Public Transport Electrification: A Scenario Based Analysis Of Trans Metro Dewata, Bali

1st Dewa Ayu Putu Adhiya Garini Putri
Faculty Of Engineering and Informatics
Universitas Pendidikan Nasional
Denpasar, Indonesia
adhiyagariniputri@undiknas.ac.id

2nd I Made Lanang Manik Arya Wangsa
Faculty Of Engineering and Informatics
Universitas Pendidikan Nasional
Denpasar, Indonesia
lanangmanikarya@undiknas

3rd I Wayan Sukadana
Faculty Of Engineering and Informatics
Universitas Pendidikan Nasional
Denpasar, Indonesia
sukadana@undiknas.ac.id

4th Putu Budiarnaya
Faculty Of Engineering and Informatics
Universitas Pendidikan Nasional
Denpasar, Indonesia
putubudiarnaya@undiknas.ac.id

5th Putu Ariawan
Faculty Of Engineering and Informatics
Universitas Pendidikan Nasional
Denpasar, Indonesia
ariawan@undiknas.ac.id

6th Ni Wayan Kharisma Vidya Poedja Putrawan
Faculty Of Engineering and Informatics
Universitas Pendidikan Nasional
Denpasar, Indonesia
kharisma09@gmail.com

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***Abstract*— This research investigates the potential scenario for transitioning Trans Metro Dewata's conventional bus operations to electric buses. It employs a multifaceted approach to assess the feasibility of this transition, considering various scenarios to evaluate potential benefits across financial and environmental dimensions. Furthermore, This study undertakes a focused analysis of the operational performance of the Metro Dewata Bus network on Corridor 3B. This corridor plays a vital role in connecting passengers between Ubung Terminal and Central Parking, Kuta. The research methodology adopted in this study prioritizes the collection of primary data. This implies that data will be gathered directly through on-site surveys. This approach is advantageous as it allows for the collection of real-world data specific to Corridor 3B, ensuring a more accurate and nuanced understanding of its operational performance. the study strongly suggests that a shift towards electric buses could lead to substantial cost savings for the Metro Dewata bus network. Both direct and indirect cost analyses support this conclusion. Further research could explore the initial investment costs associated with transitioning to electric buses and weigh them against the projected long-term operational cost savings to provide a comprehensive financial assessment.**

Keywords—cost approach, electrification, public transport

I. INTRODUCTION

The transportation sector is one of the largest contributors to emissions impacting air quality. Generally, transportation activities have negative effects, leading to noise pollution, air pollution, and traffic congestion [1]. Considering that the transportation sector constitutes over 25% of global energy consumption. In 2021, CO2 emissions reached approximately 7.7 gigatonnes and are projected to increase significantly over the next 30 years if no emission reduction scenarios are implemented [2]. It is imperative to address these externalities comprehensively to guarantee the sustainable advancement of the transportation industry [3].

Over the past decade, electrification has become a dominant trend in global transportation. Reducing automobile emissions is essential for lowering greenhouse gas levels and enhancing air quality[4], [5]. This demand encourages technological progress in the automotive sector and supports the growth of renewable energy. Therefore, adopting electric vehicles (EVs) is a valuable strategy for decreasing CO2 emissions [6]. In 2022, electric vehicle (EV) sales accounted for 14% of the global market, and this figure is projected to rise to 35% by 2030. Concurrently, significant technological and commercial advancements have been made in the field of autonomous driving[7].

In Indonesia, private vehicles dominate the transportation sector, accounting for approximately 29% of the country's total energy consumption in 2016. Consequently, the transportation sector ranks as the second-largest energy consumer, trailing only the household sector [8]. However, the Indonesian government has committed to reducing CO2 emissions by 29%, equivalent to approximately 303 million tons, by 2030, as stipulated during the 2015 United Nations Conference (COP21)[9], [10], [11]. This commitment is further supported by Presidential Regulation Number 55 of 2019, which enacts the Acceleration Program for Battery Electric Vehicles for road transportation[12]. This regulation serves as the legal framework for the development of electric vehicles (EVs) in Indonesia and has initiated a domino effect, prompting several ministries to launch EV projects across the country [3]. Despite these commitments, Indonesia remains among the top 50 most polluted cities in Asia, as reported by IQAir, with an air quality index of 71.7, classified as unhealthy. This pollution level exposes over 1 million citizens to significant health risks and results in approximately 5 million illnesses annually[13].

In Bali, Implementation of electric vehicle was prominently showcased during the G-20 Presidency event in 2022, held in Nusa Dua, Bali[14]. This initiative was supported by Presidential Instruction (Inpres) Number 7 of 2022, which mandates the use of battery electric vehicles as operational service vehicles and/or personal service vehicles for central and regional government agencies. This initiative significantly accelerated EV adoption, increasing the number of electric vehicles from 700 in 2021 to 1,500 in 2022, contributing approximately 6 percent to the national EV adoption rate [15], [16]. Moreover, in public transportation sector, Trans Metro Dewata system presents an opportunity to evaluate the feasibility and advantages of electrifying public transportation [17], [18], [19]. Leveraging Bali's abundant hydropower resources to power an electric public transport network could reduce dependence on imported fossil fuels and improve energy security [4], [20].

A substantial body of research has examined and compared the financial and environmental benefit of electric vehicles (EVs) and internal combustion engine vehicles (ICEVs). A multi-scenario analysis is used for evaluating the efficacy of diverse electric bus deployment strategies. Through the exploration of alternative operational configurations, this approach facilitates the identification of the most efficient network design. These features could encompass the number of routes served, headway times between buses, and the distribution of charging infrastructure. Previous studies have examined the financial and environmental benefits of implementing electric buses, such as in the Putrajaya area of Malaysia[1], [21]. A similar scenario has been pursued by the Moscow government and Japan as an alternative for future public transportation [4], [5], [22]. A similar trend is evident in Indonesia, where electric buses have been incorporated into public transportation systems such as the Transjakarta bus network [8]. This initiative aims to reduce CO2 emissions while simultaneously enhancing passenger convenience**.** However, this study will primarily focus on a cost-based analysis, comparing the operational costs between the current conditions with ICEVs and the planned scenario using electric buses.

II. METHODOLOGY

A. *Study Area and Data Description*

This study focuses on assessing the operational performance of the Metro Dewata Bus on Corridor 3B, which has a route length of 31 km and includes 33 bus stops. This corridor serves the area from Ubung Terminal to Central Parking, Kuta. The methodology employed in this research involves collecting primary data through on-site surveys. The primary data collected includes vehicle license plate numbers, the number of passengers boarding and alighting at each segment, travel times, and waiting times along the studied route. The research was conducted over a two-week period on Corridor 3B, covering the route from Ubung Terminal to Central Parking, Kuta, as mentioned in figure 1.

Figure 1. Route Of Bus Trans Metro Corridor 3B.

B. *Study Framework*

The study framework is divided into 3 main stages, data collection, analysis data and validation, finalization of electric bus network. The findings of this study encompass load factor, travel speed, headway, waiting transfer time, and travel duration. Figure 2 shows the methodological framework.

Stage 1: Data Collection

Passenger demand for public transportation can be categorized into two segments: current demand and potential demand. Current demand pertains to data collected from individuals who are currently utilizing public transport services. In contrast, potential demand encompasses data related to passenger willingness to use public transportation as well as those who intend to use it.

Stage II : Analysis Data and Validation

In this stage, the research involves calculating the operational performance of the Trans Metro Dewata buses on Corridor 3B, which includes assessing the load factor. The load factor is critical in determining whether the number of vehicles on a route is insufficient, adequate, or excessive. A load factor exceeding 100% indicates that the available fleet capacity is insufficient. Following this, a travel speed analysis is conducted to determine the circulation time from the departure point to passenger stops. Additionally, the study calculates headway, waiting time, and travel time to ensure proper scheduling for Trans Metro Sarbagita buses. Following the operational performance analysis, a cost-based comparative study was conducted to evaluate the differences in operational expenses between Sarbagita and electric buses.

Stage III: Finalization of Electric Bus Network

By conducting data analysis and validation, a comparative model between the implementation of electric buses and internal combustion engine vehicles (ICEVs) is obtained. This aims to provide insights into the optimal scenario for the electrification of public transportation.

III. RESULT AND DISSCUSSION

Bus and Passenger Characteristic

This study utilizes previous data from the route between Terminal Ubung and Central Parking Kuta in Corridor 3B, prior to the route change on Line 5 effective April 1, 2023. According to data obtained from the Moovit application, the operational schedule of Trans Metro Dewata buses on Line 5 runs from 04:30 to 18:00 WITA. The number of routes increased from four to five. Since its inauguration in 2020, Trans Metro Dewata Line 5 has operated with 21 buses, making it the longest route with 33 stops. As of October 31, 2022, the fare is set at Rp. 4,400 per trip, with payments accepted via QRIS or non-cash cards. The total capacity of Trans Metro Dewata buses is 40 passengers, comprising 20 seated and 20 standing. Payment methods for Trans Metro Dewata passengers include QRIS and non-cash card payments.

Understanding the travel characteristics of respondents is essential to obtain information an efficient and cost-effective way for passenger to explore a destination. Additionally, understanding the characteristics of public transport passenger in a destination is crucial for tourists to plan their itineraries effectively. It helps them determine the most convenient and reliable modes of transportation, such as buses or subways, to get around and optimize their travel experience. Table 1 depicts the characteristic of respondent amount of 110 respondents.

TABLE I. RESPONDENT CHARACTERISTICS

Characterisic	Description
Gender	The majority of users are female (60%).
Age	The majority of users are between 21 and 30 years old (67%).
Vehicle Ownership	The majority of users already own a private vehicle (78%).
Driver License	The majority of users already have a driver's license (73%).
Income	The majority of users are not employed (72%).
Expenses	The majority of users have expenses less than Rp 3,000,000 (98%).
Percentage of Transportation Expense	The majority of users spend 10-15% of their total monthly expenses on transportation (61%).
Trip Frequency	The majority of users take 1-3 trips per day (80%).
Trip Frequency	The majority of users spend Rp 5,000 - Rp 10,000 per trip (55%).

a. (analysis result, 2024)

This data reveals a distinct user profile for public transportation in Indonesia. The majority of users are young females (60%) within the 21-30 year old age bracket (67%). Interestingly, a high proportion of these users (78%) already own private vehicles and possess driver's licenses (73%). This suggests potential factors influencing their choice of public transportation, such as cost-effectiveness, environmental concerns, or limitations on private vehicle usage in certain situations. This highlights the affordability and accessibility that public transportation offers in Indonesia. Furthermore, a significant portion of users (61%) allocate a moderate percentage (10-15%) of their monthly expenses towards transportation, indicating that public transportation costs are likely aligned with their budgetary constraints. The data also provides insights into user travel frequency and spending habits. The average user takes a relatively high number of trips (1-3 trips per day - 80%), suggesting a reliance on public transportation for daily activities. Additionally, the typical trip cost falls within a moderate range (Rp 5,000 - Rp 10,000 - 55%), further emphasizing the cost-conscious nature of public transportation users in Indonesia.

Next, the operational performance analysis revealed that the average load factor for Trans Metro Dewata buses is 3.75% across the 21 buses in operation. This indicates that the load factor is significantly below the Department of Transportation's target of 70%. The average headway is 23 minutes, exceeding the planned maximum of 10-20 minutes. The average travel time per bus is 72 minutes, which falls within the Department of Land Transportation's standard of 60-90 minutes. Additionally, the average waiting time at each stop is less than 30 minutes, and the average speed of the 21 buses is 35.75 km/h. Table II illustrates the service production per kilometer per year.

TABLE II. SERVICE PRODUCTION PER KILOMETRE PER YEAR

No.	Description	Details	Unit
1	Distance per trip	31	km
2	Frequency (trips/day)	7	trips
3	Distance per day	217	km
4	Operating days per month	30	days
5	Operating days per year	360	days
6	Weeks per year	52	weeks
7	Distance per month	6,51	km
8	Distance per year	78,12	km
9	Load Factor	3.75	%

b. (analysis result, 2024)

Operating Cost Analysis

In this study, there are two types of costs considered for analysis. These include direct costs, which consist of depreciation costs, capital interest costs, maintenance costs, fuel costs, service costs, administrative costs, and taxes. Fixed costs such as depreciation are calculated as part of vehicle operating costs using the straight-line method.

Meanwhile, indirect costs are derived from personnel costs, office administration costs, cleaning costs, and management costs. First, the operational costs of the vehicles are calculated and then compared with the operational costs of the vehicles if they were converted to electric buses.

In this study, the E-Inobus model, produced by PT. Industri Kereta Api (Persero) (INKA), is used. This electric bus model was utilized during the G-20 summit in 2022 and features dimensions of 8 meters in length with a total capacity of 20 seated and 20 standing passengers (as it shown in Figure 2). The battery capacity is 138 kWh with a range of 160 km. This electric bus is a medium-capacity bus designed for bus rapid transit (BRT). For internal combustion engine vehicles (ICEVs), the Hino RK8 model is used, with a total capacity of 40 passengers and a longer range of 400 km. Table III and IV illustrates the comparison of direct and indirect costs for EVs and ICEVs.

TABLE III. COMPARISON OF CHARACTERISTIC ELECTRIC BUS AND ICEV

Category	Electric Bus (E-Inobus)	ICEV (Hino RK8)
Length	8 meters	11 meters
Seating Capacity	20 seats	20 seats
Standing Capacity	20 standing	20 standing
Battery Capacity	138 kWh	-
Range	160 km	400 km

[c.] (analysis result, 2024)

In calculating the direct and indirect costs, various indicators are considered, including employee operational costs. According to survey interviews, employee operational costs encompass 21 bus drivers and 10 conductors, with total 31 employees. These cost calculations are based on the provincial minimum wage (UMP) for Bali Province. Furthermore, direct cost calculations involve comparing the electricity costs for electric buses with the fuel costs for ICEVs. However, for vehicle operational expenses, the individual unit cost of the vehicles is excluded due to being subsidized by governmental intervention. Figure 3 depicts an E-Inobus utilized during the G20 event held in Nusa Dua, Bali. Additional calculations include spare part costs and the tax rates applicable to public transportation operating on designated routes. Moving on to indirect costs, several components fall under this category, including depreciation and maintenance expenses for the building, office inventory costs aimed at ensuring smooth operations, and route costs charged to each corridor.

Figure 3. E-Inobus, One of the electric buses manufactured by PT. INKA.

Source: inka.go.id

TABLE IV. COMPARISION OPERATING COST BETWEEN ELECTRIC BUS AND ICEV

Type Of Cost	ICEVs (Hino Rk 8)	EBV (E-Inobus)	
Direct Cost			
Manpower-Cost	1.046,55	1.046,55	Rp/Km
Fuel/Electric Cost	2.193,55	1.293,75	Rp/Km
Spare Part Cost	28,28	15,36	Rp/Km
Tax Rate	108,81	96,01	Rp/Km
Total	3.377,18	2.451,66	Rp/Km
Indirect Cost			
Depreciation cost	12,80	12,80	Rp/Km
Adminitration facility cost	3,84	3,84	Rp/Km
Office Maintenance cost	10,24	10,24	Rp/Km
Trayek Cost	3,20	0	Rp/Km
Total	30,08	26,88	Rp/Km
Total Operational Cost	3.309,34	2.481,74	Rp/Km

[d.] (analysis result, 2024)

Based on the cost comparison analysis, the operational costs for the Inobus electric bus are 37.75% lower than the direct costs for the current ICEV buses. This indicates that if the Metro Dewata buses were replaced with electric buses (E-Inobus), the direct operational costs could be reduced by Rp. 925.52 per kilometer. Therefore, for a single trip, an electric Metro Dewata bus could save approximately Rp. 28,691. For indirect costs, there is a difference of approximately 3.2%, with the electric buses being lower. This reduction is attributed to the implementation of Bali Governor Regulation No. 48 of 2019 on the Use of Battery Electric Vehicles, which eliminates route costs for electric vehicles.

IV. CONCLUSION

This study utilizes previous data from the route between Terminal Ubung and Central Parking Kuta in Corridor 3B. In Passenger characteristic analysis shows public transportation users in Indonesia are predominantly young women who own private vehicles and driver's licenses, but are not employed. The majority of users have low incomes and spend 10-15% of their monthly expenses on transportation. The average user takes 1-3 trips per day at a cost of Rp 5,000 - Rp 10,000 per trip.

The operational performance analysis reveals a mixed picture. While travel times, waiting times, and average speed meet established standards, the low load factor is a serious concern. The average load factor, a measure of passenger occupancy, sits at a concerningly low 3.75%. Further investigation into the reasons behind low ridership and potential service improvements are crucial to ensure the financial sustainability and effectiveness of the Trans Metro Dewata bus network.

This distinction between direct and indirect costs allows for a more granular understanding of the financial requirements for operating the bus network. The cost comparison analysis reveals a significant advantage for electric buses. Operational costs for the Inobus electric bus are demonstrably lower than the direct costs associated with the current Internal Combustion Engine Vehicles (ICEVs) by a margin of 37.75%. This translates to a potential reduction in direct operational costs of Rp. 925.52 per kilometer if the Metro Dewata bus network transitioned to electric buses (E-Inobus). Extrapolated to a single trip, this translates to a potential cost saving of approximately Rp. 28,691 per trip with electric buses. While the current study has effectively analysed the cost-based aspects of electric bus implementation, future research should also delve into more fundamental considerations to provide a comprehensive understanding of the transition to electric buses.

REFERENCES

[1] L. E. Teoh, H. L. Khoo, S. Y. Goh, and L. M. Chong, "Scenario-based electric bus operation: A case study of Putrajaya, Malaysia," *International Journal of Transportation Science and Technology*, vol. 7, no. 1, pp. 10–25, Mar. 2018, doi: 10.1016/j.ijtst.2017.09.002.

[2] D. Raimi, E. Campbell, R. Newell, B. Prest, S. Villanueva, and J. Wingenroth, "Global Energy Outlook 2022: Turning Points and Tension in the Energy Transition A Global Energy Outlook 2022: Turning Points and Tension in the Energy Transition," 2022. [Online]. Available: www.thefrackingdebate.com

[3] M. F. N. Maghfiroh, A. H. Pandyaswargo, and H. Onoda, "Current Readiness Status of Electric Vehicles in Indonesia: Multistakeholder Perceptions," *Sustainability*, vol. 13, no. 23, p. 13177, Nov. 2021, doi: 10.3390/su132313177.

[4] V. Conti, S. Orchi, M. P. Valentini, M. Nigro, and R. Calò, "Design and evaluation of electric solutions for public transport," in *Transportation Research Procedia*, Elsevier B.V., 2017, pp. 117–124. doi: 10.1016/j.trpro.2017.12.033.

[5] L. K. Lim, Z. A. Muis, W. S. Ho, H. Hashim, and C. P. C. Bong, "Review of the energy forecasting and scheduling model for electric buses," *Energy*, vol. 263, Jan. 2023, doi: 10.1016/j.energy.2022.125773.

[6] F. Mao, Z. Li, and K. Zhang, "A comparison of carbon dioxide emissions between battery electric buses and conventional diesel buses," *Sustainability (Switzerland)*, vol. 13, no. 9, May 2021, doi: 10.3390/su13095170.

[7] S. Teng *et al.*, "Motion Planning for Autonomous Driving: The State of the Art and Future Perspectives," *IEEE Transactions on Intelligent Vehicles*, vol. 8, no. 6, pp. 3692–3711, Jun. 2023, doi: 10.1109/TIV.2023.3274536.

[8] Y. Sunitiyoso, P. F. Belgiawan, M. Rizki, and V. Hasyimi, "Public acceptance and the environmental impact of electric bus services," *Transp Res D Transp Environ*, vol. 109, p. 103358, Aug. 2022, doi: 10.1016/j.trd.2022.103358.

[9] M. Asadnabizadeh, "Analysis of Internal Factors of the Swing States in the International Climate Change Negotiations: A Case Study of Poland in COP24," *Am J Clim Change*, vol. 08, no. 02, pp. 263–283, 2019, doi: 10.4236/ajcc.2019.82015.

[10] L. E. Loría, V. Watson, T. Kiso, and E. Phimister, "Investigating users' preferences for Low Emission Buses: Experiences from Europe's largest hydrogen bus fleet," *Journal of Choice Modelling*, vol. 32, p. 100169, Sep. 2019, doi: 10.1016/j.jocm.2019.05.001.

[11] L. Zhang, Z. Liu, W. Wang, and B. Yu, "Long-term charging infrastructure deployment and bus fleet transition considering seasonal differences," *Transp Res D Transp Environ*, vol. 111, p. 103429, Oct. 2022, doi: 10.1016/j.trd.2022.103429.

[12] *President Decree No 79 Tahun 2023 On Acceleration Of Battery Electric Vehicles Program For Road Transportation*. 2023.

[13] Iq Air, "Air quality in South Tangerang," IQ Air.

[14] Z. J. Chin Gregory T., " Infrastructure at the G20."

[15] "Study on Challenges and Opportunities for Electric Vehicle Development for Land-based Public Transport Sector in Cities of Indonesia."

[16] M. Bartłomiejczyk, "Smart grid technologies in electric power supply systems of public transport," *Transport*, vol. 33, no. 5, pp. 1144–1154, Dec. 2018, doi: 10.3846/transport.2018.6433.

[17] K. Liu, H. Gao, Y. Wang, T. Feng, and C. Li, "Robust charging strategies for electric bus fleets under energy consumption uncertainty," *Transp Res D Transp Environ*, vol. 104, Mar. 2022, doi: 10.1016/j.trd.2022.103215.

[18] Q. Chen, C. Niu, R. Tu, T. Li, A. Wang, and D. He, "Cost-effective electric bus resource assignment based on optimized charging and decision robustness," *Transp Res D Transp Environ*, vol. 118, May 2023, doi: 10.1016/j.trd.2023.103724.

[19] S. Borén, "Electric buses' sustainability effects, noise, energy use, and costs," *Int J Sustain Transp*, vol. 14, no. 12, pp. 956–971, Oct. 2020, doi: 10.1080/15568318.2019.1666324.

[20] S. R. Shakya and R. M. Shrestha, "Transport sector electrification in a hydropower resource rich developing country: Energy security, environmental and climate change co-benefits," *Energy for Sustainable Development*, vol. 15, no. 2, pp. 147–159, Jun. 2011, doi: 10.1016/j.esd.2011.04.003.

[21] I. Veza *et al.*, "Electric Vehicles in Malaysia and Indonesia: Opportunities and Challenges," *Energies (Basel)*, vol. 15, no. 7, Apr. 2022, doi: 10.3390/en15072564.

[22] L. Gabsalikhova, G. Sadygova, and Z. Almetova, "Activities to convert the public transport fleet to electric buses," in *Transportation Research Procedia*, Elsevier B.V., 2018, pp. 669–675. doi: 10.1016/j.trpro.2018.12.127.