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Energy Efficiency and Greenhouse Gas Emission Reduction from the Shift of Private Vehicles to Mass Transportation Operated by Transjakarta

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***Abstract*—The Bus Rapid Transit (BRT) system in a city is a key element of sustainable transportation because it offers a solution to reduce congestion by encouraging people to use public transit. Jakarta has one of the best-implemented BRT systems in Indonesia and serves as a significant mitigation strategy to reduce greenhouse gas (GHG) emissions from road transport. This study seeks to assess the potential GHG emissions reduction from the operation of Jakarta's BRT system, as well as the fuel efficiency improvements resulting from the shift of private vehicle users to mass public transport. The study used quantitative data, comparing BRT operational data with the average trips of private vehicles assumed to switch to buses. The findings show that the potential reduction in GHG emissions from diesel-fueled BRT operations in Jakarta in 2023 is 256.906,12 tons of CO_2, while the potential decrease in GHG emissions from CNG-fueled BRT operations is 61.706,62 tons of CO_2. Furthermore, BRT operations contribute to energy efficiency by saving fuels as people shift from using private vehicles to using BRT for their daily mobility. The potential energy efficiency from the operation of the BRT system in Jakarta in 2023 is 794.341,57 Barrel Oil Equivalent (BOE), with 646.135,58 BOE for diesel-fueled and 153.221,88 BOE for CNG-fueled operations. (*Abstract*)**

Keywords—energy efficiency, GHG emission reduction, BRT operation, Transjakarta

I. INTRODUCTION

The global impact of climate change has become a major concern for the international community, including Indonesia. As an archipelagic country with various natural resources, high biodiversity, and a very large population, Indonesia is very vulnerable to the negative impacts of increasing greenhouse gas concentrations in the atmosphere and at the same time has great potential to contribute to overcoming climate change. One of the important steps taken by the Indonesian Government is to ratify the Paris Agreement to the United Nations Framework Convention on Climate Change through Law Number 16 of 2016 in October 2016. Through this agreement, Indonesia with other countries in the world committed to holding the rate of global temperature rise below 2°C and continuing efforts to suppress global temperature rise to 1.5°C above pre-industrial levels.

The Indonesian Government's commitment to addressing climate change has been outlined in the First NDC (Nationally Determined Contribution) document in 2016 with a target of reducing GHG emissions with its efforts of 29% from Business as Usual (BAU) conditions in 2030, and up to 41% if there is international funding assistance [1]. Then, in 2022 the Indonesian Government re-issued the Enhanced NDC document with an increase in the 2030 GHG emission reduction target to 31.89% from BAU conditions in 2030 with national efforts, and up to 43.2% with international funding assistance [2].

Based on the GHG emission inventory report 2023 published by the Ministry of Environment and Forestry, the transportation sector is one of the most important subsectors of the energy sector in Indonesia because since 2012 transportation has become the largest energy user. During the period 2000 to 2022, the average growth rate of GHG emissions in the transportation subsector was 4.8% per year. In 2022, GHG emissions in the transportation subsector were 158,930 Gg CO2e, an increase of 10% compared to 2021 which was 143,910 Gg CO2e. GHG emissions from the transportation subsector are separated into civil aviation, land transportation (roads and railways), and water navigation. GHG emissions are dominated by land transportation activities. In 2022, land transportation emissions contributed 95% of the total GHG emissions in the transportation subsector [3].

With this background, Indonesia is trying to improve public transportation services, especially in metropolitan cities, including Jakarta. As in [4], Jakarta's traffic congestion is caused by uncontrolled vehicle growth, an insufficient public transportation system, and a lack of traffic discipline. Congestion leads to the loss of both time and economic value due to reduced travel speeds and extended travel durations. This situation results in decreased fuel efficiency, accelerated wear and tear on vehicles, increased air pollution, and higher GHG emissions. Hence, a BRT system is therefore being developed by the government.

II. LITERATURE REVIEW

A. Definition of BRT System

BRT is "a high-quality bus-based transit system that delivers fast and efficient service, including dedicated lanes, busways, traffic signal priority, off-board fare collection, elevated platforms, and enhanced stations" [5]. Based on the BRT Standard, BRT is "a bus-based rapid transit system that can achieve high capacity and speed at relatively low cost by combining segregated bus lanes that are typically median aligned, off-board fare collection, level boarding, bus priority at intersections, and other quality-of-service elements (such as information technology and strong branding)" [6].

BRT is a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective services at metro-level capacities [7]. This is achieved by implementing dedicated lanes, strategically positioned bus-ways and distinctive stations at the center of the roadway, off-board fare collection, and efficient, frequent service operations. Due to its resemblance to light rail and metro systems, BRT offers greater reliability, convenience, and speed compared to conventional bus services. With appropriate design, BRT can mitigate most of the delays that typically hinder regular buses, including traffic jams and onboard fare payment queues. As a mode of transport that prioritizes safety, cleanliness, and efficiency, BRT enhances individuals' time and serves as an intelligent response to the urban transport challenges faced by cities.

B. Elements of the BRT System

As in [8], five essential elements define BRT, which most significantly result in a faster trip for passengers and make traveling on transit more reliable and more convenient, which are : (1) Dedicated right-of-way; (2) Busway alignment; (3) Off-board fare collection; (4) Intersection treatments; (5) Platform-level boarding. Besides the five elements of BRT, four other components ensure BRT is well designed, these are: (1) Service planning, service is the key to good public transportation; (2) Stations and Buses, stations are an important part of the BRT system, as they provide passengers with an introduction to the system; (3) Communications, is another substantial thing to communicating the BRT system to the passengers; (4) Access and integration, the BRT corridors must be accessible by the passengers and also integrate with another public place, and to another transport mode.

As in [7], the C40 BRT Network has identified a core set of general principles essential for the successful development of a robust Bus Rapid Transit (BRT) system aimed at reducing GHG emissions:

a. Promote a stronger integration of spatial and transport planning to facilitate compact development, thereby minimizing car dependency and fostering more sustainable travel patterns;

b. Provide enhanced alternatives to private vehicle usage, including more sustainable and higher occupancy transportation options such as mass transit and non-motorized transport modes;

c. Enhance the management of road space and transportation demand through strategies such as parking regulations, congestion pricing, incentives, and increasing public awareness of sustainable travel options.

Jakarta was the first city in Indonesia to use the BRT system for public transportation. This system has been run by Transjakarta since February 1, 2004. The Transjakarta system was also designed on the same basis as the TransMilenio system in Bogota, Colombia, making it the first BRT system in Southeast and South Asia [9].

Transjakarta currently offers a range of services. Besides the BRT system which stops at designated BRT lanes, Transjakarta also provides feeder services that stop outside the Transjakarta BRT lane network. Transjakarta also has a Mikrotrans service, which is a feeder public transportation service that serves stops up to residential areas. In addition, there is also Royaltrans with premium buses that offer comfort and complete facilities to support mobility in Jakarta, as well as tourist bus services provided to explore various historical, iconic, and interesting places in Jakarta. Transjakarta has a service called Transjakarta Cares to help passengers with special needs. This service is for people with disabilities in Jakarta making it easier for them to reach bus stops that are accessible for them [10].

Increasing vehicles in Greater Jakarta will increase traffic congestion, increase travel time, and create stress in society. This will lead to people switching to more efficient transportation modes, by using public transportation. In November 2023, with 1.171.541 daily passengers, Transjakarta reached the highest number of passengers since Covid-19. Transjakarta service coverage has now reached 82.3 % of the area of Jakarta City. This indicates that upon leaving your residence, you can get Transjakarta service less than 500 meters away with Transjakarta bus stops [11]. TransJakarta) operates 4,370 buses and 2,968 microtrans in 2024 to enhance the quality of public transportation services in Jakarta. TransJakarta has increased its service coverage which currently operates 14 corridors with a total of 409 kilometers in length, thus making it the longest BRT system in the world [12], and has become an important public transit option that connects the lives of people in Jakarta.

C. BRT System Advantages

The implementation of Bus Rapid Transit (BRT) in Jakarta has tangible positive impacts on the environment, such as decreased air pollution and GHG emissions and improved energy efficiency resulting from the promotion of mass public transportation usage. The BRT system has demonstrated its productivity and viability in numerous cities. Curitiba's transportation uses 30% less fuel per capita than other major Brazilian cities. During the first five months of operation, Bogota's TransMilenio busway experienced a 93% decrease in fatalities and a 40% reduction in pollutants. An improvement in the quality of life for low-income residents of Bogota has been seen in the area, with savings in travel time and costs influenced by the TransMilenio system [13].

The BRT system in Johannesburg (Rea Vaya Phase 1A) indicates the travel time reduction. Notably, 53% of the corridor is allocated to segregated, exclusive BRT lanes. This design minimizes delays caused by congestion in mixed traffic lanes, allowing the BRT to maintain a commendable average speed of 30 km/hr. The primary beneficiaries of the enhanced travel time are expected to be the 83% of users switching to Rea Vaya from taxis, private vehicles, or traditional buses. Rea Vaya Phase 1A plays a significant role in preventing 26 road fatalities annually. The transition of passengers from higher-emission transportation options to Rea Vaya's high-capacity Euro IV low-sulfur diesel buses, along with the elimination of minibus taxis from the streets, plays a significant role in reducing CO2e emissions. Over a decade, Johannesburg has successfully achieved a reduction of nearly 400,000 metric tons of CO2e emissions for Rea Vaya Phases 1A and 1B combined [14].

The total present value of the benefits from Istanbul's Metrobüs system, projected over the 2007-2026 timeframe, is estimated at USD 9.95 billion in 2012 dollars. A significant portion of these benefits, specifically 64 percent or USD 6.4 billion, arises from the reduction in travel time experienced by Metrobüs users. Additionally, the reduction in vehicle operating costs contributes USD 2.2 billion, while road safety improvements yield USD 881.2 million. The financial impact of preventing premature deaths linked to increased physical activity is valued at USD 392 million, and the benefits from reduced CO2 emissions amount to USD 152 million. The Istanbul Metrobüs BRT system is projected to decrease carbon dioxide emissions by 167 tons per day and reduce annual fuel consumption by 60,955 tons through reorganizing and consolidating informal transit and conventional bus services [14].

Calculations have been conducted regarding the potential decrease in GHG emissions and improvement in energy efficiency resulting from the community's shift from private vehicles to mass transportation.

III. RESEARCH METHOD

This study adopts a quantitative approach to comparing GHG emissions from Transjakarta operations with those from private vehicle users transitioning to Transjakarta. The authors analyzed activity data from diesel-fueled Transjakarta buses in 14 corridors and CNG-fueled buses in 12 corridors in 2023. The data included the number of buses, bus capacity, number of trips per day, corridor length, and average fuel consumption per day.

The typical formula for calculating the potential energy efficiency of Transjakarta operations is as shown below:

$$EE = ECb - ECm \quad (1)$$

EE : Energy Efficiency

ECb : Energy consumption in the baseline condition

ECm : Energy consumption in mitigation condition

Energy consumption in baseline condition refers to the energy consumed by private vehicles in operation before users switch to Transjakarta. Energy consumption in mitigation conditions refers to the energy consumption of Transjakarta bus operations.

Meanwhile, the formula for calculating GHG emission reduction is as follows:

$$ER = BE - ME \quad (2)$$

BE : Baseline Emission

ME : Mitigation Emission

ER : Emission Reduction

Baseline emissions are the GHG emissions produced by private vehicles when they are being used normally before people start using Transjakarta. Mitigation emissions are the greenhouse gas emissions that come from Transjakarta bus services.

IV. RESULTS AND DISCUSSION

This study utilizes operational data in 2023 concerning 1,092 diesel buses functioning across 14 primary corridors, excluding feeder transportation routes, microtrans, and other forms of transit. It also considers 286 CNG-fueled buses operating in 12 corridors, noting that corridors 4 and 14 do not feature any CNG buses.

A. Energy Efficiency

This study shows that Transjakarta can save 646,135.58 BOE from diesel-fueled buses and 153,221.88 BOE from CNG-fueled buses, in the year 2023. The energy efficiency per corridor results are shown in Table 1 for diesel-fueled BRT buses and Table 2 for CNG-fueled BRT buses.

TABLE I. ENERGY EFFICIENCY FOR DIESEL-FUELED BRT BUSES

Diesel-fueled BRT	Energy Consumption Baseline (BOE)	Energy Consumption Mitigation Condition (BOE)	Energy Efficiency (BOE)
Cor 1	111,101.99	1,017.56	110,084.43
Cor 2	35,013.96	270.52	34,743.44
Cor 3	35,206.34	333.12	34,873.22
Cor 4	19,238.44	140.35	19,098.09
Cor 5	43,094.10	327.03	42,767.08
Cor 6	59,927.74	491.49	59,436.25
Cor 7	59,927.74	511.95	59,415.78
Cor 8	33,090.12	499.37	32,590.74
Cor 9	48,096.10	765.12	47,330.98
Cor 10	61,178.24	690.15	60,488.09
Cor 11	50,019.94	369.05	49,650.89
Cor 12	50,019.94	478.71	49,541.23
Cor 13	45,787.48	438.79	45,348.69
Cor 14	769.54	2.87	766.67
Total Energy Efficiency			**646,135.58**

TABLE II. ENERGY EFFICIENCY FOR CNG-FUELED BRT BUSES

CNG-fueled BRT	Energy Consumption Baseline (BOE)	Energy Consumption in Mitigation Condition (BOE)	Energy Efficiency (BOE)
Cor 1	49,827.56	599.17	49,228.39
Cor 2	4,040.07	40.98	3.999.09
Cor 3	13,851.68	172.08	13,679.60

CNG-fueled BRT	Energy Consumption Baseline (BOE)	Energy Consumption in Mitigation Condition (BOE)	Energy Efficiency (BOE)
Cor 5	13,851.68	138.01	13,713.67
Cor 6	673.35	7.25	666.09
Cor 7	673.35	7.55	665.79
Cor 8	769.54	15.25	754.29
Cor 9	42,324.57	884.01	41,440.56
Cor 10	26,549.05	41.39	26,507.65
Cor 11	769.54	7.45	762.08
Cor 12	480.96	6.04	474.92
Cor 13	1,346.69	16,94	1,329.75
Total Energy Efficiency			**153,221.88**

B. *GHG Emissions Reduction*

The operation of Transjakarta's BRT system in 2023 also has a positive impact on the environment, by reducing GHG emissions by 318,612.74 tons of CO_2, of which 256,906.12 tons of CO_2 comes from diesel buses, and 61,706.62 tons of CO_2 from CNG-powered buses.

TABLE III. GHG EMISSIONS REDUCTION FROM TRANSJAKARTA BRT SYSTEM

BRT Corridor	GHG Reduction (tonCO_2)	
	Diesel-fueled buses	***CNG-fueled buses***
Cor 1	43,770.68	19,816.58
Cor 2	13,814.89	1,606.75
Cor 3	13,865.83	5,508.85
Cor 4	7,593.99	-
Cor 5	17,005.36	5,508.87
Cor 6	23,633.08	267.79
Cor 7	23,624.72	267,79
Cor 8	12,956.27	306.04
Cor 9	18,815.74	16,832.41
Cor 10	24,049.26	10,558.60
Cor 11	19,742.67	306.05
Cor 12	19,697.87	191.28
Cor 13	18,030.89	535.58
Cor 14	304,88	-
Total	**256,906.12**	**61.706,62**

V. CONCLUSION

One of the mass transit systems in Jakarta that links people to their everyday activities is the BRT system run by Transjakarta. This system has a positive environmental impact when assessing the potential decrease of GHG emissions, as well as saving the nation's energy usage. Transjakarta's BRT system in 2023 reduced GHG emissions by 318,612.74 tons of CO_2, from diesel-fueled buses and 61,706.62 tons of CO_2 from CNG buses. Furthermore, Transjakarta operations can save a total of 799,357.46 BOE of energy, derived from 646,135.58 BOE and 153,221.88 BOE from diesel and CNG buses, respectively.

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