

Comparative Analysis of the Financial Feasibility of Electric and Diesel BRT Buses in Medan (Merdeka Square–Tembung)

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Abstract: Public transport electrification offers energy efficiency and emission reductions but requires a substantially higher initial investment than conventional diesel technology. This study evaluates the financial feasibility of electric versus diesel buses on Medan BRT Corridor 5 (Lapangan Merdeka–Tembung) from the operator's perspective. A 12-year discounted cash-flow model was employed using Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). Operational inputs comprised eight buses, an annual fleet mileage of 735,840 km, a flat fare of IDR 5,000 per passenger, and a projected demand growth of 6% per annum. Electric bus CAPEX reached IDR 37.952 billion—136.37% higher than diesel—whereas its annual OPEX was IDR 4.247 billion, representing a 21.41% reduction. Under a full CAPEX–OPEX burden, neither option was financially viable, yielding negative NPVs of –IDR 23.998 billion for diesel and –IDR 37.423 billion for electric buses. However, under a CAPEX subsidy scheme, the electric bus became feasible with an NPV of IDR 685.91 million and an IRR of 13.00%. The Buy-the-Service (BTS) framework rendered both technologies feasible, though diesel yielded higher financial returns. Sensitivity analysis confirmed load factor as the most critical determinant. Therefore, successful electric BRT deployment requires structured CAPEX subsidies, performance-based BTS payments, and integrated policies to improve transit ridership.

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INTRODUCTION

Urban growth and increased mobility place public transportation as a crucial element in maintaining accessibility, productivity, and the quality of urban environments. In developing cities, mass transit systems need to provide adequate capacity without increasing reliance on private vehicles. Bus Rapid Transit (BRT) offers operational flexibility, lower infrastructure requirements than rail systems, and the ability to scale up incrementally as demand grows (Cervero, 2013), (Nikitas & Karlsson, 2015).

Current BRT developments are not only geared toward increasing service capacity but also toward fleet decarbonization. Electric buses produce very low local emissions during the operating phase, produce less noise, and are more energy efficient than combustion-engined buses. (Borén, 2020) points out that the benefits of electric buses extend beyond energy use and include reduced social costs due to noise and emissions. However, acquiring an electric fleet requires significant upfront investment, charging infrastructure, battery management, and guaranteed energy supply. Therefore, technological superiority does not automatically equate to financial viability for operators.

Comparisons of electric and diesel buses require a lifetime cost approach. (Sheth & Sarkar, 2019) found that electric buses can achieve competitive lifecycle costs when energy and maintenance savings offset the initial investment. Similar findings were presented by (Szumska et al., 2022), who

emphasized the importance of energy consumption, operating intensity, energy prices, and service life in total cost of ownership. (Khan & Onat, 2023) added that bus technology comparison results are highly sensitive to system boundaries, cost components, energy sources, and operational assumptions.

The city of Medan has begun operating electric buses as part of its public transportation modernization. Corridor 5 connects Merdeka Square with Tembung and serves as a link between the eastern region and the city center (D. K. K. Medan, 2024). This corridor is crucial because it intersects with commercial activities, residential areas, and railway hubs. The implementation of electric buses on this corridor supports the low-emission transportation agenda, but the sustainability of the service is also determined by the funding scheme's ability to cover fleet and operational costs.

From an operator's perspective, investment decisions cannot simply be based on vehicle price comparisons or energy costs per kilometer. Investments must be assessed through cash flows that consider CAPEX, OPEX, fare revenue, residual value, discount rate, and payback period. (Oyinna et al., 2025) assert that the combination of Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP) provides a more complete picture than any single indicator. This approach is crucial for capital-intensive public transportation projects with uncertain demand.

This gap arises because most bus electrification research focuses on large cities or the total cost of ownership, while operator analysis of BRT corridors in developing cities is limited. Furthermore, feasibility is heavily influenced by load factors and subsidy structures. An efficient fleet can still generate negative cash flow when occupancy rates are low, fares do not cover costs, or infrastructure investments are fully borne by operators. Conversely, service purchase schemes can alter the distribution of risk between the government and operators.

This study aims to compare the CAPEX and OPEX structures of electric buses and diesel buses on Corridor 5 BRT Medan City; assess the feasibility based on NPV, IRR, and PP in the CAPEX–OPEX, CAPEX subsidy, and Buy the Service (BTS) schemes; and test the sensitivity of the results to load factors, discount rates, electricity tariffs, and monetization of CO₂ emission reductions.² The analysis is aimed at explaining the conditions under which electrification can be implemented sustainably, not simply at determining the lowest-cost technology.

RESEARCH METHOD

Research location and data

The research uses a quantitative approach with a comparative case study on Corridor 5 of Medan City BRT, Merdeka Square–Tembung route. The objects of analysis are eight Higer KLQ6106GABEV electric buses and a comparison scenario of eight Hino RM 280 diesel buses. The diesel scenario is a hypothetical business as usual scenario because the corridor has been operated using electric buses. Primary data comes from passenger enumeration surveys on Mondays, Wednesdays, and Fridays, each in the morning and afternoon periods for two-way trips. Secondary data includes fleet specifications, vehicle prices, energy rates, maintenance costs, passenger fares, BTS payment values, and passenger reports April 2025–March 2026.

The single-trip route length for Corridor 5 is 21 km (42 km per round trip). With 8 operational buses completing 6 round trips daily over 365 operational days, the total fleet mileage (Vehicle Kilometer Traveled/VKT) equals 735,840 km/year. Based on a vehicle capacity of 55 passengers and a survey-derived average load factor of 41.96% (averaging ~23 passengers per trip), total year-one

passenger demand is calculated at 591,192 passengers/year. Applying the standard fare of IDR 5,000 per passenger, gross farebox revenue in the first year is IDR 2.955 billion, assuming a projected annual passenger growth rate of 6%.

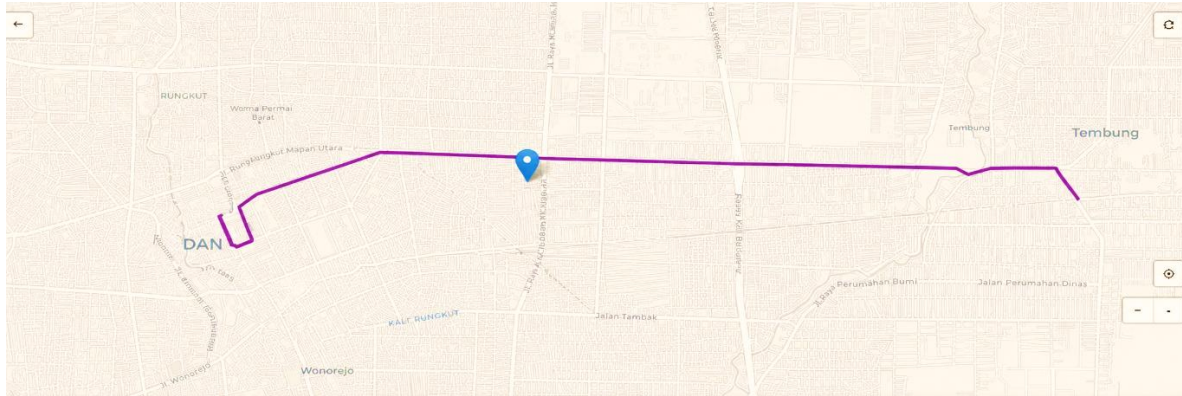


Figure 1. Corridor 5 BRT Medan City route Merdeka Square–Tembung
Source: research document, 2026.

Preparation of costs and cash flow

Operating and maintenance costs (OPEX) were structured in accordance with Indonesian Ministry of Transportation Regulation No. KM 251 of 2022. OPEX includes energy costs (IDR 1,700/kWh for electric buses vs. subsidized/industrial diesel fuel rates), driver and staff salaries, routine maintenance, insurance, and licensing. For electric buses, periodic battery replacement is annualized as a depreciation charge of IDR 202.51 million per bus/year (assuming a 6–8 year battery lifespan) integrated directly into annual OPEX, bringing total electric bus OPEX to IDR 4.247 billion/year (W. K. Medan, 2024) (Johnson et al., 2020).

Feasibility indicators and scenarios

NPV calculates the difference between the present value of all cash inflows and outflows. IRR is the discount rate that makes NPV equal to zero, while PP indicates the time required to recoup the initial investment. The feasibility criterion is $NPV \geq 0$, $IRR \geq \text{discount rate}$, and PP does not exceed the project horizon.

$$NPV = \frac{\sum CF_t}{(1+r)^t} \quad (1)$$

$$0 = \frac{\sum CF_t}{(1+IRR)^t} \quad (2)$$

Three financial schemes were analyzed. First, the CAPEX–OPEX scheme charges the operator with all investment and operational costs. Second, the OPEX scheme assumes government subsidies for CAPEX, leaving the operator with only operational costs. Third, the BTS scheme uses government payments per kilometer of service. Additional analysis monetizes CO₂ emission reductions₂ with a carbon value of Rp. 40/kg CO₂. Sensitivity was assessed at load factors of 10%, 20%, 30%, 50%, and 70%; discount rates; and optimistic, moderate, and pessimistic electricity tariffs.

Table 1. Operational parameters and demand for Corridor 5

Parameter	Mark
One-way route length	21 km
Number of operating buses	8 units
Ritase	6 trips/day
VKT fleet	735,840 km/year
Bus capacity	55 passengers
Survey load factor	41.96%
Basic passengers	591,192 people/year
Passenger fares	Rp. 5,000

Source: research data processing results, 2026.

RESULTS AND DISCUSSION

Comparison of investment and operating costs

These findings confirm the classic trade-off between high upfront capital costs and operational efficiency. The high CAPEX of electric buses (IDR 37.952 billion vs. IDR 16.056 billion for diesel) presents a substantial barrier for private operators. Although electric buses yield a 21.41% annual OPEX savings, operational cost reductions alone are insufficient to bridge the initial CAPEX gap over the 12-year lifespan without institutional financial support. This aligns with (Basma et al., 2022) who emphasized that energy efficiency in electric transit translates into financial viability only when paired with adequate capital subsidy mechanisms (Avenali et al., 2024) also emphasize that technological and macroeconomic uncertainty can alter the optimal timing of electrification, so procurement decisions need to consider financing schemes, not just vehicle prices.

On the operational side, diesel buses require OPEX of IDR 5.404 billion per year, while electric buses require IDR 4.247 billion after battery depreciation. Electric buses save approximately IDR 1.157 billion per year, or 21.41%. Before battery depreciation, electric buses' operating costs were recorded at IDR 4.044 billion. These advantages stem from energy efficiency and simpler maintenance requirements. This pattern is consistent with (Sheth & Sarkar, 2019) and (Basuki, 2025), who found that energy and maintenance costs are the primary sources of electric buses' advantages.

However, the annual savings are not enough to cover the CAPEX gap of IDR 21.896 billion over a 12-year horizon. Simply put, the investment gap is equivalent to nearly 19 years of OPEX savings at nominal value, even before considering the time value of money. Therefore, lower operating costs should be interpreted as a technical and operational advantage, not automatic proof that the electricity investment is financially viable.

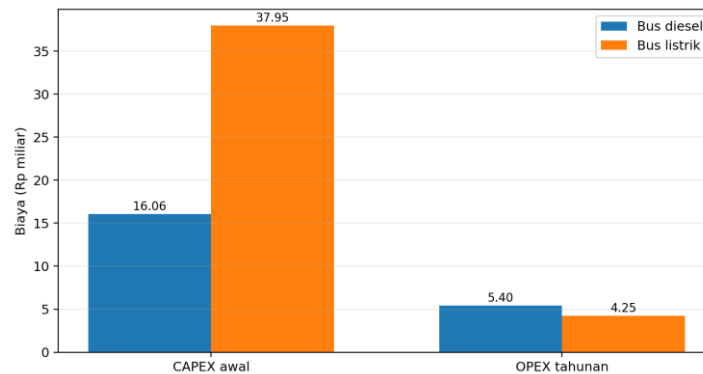


Figure 2. Comparison of initial CAPEX and annual OPEX
Source: research data processing results, 2026.

Financial feasibility based on financing scheme

Table 2. Summary of financial feasibility of diesel buses and electric buses

Scheme	Bus	NPV	IRR	PP	Information
CAPEX-OPEX	Diesel	-Rp 23.998 billion	-21.26%	>12 years	Not yet worthy
CAPEX-OPEX	Electricity	-Rp 37.423 billion	-12.37%	>12 years	Not yet worthy
CAPEX/OPEX subsidies only	Diesel	-Rp7.942 billion	< discount	>12 years	Not yet worthy
CAPEX/OPEX subsidies only	Electricity	Rp. 685.91 million	13%	<12 years	Worthy
Buy the Service	Diesel	Rp 91.319 billion	92.58%	1.22 years	Worthy
Buy the Service	Electricity	Rp 78.051 billion	42%	2.76 years	Worthy

Source: research data processing results, 2026.

Under the full CAPEX-OPEX scheme (where the operator bears all capital and operating costs), neither technology is financially feasible. The diesel bus scenario yields an NPV of -IDR 23.998 billion with an IRR of -21.26%, while the electric bus scenario results in an NPV of -IDR 37.423 billion with an IRR of -12.37%, both having payback periods exceeding the 12-year project horizon. Although electric buses reduce annual OPEX by IDR 1.157 billion, the cumulative present value of these operational savings over 12 years (IDR 7.883 billion at a 10% discount rate) is insufficient to offset the substantial initial capital expenditure gap (CAPEX gap) of IDR 21.896 billion (Indonesia, 2022).

Under the CAPEX subsidy scheme, the financial viability of electric buses improves significantly, yielding a positive NPV of IDR 685.91 million, an IRR of 13.00% (exceeding the 10% discount rate), and a payback period of 11.4 years. Conversely, diesel buses under the non-subsidized capital framework remain unfeasible with an NPV of -IDR 7.942 billion and an IRR of -2.15%]."

When CAPEX is assumed to be subsidized, the position of electric buses changes. The NPV of electric buses becomes positive at Rp685.91 million, the IRR is 13%, and the payback period is under 12 years. In contrast, diesel buses still generate a positive NPV of Rp 685.91 million. -Rp 7.942 billion. This difference confirms that the main obstacle to electrification lies in the initial investment, not daily operations. If the government covers the procurement of vehicles and chargers, the energy efficiency and maintenance of electric buses will begin to show up in the operators' cash flow.

The BTS scheme yielded a positive NPV for both technologies. Diesel buses achieved an NPV of IDR 91.319 billion, an IRR of 92.58%, and a payback period of 1.22 years. Electric buses achieved an NPV of IDR 78.051 billion, an IRR of 42%, and a payback period of 2.76 years. From a purely financial perspective, diesel buses demonstrated a higher return due to the smaller investment. However, BTS made demand and investment risks more manageable, ensuring electric buses remained viable and compatible with public service objectives.

These findings reinforce the view that procurement schemes determine electrification success. (Triatmojo et al., 2023) emphasize that electric bus adoption requires an assessment of total cost of ownership factors and policy support. For the government, BTS is not simply an operational subsidy, but rather a risk-sharing mechanism that allows operators to maintain service standards without bearing the full impact of demand uncertainty and capital costs.

The influence of load factor and discount rate

Sensitivity analysis indicates that load factor (passenger occupancy rate) is the most critical determinant of financial feasibility. While higher load factors increase farebox revenue linearly, variations in the discount rate (ranging from 6% to 12%) at the current baseline load factor (41.96%) are unable to shift the electric bus investment into profitability under a full self-financing scheme (Efriana et al., 2019).

The BTS scheme is the most stable against demand variations. All combinations of 10–70% LF and 6–12% discount rates yield positive NPVs for both diesel and electric buses. While these results demonstrate operator viability, BTS payment amounts still need to be calibrated against actual costs and performance. Underpayments threaten service continuity, while overpayments increase budgetary burdens without incentivizing efficiency.

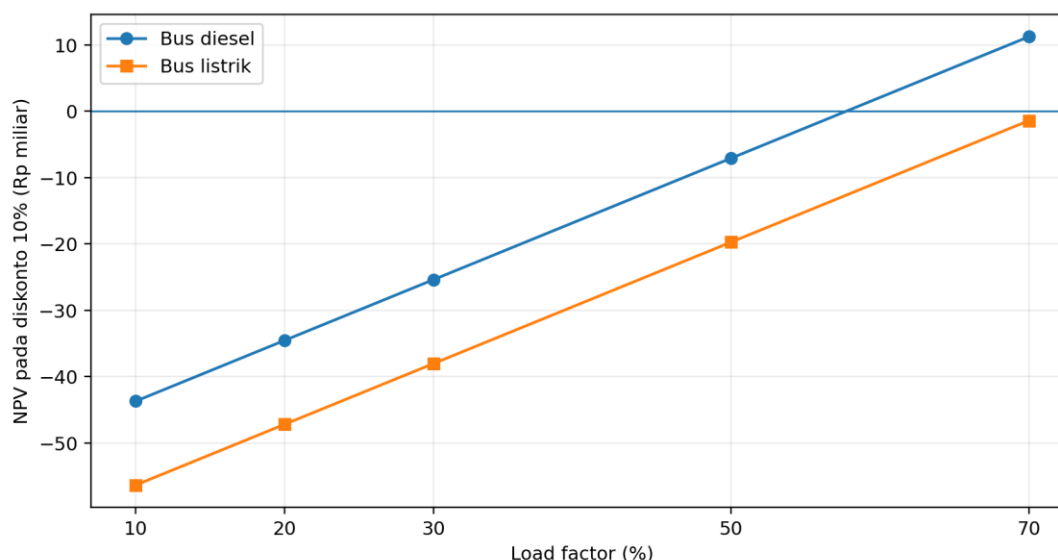


Figure 3. NPV sensitivity to load factor at 10% discount

Source: research data processing results, 2026.

Electricity tariffs and monetization of emission reductions

Electricity tariffs serve as a secondary sensitivity variable. Tariff reductions improve the NPV of electric buses, but at discount rates of 10–50%, all electricity tariff scenarios still yield negative NPVs under the CAPEX–OPEX model. At discount rates of 70% and optimistic tariffs, electric buses are feasible at 6–10% discount rates, but become negative again at 12%. As tariffs move toward moderate or pessimistic scenarios, the feasibility probability decreases. In other words, energy prices are important, but they cannot replace the need for occupancy rates and capital support.

Monetization of CO₂ emission reductions₂ has not yet changed the investment status. With a carbon value of Rp. 40/kg CO₂, the NPV of electric buses improves from-Rp37.423 billion to around-Rp37.218 billion. The Rp204.72 million improvement represents only about 0.55% of the baseline NPV. This value indicates that the domestic carbon price used is still too low to cover the CAPEX gap. However, the environmental benefits remain relevant as a basis for public policy because the operator's analysis did not include all social, health, noise, and local pollutant reduction benefits.

The limitations of the analysis should be noted. Electric bus emissions are calculated based on the electrical system emission factor, so the results will change as the energy mix becomes cleaner. Furthermore, the study only monetizes CO₂ and does not include reductions in PM, NO_x, noise, or displacement of private vehicle users. A broader social benefit assessment may yield different economic conclusions regarding the operator's financial viability (Basma et al., 2022).

Policy and operational implications

The research findings suggest that technology choice and financing options must be considered simultaneously. Diesel buses are lighter in initial investment but have higher operating costs and are not aligned with long-term decarbonization goals. Electric buses are more efficient and potentially environmentally beneficial, but require support during the investment phase. Therefore, charging the operator the entire CAPEX is not an appropriate design for a corridor with a load factor of around 42%.

The government can cover chargers and part of the fleet procurement through grants, equity participation, or concessional financing. The BTS scheme is then used to pay for service kilometers based on performance indicators, such as punctuality, energy consumption, and occupancy targets. The payment structure needs to be periodically evaluated to ensure it reflects actual operational expenditure (OPEX) and does not eliminate efficiency incentives (Borén, 2020).

Increasing the load factor is the most important strategy. Integration with the Tembung railway, the feeder network, bus stop arrangements, real-time travel information, and schedule synchronization can increase demand without relying solely on fare increases. Park-and-ride policies and restructuring of feeder routes can also expand service coverage.

Operators need to optimize off-peak charging, monitor energy consumption per unit, establish battery replacement funds, and develop non-fare revenue. Battery management is crucial because degradation can impact operating costs and fleet availability. Longer-term operational data is also needed to allow projections to capture seasonal variations, holidays, and changes in travel behavior.

The deployment of transit fleets on primary urban corridors in Medan City, specifically the Merdeka Square–Tembung route, reveals a complex financial dynamic between Battery Electric Bus (BEB) technology and conventional Diesel Bus (DB) systems. This financial feasibility assessment is evaluated through key indicators: Total Cost of Ownership (TCO), Net Present Value (NPV), Internal

Rate of Return (IRR), and Payback Period (PP), spanning a 12-to-15-year vehicle lifecycle planning horizon. The operational profile of the Merdeka Square-Tembung corridor characterized by variable urban congestion and moderate-to-high daily mileage serves as a critical variable in determining the financial break-even point for both vehicle powertrains.

From a Capital Expenditure (CapEx) perspective, acquiring an electric bus fleet for the Merdeka Square-Tembung corridor demands a substantially higher upfront capital commitment compared to diesel buses. This elevated CapEx is primarily driven by the cost of large-capacity lithium-ion battery packs and specialized electric powertrain components. As highlighted by (Topal & Nakir, 2018), the procurement cost of an electric bus unit typically ranges from two to two-and-a-half times higher than that of an equivalent diesel bus. This capital-intensive entry barrier poses a primary financial hurdle for public transit operators, particularly in developing economies facing capital constraints.

Beyond vehicle acquisition, CapEx for an electric fleet encompasses charging infrastructure deployment at main depots and intermediate terminals. Establishing overnight charging facilities at the central depot or opportunity chargers at the Merdeka Square and Tembung nodes requires considerable investment in high-efficiency charging hardware and civil engineering works. These findings align with (Sclar et al., 2019), who emphasized that the primary financial barrier to electric bus adoption lies not only in vehicle acquisition costs, but also in the upfront financing of missing charging infrastructure.

The scale and complexity of charging infrastructure investment are directly influenced by the interaction between fleet operations and local power grid capacity. (Xylia et al., 2017) noted that locating and sizing charging stations within Bus Rapid Transit (BRT) systems must align with operational schedules to prevent severe peak-demand loads on the regional power grid. In Medan, grid integration enhancements and transformer installations at the main depot represent additional capital expenditures that must be absorbed prior to commercial revenue service.

Despite the heavy initial investment burden of electric buses, Operational Expenditure (OpEx) analysis demonstrates cumulative financial advantages over the vehicle lifecycle. Energy cost savings serve as the largest contributor to reducing daily OpEx on the Merdeka Square-Tembung route. (Lajunen, 2014) demonstrated that electric motor energy conversion efficiency far exceeds the thermal efficiency of internal combustion engines (ICE), making electricity consumption per kilometer significantly cheaper than diesel fuel consumption.

Electric bus OpEx efficiency is further amplified in the stop-and-go traffic conditions typical of the corridor between Merdeka Square and Tembung. Regenerative braking systems allow electric buses to recover kinetic energy during deceleration and feed it back into the battery. (Gao et al., 2017) confirmed that operating electric buses on low-to-medium speed urban transit routes optimizes energy consumption, directly lowering daily operating expenses for transit operators.

In addition to energy efficiency, maintenance costs for electric buses are significantly lower than those for conventional diesel buses. The simpler design of electric powertrains with far fewer moving parts minimizes the need for routine part replacements such as engine oil, filters, transmissions, and exhaust systems. (Mahmoud et al., 2016) established that routine maintenance cost reductions for electric buses can reach 30% to 50% over the vehicle lifecycle compared to diesel fleets.

Consistent daily OpEx reductions create cumulative operational savings that offset high upfront CapEx over time. The accumulation of operational cash flow savings along the Merdeka Square-Tembung corridor gradually closes the initial investment gap. A comparative study by (Ahmadi, 2019)

indicated that higher fleet utilization and greater daily vehicle mileage accelerate the rate at which operational savings offset the initial electric bus investment premium.

Daily mileage acts as a critical determinant for the financial feasibility threshold of electric buses. On the Merdeka Square–Tembung route, high service frequencies and adequate daily mileage allow electric buses to achieve a well-defined Payback Period. (Li et al., 2022) concluded that in medium-sized cities, the economic feasibility of electric buses relies heavily on achieving a minimum daily mileage threshold to realize operational savings within the NPV horizon.

Financial risk analysis for electric buses involves significant uncertainty surrounding battery performance degradation. Electric bus batteries experience capacity fading over time due to charge cycles and environmental factors. Pihlatie et al. (2014) showed that capacity degradation below operational thresholds (typically 70–80% of original capacity) mandates mid-life battery pack replacements (between years 6 and 8), representing a major reinvestment expenditure.

Mid-life battery replacement costs impact the project's Net Present Value (NPV) trajectory and cash flows. Unanticipated battery replacement expenses can severely compress the project's Internal Rate of Return (IRR). (Nurhadi, 2014) emphasized the utility of battery leasing models or manufacturer performance guarantees to mitigate mid-life capital expenditure risks in electric fleet management.

Charging schedules and operational management also dictate electric bus cost efficiency. (Perumal & Lusby, 2021) explained that integrated bus scheduling and charging strategies prevent operators from incurring peak-load electricity tariff penalties. Cost-effective energy usage for the Merdeka Square–Tembung route is maximized when fleet charging occurs primarily overnight at the depot, taking advantage of lower off-peak electricity rates.

Power grid capacity constraints and space limitations in dense urban areas like Medan require a structured infrastructure strategy. (He et al., 2019) highlighted that poorly situated fast-charging stations lead to additional operational costs and accelerated battery degradation. Consequently, a hybrid charging infrastructure strategy combining slow overnight depot charging with limited fast-charging at route termini presents a balanced approach between operational reliability and capital cost control.

Financial analysis for diesel buses on the Merdeka Square–Tembung route reveals an opposite cash flow profile: low initial CapEx offset by exposure to fuel price volatility and escalating maintenance costs as engine components age. (Quak et al., 2016) observed that while diesel buses offer high operational flexibility and low initial capital entry costs, long-term trends show unstable OpEx trajectories due to fluctuating fossil fuel prices and increasingly stringent emissions regulations.

Financial feasibility evaluation indicates that deploying electric buses on the Merdeka Square–Tembung BRT corridor offers superior long-term economic returns, yielding a positive NPV and a competitive IRR exceeding the hurdle rate, despite requiring a longer Payback Period. (Mundaca & Luth Richter, 2015) concluded that transitioning to electric public transit is economically viable when supported by appropriate financing structures, high operational efficiency, and policy incentives that mitigate initial capital expenditure barriers.

CONCLUSION

Electric buses on Medan City's BRT Corridor 5 have a CAPEX of Rp37.952 billion, 136.37% higher than diesel buses, but an annual OPEX of Rp4.247 billion, 21.41% lower. In a scheme that

charges both CAPEX and OPEX to operators, both alternatives are not feasible for 12 years; the NPV of diesel buses is-Rp23.998 billion and electric buses-Rp37.423 billion, with a negative IRR and PP exceeding the analysis horizon. When CAPEX is subsidized, electric buses become feasible with an NPV of Rp685.91 million and an IRR of 13%, while diesel buses remain unfeasible. The BTS scheme makes both technologies feasible, although the financial indicators for diesel buses are higher. Load factor is the most important variable. At full investment, new electric buses generate a positive NPV at a 70% discount rate; with CAPEX subsidies, feasibility begins to emerge at a 30% discount rate. Electricity tariffs and carbon monetization improve outcomes but cannot address the high CAPEX alone. Medan City's BRT electrification should be supported by structured CAPEX subsidies, performance-based BTS payments, multimodal integration to increase occupancy, and disciplined energy and battery management.

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