme for the Transport Sector under Decision No. 876/QĐ-TTg (2022) [14] and the Net-Zero by 2050 Roadmap outlined in Decision No. 888/QĐ-TTg (2022) [15].

2.2. Environmental Cost–Benefit Tool: eMob Calculator

This study uses the UNEP eMob Calculator [16], developed under the Global Electric Mobility Programme (GEMP), to simulate energy consumption, greenhouse-gas (GHGs) emissions, air-pollutant emissions, and associated cost streams for the bus fleet under two scenarios through 2050. As part of the GEMP, the tool has been implemented in more than 24 countries to promote the uptake of electric vehicles and the development of charging infrastructure through standardized quantitative assessments [17].

The eMob Calculator applies fixed assumptions on economic context, emissions, vehicle performance and costs. GRDP projections follow the growth trajectory set in Decision No. 1569/QĐ-TTg (2024) [18] on the Capital Master Plan. A time-varying grid emission factor is used in accordance with the national energy transition pathway under Decision No. 888/QĐ-TTg (2022) [15]. Energy consumption is defined separately for electric, diesel and CNG buses, with a uniform annual mileage applied across technologies. For e-buses, battery lifetime and replacement cycles are explicitly accounted for. The model also incorporates capital and operating costs for charging infrastructure, technology-specific vehicle purchase prices, fuel and electricity price escalation, and a fixed discount rate. In the simulations, electricity supply for e-bus operation is assumed to come from the existing national grid without a changing renewable share.

Emission factors for Euro IV, Euro V and Euro VI technologies draw on international regulatory benchmarks, including Regulation (EU) No 582/2011 (2011) [19] and UN GTR No. 4 (2006, amended in 2021) [20,21], and are interpreted in line with the national transition framework set out in Decision No. 2066/QĐ-UBND (2025), Decision No. 876/QĐ-TTg (2022) [14] and Decision No. 888/QĐ-TTg (2022) [15].

Beyond reporting costs, the eMob Calculator quantifies environmental benefits when shifting to electric mobility, including reductions in GHGs emissions and local air pollutants, with direct applicability to e-buses. In parallel, it supports economic evaluation by estimating operating costs, maintenance, and fuel or electricity savings relative to ICE vehicles. The tool is delivered as an Excel workbook, is straightforward to use, and does not require advanced transport-modeling expertise. It enables users to construct scenarios and to project energy use, GHGs and air-pollution emissions, and related costs (vehicle capital, fuel or electricity, maintenance, and charging infrastructure) through 2050. The eMob Calculator has been applied in multiple projects and studies; for example, analyses in Dar es Salaam and Kigali used the tool to assess the impacts of SOLUTIONSplus interventions on GHGs emissions and air quality [22]. Evidence from multiple contexts supports this setup: in Australia, operational-phase dominance and grid carbon intensity can make e-bus GHGs exceed diesel (1.2–1.4 times) [23], whereas cleaner-grid settings like Canadian cities yield sizable cumulative cuts (18.7–34.6% over 2019–2030) [24]. Methodologically, multi-scenario designs for developing economies illustrate how to couple emissions-reduction potential with grid-impact assessment (10–100% penetration to 2050) [25].

2.3. DPSIR Analytical Framework

The DPSIR framework was used as an interpretive structure rather than an additional analytical model. The Driving Forces (D) comprised Hanoi's transport configuration, rapid urbanisation, rising mobility demand, and reliance on ICE buses. These translated into Pressures (P) represented by simulation-based indicators such as fuel use and emissions. The State (S) was inferred from the divergence between scenarios: Scenario 1 indicated continued combustion lock-in, while Scenario 2 reflected post-electrification conditions. The Impacts (I) were measured directly as avoided energy use, emissions, and operating costs, without secondary valuation. The electrification pathway in Scenario 2, consistent with Decision No. 6004/QĐ-UBND (2024) and Decision No. 876/QĐ-TTg (2022), was interpreted as the Response (R) addressing the identified pressures

3. Result and Discussion

3.1. Environmental Benefits

The evolution of energy use and emissions under both scenarios highlights the clear environmental benefit of fleet electrification (Figure 2). From 2015 to 2025, energy demand follows a similar path in both cases due to continued reliance on ICE buses, but the trajectories diverge sharply thereafter. Scenario 1's energy use keeps rising, surpassing 120 million Lge by 2050, whereas Scenario 2 levels off after 2030 at a much lower level. By 2050, the cumulative difference exceeds 1 billion litres of gasoline equivalent—evidence of major fossil fuel savings driven by the higher efficiency of electric drivetrains rather than reduced transport demand.

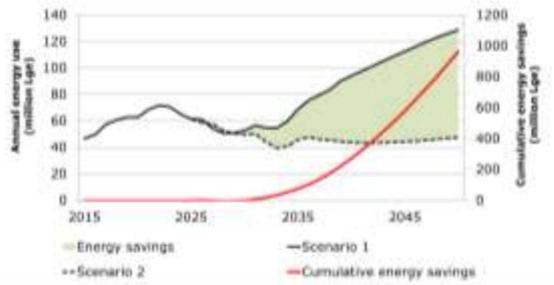

Figure 2. Annual energy use and cumulative savings.

A similar trend appears in particulate matter (PM) emissions (Figure 3). Both scenarios show a slight decline until 2025, reflecting gradual fleet renewal within the combustion-based system. After that, Scenario 1 stabilises at around 25–30 thousand tons per year, while Scenario 2 falls below 10 thousand tons by the early 2030s. The cumulative avoided emissions rise quickly, reaching about 400 thousand tons by 2050. Since PM emissions are concentrated along transport corridors, most of this reduction would occur in densely populated urban areas.

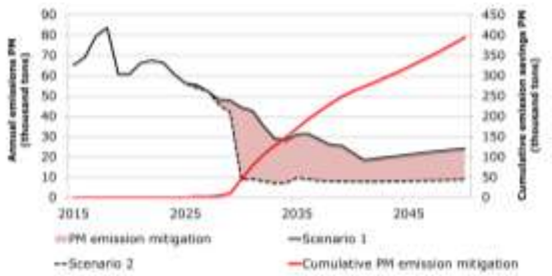

Figure 3. Annual PM emissions and cumulative reduction.

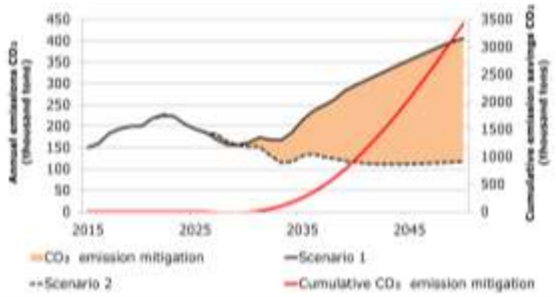

Figure 4. Annual CO_2 emissions and cumulative reduction.

CO_2 emissions show a comparable divergence (Figure 4). In Scenario 1, annual emissions stabilise at around 350–400 thousand tons by the late 2040s, while Scenario 2 declines to roughly 100 thousand tons by the early 2030s before levelling off. The cumulative reduction reaches about 3.5 million tons by 2050. This trend confirms that electrification provides a sustained environmental advantage even without major changes in the power mix. Since the estimates assume a static grid, further decarbonisation of electricity generation would enhance the CO_2 benefits of fleet electrification.

NO_x emissions show the largest proportional decline among all variables (Figure 5). In both scenarios, emissions peak at nearly 4,000 thousand tons before gradually decreasing. After electrification, Scenario 2 falls sharply to about 500–700 thousand tons, while Scenario 1 declines only to around 1,750–2,000 thousand tons. The cumulative difference between the two pathways reaches nearly 20 million tons by 2050. These patterns suggest that most NO_x mitigation occurs within the first decade after electrification, followed by slower incremental gains.

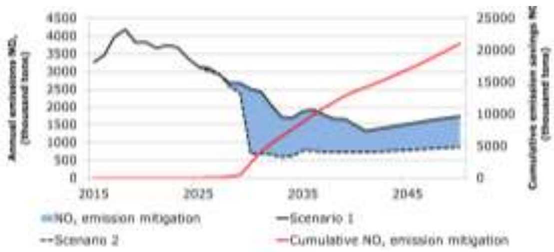

Figure 5. Annual NO_x emissions and cumulative reduction.

Across all environmental indicators, the greatest relative reduction occurs in NO_x, followed by PM, CO_2, and energy use. This ranking aligns with expectations: PM and NO_x emissions from ICE buses are directly tied to combustion, while CO_2 reductions also depend on the electricity mix's carbon intensity. Overall, the results confirm that electrification delivers the strongest benefits for pollutants associated with direct combustion, especially those with short atmospheric lifetimes.

From a policy perspective, this combined outcome provides quantitative validation for Hanoi's current transition strategy under Decision No. 6004/QĐ-UBND (2024) [3], which prioritises full-scale fleet electrification as the primary pathway for both climate and air-quality improvement. Rather than relying on incremental measures such as fuel blending or exhaust after-treatment, the results demonstrate that replacing ICE buses with electric models delivers simultaneous benefits across multiple pollutants without requiring additional regulatory instruments. Moreover, the energy savings align with national energy security objectives under Decision No. 876/QĐ-TTg (2022) [14], while the observed declines in CO_2 emissions are consistent with Vietnam's Net-Zero 2050 trajectory under Decision No. 888/QĐ-TTg (2022) [15]. In this sense, the four environmental outcomes shown here not only reinforce the chosen policy direction but also indicate that fleet electrification is one of the rare interventions that advances air quality, climate mitigation, and fuel security goals concurrently within a single sector.

City-level trends across Asia show that Hanoi's modeled transition is feasible and consistent with regional policy trajectories. Shenzhen achieved full fleet electrification in 2017 with about 16,359 e-buses, demonstrating that large-scale replacement is attainable within a decade when charging, depot, and grid upgrades are co-planned [26]. In Singapore, the Land Transport Authority targets a 100% cleaner-energy fleet by 2040, with over 1,000 e-buses already committed and a 50% electric share expected by 2030 [27]. Seoul is following a dual pathway using both battery-electric and hydrogen buses, aiming for 70% and then 100% airport-bus conversion by 2026 and 2030, supported by 1,300 intra-city clean buses and new refueling and charging facilities [28]. Globally, more than 50,000 e-buses were sold in 2023, bringing the total stock to 635,000, most of them in China [29]. Relative to these benchmarks, Hanoi under Scenario 2 can be seen as a late but credible follower, with strong potential for convergence if vehicle procurement and charging infrastructure expand in line with current policy commitments.

3.2. Economic Benefits

Avoided operational cost trends mirror the environmental benefits but display a more delayed onset (Figure 6). Annual costs remain within 50–90 million USD across both scenarios before diverging after 2025. Scenario 2 stabilises at consistently lower levels, yielding 30–50 million USD in annual savings by the late 2040s. Cumulative savings increase progressively, approaching 200 million USD by 2050.

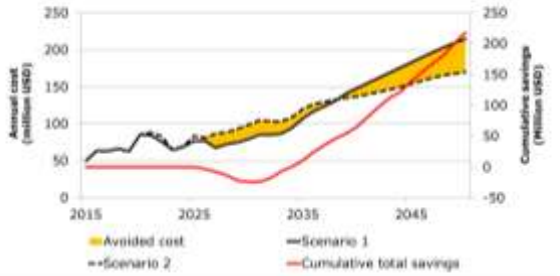

Figure 6. Annual operational cost and cumulative savings.

Although cost savings emerge later than emission benefits, their magnitude is large enough to offset part of the capital and battery replacement costs if reinvested strategically. The initial drop below zero in cumulative savings reflects the upfront investment in vehicles and infrastructure, which temporarily exceeds operating savings during the early phase (around 2028–2033), before net financial benefits accumulate in subsequent years. This aligns with the efficiency-based financing framework articulated in Decision No. 876/QĐ-TTg (2022) [14], which proposes cost-recovery mechanisms linked to operational savings. The modelled results provide quantitative justification for integrating leasing structures or tariff incentives into electrification policy so that cost benefits can be captured early rather than deferred to long-term system operation.

Taken together, the environmental and economic results suggest that Hanoi's current policy direction, focused on accelerating the electrification of its public bus fleet, is technically sound across multiple dimensions. Although the benefits appear over different timeframes, the overall transition pathway aligns well with national and municipal goals on energy efficiency, air quality improvement, climate mitigation, and fiscal sustainability.

3.3. Interpretation of the Transition Pathway through DPSIR

The baseline trajectory in Scenario 1 reflects the combined Driving Forces (D) of rapid urbanisation, rising mobility demand and the continued dominance of ICE technology in Hanoi's bus fleet. These forces manifest as Pressures (P) through sustained annual resource use and emissions: fuel demand exceeding 120 million Lge, PM stabilising at 25–30 thousand tons, CO_2 above 350 thousand tons and NO_x near two million tons by mid-century. Such persistent loads indicate a State (S) of technological lock-in, where transport services remain structurally dependent on combustion-based systems despite incremental efficiency gains.

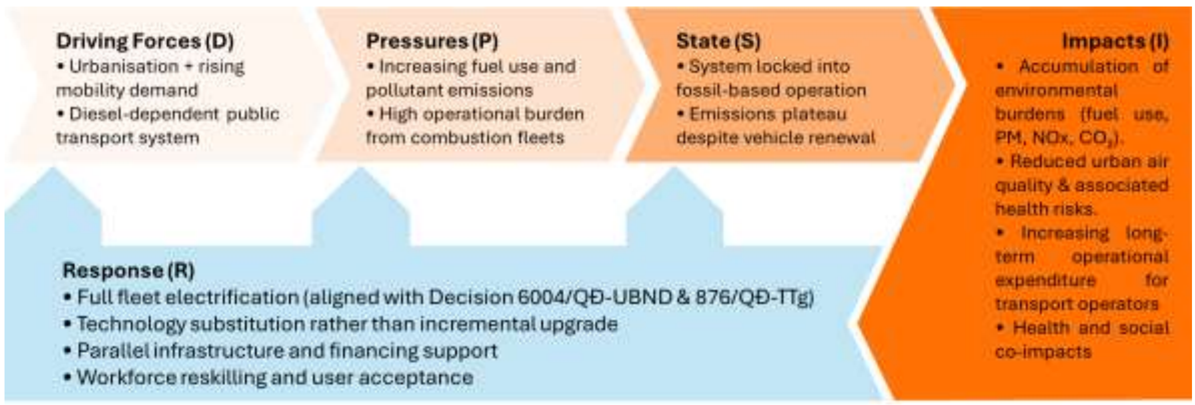

Figure 7. DPSIR-based interpretation of the bus electrification transition in Hanoi.

Scenario 2 represents a systemic Response (R) consistent with Decision No. 6004/QĐ-UBND (2024) and Decision No. 876/QĐ-TTg (2022), viewing electrification as full technological substitution rather than a marginal upgrade. Once implemented, total energy demand stabilises after 2030, while PM and NO_x fall below 10 thousand and 700 thousand tons, and CO_2 approaches 100 thousand tons. The resulting Impacts (I) include cumulative reductions of about one billion litres of fuel, 400 thousand tons of PM, 3.5 million tons of CO_2, 20 million tons of NO_x, and 200 million USD in operating costs.

Beyond environmental gains, the social Impacts are also notable. Lower PM and NO_x along dense corridors yield immediate health benefits, while electrification shifts rather than reduces labour demand, requiring retraining for battery and charging operations. Public acceptance depends on perceived improvements in noise, reliability, and service quality, showing that the Response is systemic, not purely technological. Its effectiveness depends on enabling conditions: large-scale electrification demands charging infrastructure, grid upgrades, and maintenance capacity. Though upfront and battery costs are high, these challenges should be built into policy design. Beyond cost savings, removing combustion along key routes cuts $PM_{2.5}$ and NO_x exposure and improves reliability through lower noise and fuel-price volatility. Electrification thus emerges as a structural system response requiring coordinated infrastructure, fiscal support, and behavioural adaptation.

4. Conclusion

This study offers a policy-based, system-level comparison that defines a quantitative baseline for Hanoi's transition pathway. The findings provide both environmental and economic justification for accelerated fleet electrification and supply evidence to guide investment planning and policy alignment. Several aspects remain outside the present scope but warrant future research. Subsequent studies could incorporate a decarbonising power mix, assess upstream and end-of-life impacts, and test sensitivity to fuel prices, technology learning rates, and infrastructure deployment. It would also be valuable to consider spatial variation in routes, depot capacity, and behavioural or institutional factors. These extensions would not alter the main conclusions but would strengthen the analysis as bus electrification progresses from planning to full-scale implementation.

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