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ENHANCING URBAN MICRO-MOBILITY: ENVIRONMENTAL IMPACT OF INTEGRATED BIKE SHARING AT COMMUTER RAIL STATIONS IN YOGYAKARTA URBANIZED AREA

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Abstract. Climate change, particularly CO_2 emissions from the transportation sector, poses a significant global challenge. Promoting micro-mobility services, especially bike sharing programs, is crucial in addressing this issue. This study examines the environmental benefits of integrating bike sharing programs with public transportation by estimating the potential CO_2 emission reductions through the avoided motorized trips approach. Data were collected via a commuter line passenger survey in the Yogyakarta Urbanized Area, resulting in 157 valid responses. The estimation considered specific data inputs: trip distance, emission factor, energy factor of transportation mode, and the number of people traveling by mode. Two scenarios related to bike sharing demand and commuter line ridership were employed. The findings reveal that bike sharing demand ranges from 16.03% to 48.08%. In terms of CO_2 emissions reduction, the study indicates that avoided motorized trips through bike sharing as an egress mode can potentially reduce cumulative CO_2 emissions by up to 567,158.35 tons CO_2e by 2030. This reduction corresponds to 0.487% and 160.113% of the national and provincial reduction targets, respectively. These findings provide insightful information to promote sustainable transportation provision.

Keywords: Micro Mobility; Bike Sharing; Environmental Benefit; Potential Emission Reduction

[Judul: Meningkatkan Mobilitas Mikro Perkotaan: Dampak Lingkungan Sistem *Bike Sharing* yang Terintegrasi di Stasiun Kereta Komuter di Kawasan Perkotaan Yogyakarta]. *Perubahan iklim, khususnya melonjaknya emisi CO_2 dari sektor transportasi, merupakan tantangan global pada saat ini. Mempromosikan layanan mobilitas mikro, khususnya program bike sharing, sangat penting dalam mengatasi masalah ini. Penelitian ini mengkaji manfaat lingkungan dari integrasi program bike sharing dengan transportasi publik dengan memperkirakan potensi pengurangan emisi CO_2 melalui pendekatan perjalanan menggunakan kendaraan bermotor yang beralih menggunakan bike sharing. Data dikumpulkan melalui survei penumpang kereta komuter di Kawasan Perkotaan Yogyakarta, yang menghasilkan 157 tanggapan yang valid. Estimasi ini mempertimbangkan input data spesifik: jarak perjalanan, faktor emisi, faktor energi moda transportasi, dan jumlah orang yang melakukan perjalanan dengan moda tertentu. Dua skenario yang terkait dengan permintaan dan proyeksi jumlah penumpang kereta komuter digunakan pada penelitian ini. Temuan menunjukkan bahwa permintaan bike sharing berkisar antara 16.03% hingga 48.08%. Dalam hal pengurangan emisi CO_2, studi ini menunjukkan bahwa alih-alih menggunakan kendaraan bermotor, menggunakan bike sharing sebagai moda lanjutan berpotensi mengurangi emisi CO_2 secara kumulatif hingga 567.158,35 ton CO_2 pada tahun 2030. Pengurangan ini setara dengan 0.487% dan 160.113% dari target pengurangan nasional dan provinsi. Temuan ini memberikan informasi yang mendalam untuk mendorong penyediaan transportasi yang berkelanjutan.*

Kata Kunci: *Mobilitas Mikro; Bike Sharing; Manfaat Lingkungan; Potensi Pengurangan Emisi*

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1. INTRODUCTION

The world has been dealing with the impact of climate change since rapid motorization continues to grow. Studies have reported that the transportation sector is one of the significant contributors to greenhouse gas (GHG) emissions. Specifically in Indonesia, the transportation sector contributed around 22% to 24% of GHG emissions (Cardama et al., 2023; International Energy Agency, 2021). This might occur due to high demand mobility caused by considerable of residential land use in Indonesia (Basuki & Rahayu, 2022). In addition, according to the Ministry of Energy and Mineral Resources (MoEMR) of the Republic of Indonesia, the GHG emissions by the transportation sector have been increasing at an average rate of 7.17% per year (Ministry of Energy and Mineral Resources, 2020).

In response to this matter, the Government of Indonesia (GoI) through Ministry of Transportation had issued Ministerial Decree Number 8 Year 2023 concerning the detailed mitigation action in transportation sector responding the climate change issue. It is important to note that the regulation encourages the usage of non-motorized transportation as an urban micro-mobility, including a bike sharing scheme, in the future development of Greater Jakarta. On the other hand, the GoI has attempted to suppress GHG emissions by 917,264 tons of CO_2e from land transportation, with 84% coming from Bus Rapid Transit (BRT) implementation in 2022 (Ministry of Transportation, 2023).

In line with the abovementioned issue, it is critical to discover an alternative breakthrough associated with CO_2 emissions reduction from the transportation sector by considering bike sharing programs as urban micro-mobility services. This type of mode has the potential to suppress carbon-produced vehicle usage while reducing congestion in urban areas. In addition, the study in Lisbon reported that people can rely on bike sharing programs as their main mode during the public health crises, for instance, the COVID-19 pandemic, where mass transportation might pay less attention in health protocol (Filipe Teixeira, Silva, & Moura e Sá, 2022). Hence, this study solely focuses on examining the environmental impact of the bike sharing program. In this study, the proposed program was designed as an egress mode for the last mile trip, or in other words, integrated with public transportation nodes.

This study highlights two added values which could be novelty compared with existing literature. Firstly, as this study designed the bike sharing program as an egress mode of public transportation, therefore the study took commuter line stations within the Yogyakarta Urbanized Area (YUA) in Indonesia as a case study. It can be argued that there are limited studies estimating the potential GHG emissions reduction of bike sharing programs, particularly in the context of urban areas in developing countries with less cycling demand (more details regarding the related earlier studies are provided in the next section of this study). This case study is also relevant as bike sharing programs have the potential to be implemented according to the provincial development plan. Moreover, previous research has identified a unique characteristic regarding the correlation between outdoor activities and specific types of green spaces in Yogyakarta. The findings suggest that the majority of individuals are more likely to engage in outdoor activities in non-green spaces (Afrianto, Roychansyah, & Herwangi, 2023).

Secondly, this study captured potential emission reduction by mainly using the avoided motorized trips approach, which means existing motorized trips could potentially be replaced by bike sharing trips. This approach was conducted by identifying the existing mode and preferred future mode of commuter line passengers, whether using bike sharing or not, utilizing revealed and stated preference data.

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Since the study aims to examine the environmental benefits of the future bike sharing program with consideration of the avoided motorized trips, it could be achieved by reaching two objectives. First, the potential bike sharing demand was obtained using a stated-choice experiment. Second, the potential reduction of CO_2 emissions was estimated, and the results from different scenarios were compared. The key findings of this study provide useful information to related stakeholders in general, that aimed to promote sustainable transportation by enhancing micro-mobility services integrated with existing public transportation services.

The remainder of this paper is organized as follows. Section 2 describes a synthesis of earlier studies on environmental benefits from diverse sustainable transport, both implemented project and future implementation. Section 3 explains YUA information and the detailed methodology, including the scenario design, data collection, and emission reduction formula. Section 4 elaborates on the research findings. Finally, section 5 concludes the study.

Environmental Benefit from Diverse Sustainable Transport Implementation

Bike sharing has been becoming an increasingly popular mode for short-distance trip, specifically in its role as integrated mode with public transportation. The findings from Beijing emphasized that the availability of bike sharing docking stations around the metro rail station could reduce motorized usage as a transfer mode (Zhao & Li, 2017). Moreover, a study from County Dublin investigated micro-mobility services usage, namely shared e-scooter, bike sharing, and walking, in terms of first and last mile of public transport (Oeschger, Caulfield, & Carroll, 2023). It revealed that bike sharing has the prospect of replacing private motorized vehicles as an access and egress mode. Nevertheless, these findings regarding the specific reason behind this relation need further examination.

There have been many studies which estimated CO_2 emission reduction within diverse sustainable transportation implementation. The study from Yogyakarta examined the potential environmental co-benefits, including CO_2 emission reduction, of light BRT implementation, namely Trans-Jogja in Yogyakarta (Dirgahayani, 2013). The study considered the passenger's previous mode before they used BRT to identify a mode shift to BRT or in this case it called avoided motorized trips by BRT trips. The study revealed that the avoided motorized trips by shifting to Trans-Jogja was expected to reduce CO_2 emission by approximately 1,313,016.05 tons CO_2e in ten years period.

Using combined work-from-home (WFH) and electric vehicle (EV) scenarios, the study from Dublin conducted a simulation of the potential CO_2 emissions reduction from commuting trip (Stefaniec et al., 2024). The study used the CO_2 emissions generated from commuting trips in 2019 (known as before the COVID-19 pandemic) as a baseline reference. The findings emphasized that with a combination of a high WFH scenario and EVs, the share ratio increased to 33.38%, and the CO_2 emissions could be reduced by up to 35% compared to the baseline reference.

In terms of bike sharing, the study from Shanghai, China, investigated CO_2 emissions reduction of bike sharing trips using big data from the bike sharing operator (Zhang & Mi, 2018). Moreover, the CO_2 emissions reduction estimation was calculated using bike sharing trip distance consideration. They divided bike sharing users into two groups based on a threshold distance of 1 km: trips that were less than 1 km were assumed to replace non-motorized trips, while trips more than 1 km were assumed to replace motorized trips. It found that the CO_2 emissions reduction of bike sharing trips was 25,240 tons CO_2e in 2016.

Another study from the USA presented the findings of environmental impact during the bike sharing implementation in 2016 (Kou, Wang, Chiu, & Cai, 2020). They estimated CO_2 emission reduction in eight cities in the USA, encompassing New York, Chicago, Boston, Philadelphia, Washington D.C., Los Angeles, San Francisco, and Seattle, by using combined bike sharing data trips from operators and trip patterns generated from the National Household Travel Survey (NHTS). The study revealed that the bike sharing system could contribute to reducing maximum CO_2 emission by 5,417 tons

CO_2e. This is highly correlated with high bike sharing trips, which accounted for 10,262,649 trips taken from New York in 2016. Furthermore, the study found that the one additional bike sharing trip was equal to marginal emission reduction by 533 g CO_2e. The location of the docking station is highly correlated to contribute to more CO_2 emission reduction due to high trip demand. In addition, the study compared the contribution of estimated emissions reduction to total GHG emissions from the transportation sector in each city. The study found that bike sharing trips in Washington DC potentially contributed to emissions reduction by 0.077% of total GHG emissions of 1.74 million MT CO_2e per year.

Despite the environmental benefit, generally, bicycle mode is considered as near-zero emission mode as the production phase of the mode by using aluminum material production still generates the carbon emission (Coelho & Almeida, 2015). Using the life cycle assessment software SimaPro, the study identified three components of bicycles responsible for causing environmental impact: the wheel, the fork, and the body.

Regarding the present study, the method proposed in this study incorporated the avoided fuel consumption of motorized vehicles which may produce emissions, to the estimation. This methodology has also been applied in previous studies conducted in Yogyakarta, which examined the local Bus Rapid Transit (BRT) system as detailed by (Dirgahayani, 2013), and in eight cities across the United States, focusing on bike sharing systems as investigated by Kou et al. (2020). Accordingly, the case study presents a unique and novel contribution that may address a literature gap in the existing studies by providing an investigation of the potential CO_2 emission reduction from future bike sharing integration with commuter rail stations within YUA, which is characterized as an urban area with less cycling demand in developing countries.

2. METHOD

2.1. *Case Study: Yogyakarta Urbanized Area*

Yogyakarta Urbanized Area (YUA), an urban area formed by the rapid development of Yogyakarta City, is part of Yogyakarta Special Region (YSR) Province in Southern Java Island of Indonesia. According to YSR Regional Regulation Number 5 Year 2019, YUA consists of Yogyakarta City and partly Sleman Regency and Bantul Regency. The YUA area delineation can be depicted as shown in Figure 1. The total area of YUA is 180.78 km^2 with almost 1 million inhabitants by 2023 (Badan Pusat Statistik, 2024). Hence, YUA is classified as a small-sized urban area in terms of the population.

Between 2019 and 2020, PT. Trijaya Komunika operated a bike sharing service branded as JogjaBike. The docking stations were strategically located near prominent tourist attractions, such as Malioboro and The Sultan Palace. However, the COVID-19 pandemic severely impacted all sectors, including tourism and transportation services, leading to the cessation of JogjaBike operations. Figure 2 illustrates the monthly number of bike-sharing trips during the operational period.

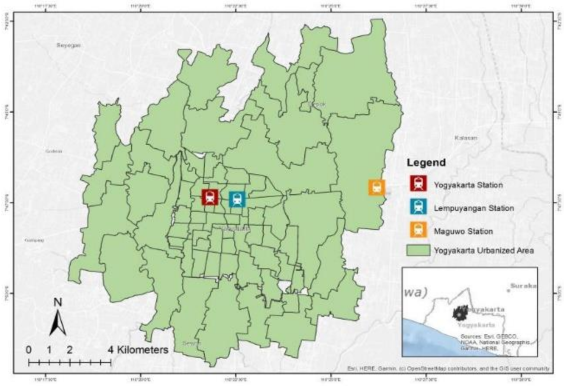

Figure 1. Map of YUA Including Commuter Rail Locations

2.2. *Scenario Design*

3.2.1 *Bike Sharing Demand Scenarios*

To estimate the potential CO_2 emission reduction, the study needs to find out the mode shift regarding the existing egress mode and the preferred egress mode when the bike sharing is integrated into commuter line station in the future development. The commuter line passenger survey conducted in Q2 of 2022. First, the survey collected the existing egress mode used by commuter line passengers for their last mile trip. Then the study employed experimental choice survey, namely stated preference, to capture their preferred egress mode whether choosing bike sharing or not if bike sharing integrated in the commuter line station. It means that in this study bike sharing mode was determined as a hypothetical choice. Accordingly, eight scenarios, denoted with Scenario 1 (S1) to Scenario 8 (S8), were developed comprising four combined bike sharing attributes with two different levels of each attribute as shown in Table 1.

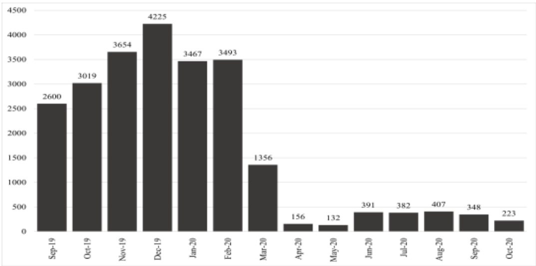

Figure 2. Ridership of Bike Sharing During the Operational Period (trips/month)
Source: PT Trijaya Komunika

The bike sharing attributes refer to integrated payment, information application, tariff, and walking distance. The attribute serves as a fundamental element in facilitating seamless utilization of public transportation. The integrated payment was categorized into two levels: available and not available. Meanwhile, the information application refers to an application on a mobile phone that can inform passengers the location of the docking station and the availability of the bikes. The information application attribute was divided into two levels: available and not available. Next attribute is the bike sharing tariff that was comprised into two levels: tariff 1 and tariff 2 that represent the category of tariff provision that is commonly used in public transportation realm, namely progressive and flat tariffs respectively. The walking distance means the distance between the final docking station to the user's end destination. The attribute was classified into two levels: 200 m and 500. This was determined based previous study on YUA (Basuki, 2017). An example from the first scenario, the respondents were queried about their willingness to choose bike sharing if the condition is set as follows: integrated payment is available, information application is available, the bike sharing rental tariff set at tariff 1, and a final docking station located 200 meters from their destination.

The survey targeted commuter line passengers who considered YUA as their destination for various trip purposes, from working to leisure trips. The surveyors were deployed to three commuter rail stations within YUA, namely Yogyakarta Station, Lempuyangan Station, and Maguwo Station. Additionally, to capture data from commuter line passengers who have travelled to YUA within the past six months, the survey was disseminated via social media platforms. The question lists were available on an online questionnaire form. In response to distance, since the study examines the use of potential pedal-powered bike sharing for the last mile trip, the responses that have an egress distance of more than 5 km were excluded. It refers to the ideal distance to ride the bicycle ranges from 1 to 5 km, and associated with suitable mode to be used for short-distance trip (Adnan, Altaf, Bellemans, Yasar, & Shakshuki, 2019; Pucher & Buehler, 2008). Finally, the study used 157 responses from the survey covering 47.44% female and 52.56% male passengers.

Table 1. Bike Sharing Demand Scenarios of Stated Choice Experiment

Scenario	**Attributes**			
	Integrated payment	**Information application**	**Tariff**	**Walking distance (m)**
S1	Available	Available	Tariff 1[a]	200
S2	Available	Available	Tariff 1	500
S3	Available	Not available	Tariff 1	200
S4	Available	Not available	Tariff 2[b]	500
S5	Not available	Available	Tariff 2	200
S6	Not available	Available	Tariff 2	500
S7	Not available	Not available	Tariff 1	500
S8	Not available	Not available	Tariff 2	200

[a] IDR 3000 for the first hour and IDR 3500 for the next hour

[b] IDR 5000/ hour

2.2 Commuter Line Ridership Scenario

This study also considers two scenarios, referring to commuter line ridership growth, as defined in Table 2. Baseline scenario is defined as the number of commuter line passengers assumed to be constant over the years from 2024 to 2030. On the other hand, the development scenario was designed by considering the assumption of public transport ridership growth rate from Asian Development Bank (ADB). Based on ADB, it is important to note that the public transport ridership in Asian cities would increase by 3% per year until 2030 (Gota & Huizenga, 2022). Figure 3 illustrates the projected number of commuter line passengers for each scenario from 2024 to 2030. The data for existing passengers from 2021 to 2023 were sourced from the operator, PT. KAI Commuter. The projected number of passengers was adjusted by considering only for one direction heading to YUA and alighting at three commuter line stations within YUA. Eventually, the eight scenarios, as explained in the earlier section, encompass two ridership scenarios respectively. Accordingly, the last mile demand and commuter line ridership scenarios were combined to build sixteen distinct scenarios. Hence, the value of potential emission reduction was obtained from the respective sixteen scenarios and subsequently to be compared.

Table 2. Commuter Line Ridership Scenario Definitions

Scenario	Description
Baseline	The number of commuter line passengers from 2024 to 2030 is constant
Development	The growth of commuter line passengers increased by 3% per year from 2024 until 2030

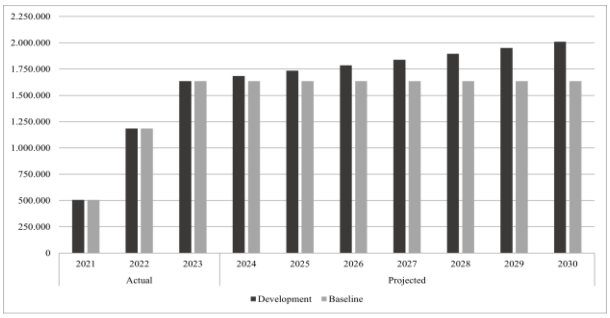

Figure 3. Number of Commuter Line Passengers per Direction Used in the Estimation

2.3. *Emission Reduction of Avoided Motorized Trips by Using Bike Sharing*

The potential emission reduction was generated from the avoided motorized trips. It means commuter line passengers intended to shift to bike sharing instead of using motorized vehicles to travel at last mile trip phase. In relation to motorized vehicles, there were four types of motorized vehicles assessed in this study. They are private cars, private motorcycles, car-based ride hailing, and motorcycle-based ride hailing. The potential emission reduction was quantified using the formula adopted from WRI Indonesia (Noor et al., 2020). In general, the total avoided emission per person is expressed by the formula:

$$TEP_p = \sum_{i=1}^{N} \frac{D_i}{FCF_{ij}} \times \frac{EFs_k}{PT_i} \quad (1)$$

Where *i* is the number of trips (1, 2, 3, ….,N), *Di* is the total distance (km) for the i^{th} trip, *FCF* is the energy factor for the transportation mode *j*, *EF* is the emission factor, *PT* is the number of people traveling together on the i^{th} trip, TEP_p is total avoided emission per person.

As mentioned in the earlier section, commuter line passengers informed their existing egress mode as well as the preferred egress mode, using bike sharing or not. Moreover, the survey also asked about the trip distance travelled by commuter line passengers after alighting from the commuter line by using existing motorized vehicles. These data were determined as the total distance by mode (*Di*). On the other hand, the value of vehicle occupancy rate was assumed to be the number of people travelling together by mode (PT). Those value were obtained based on the prior study from YUA (Risdiyanto, Yulianti, & Palupi, 2021).

Some assumption were considered in this study to determine energy factor (FCF) and emission factor (EF) based on given standard from WRI Indonesia (Noor et al., 2020). This study assumed that motorized vehicles are mainly fueled with gasoline. Following the discontinuation of RON 88 gasoline from the market, this study utilizes the emission factor corresponding to RON 92 gasoline. This choice is predicated on the assumption that RON 92 gasoline is the recommended fuel type for motorized vehicle users in Indonesia. Hence, the emission factor was assumed to be 2.39 kg CO_2/liter. This value applied for all types of mode.

3. RESULT AND DISCUSSION

3.1. Potential Avoided Motorized Trips

This section discusses the findings of mode shift from existing motorized vehicles to bike sharing. The mode shift dynamics are presented in Table 3. The findings reveal that Scenario 1 markedly enhances the preference for bike sharing as an egress mode among commuter line passengers, achieving a cumulative bike sharing share of 48.08%, outperforming other scenarios. The result also found that motorized users, namely MC (18.59%) and MC RH (21.15%) users, would prefer to choose bike sharing as an egress mode when implementing Scenario 1. Besides, it confirmed the earlier study which revealed that most of commuter line passengers in YUA used motorcycle and motorcycle taxi as their egress mode (Irawan, Putri, Belgiawan, & Dwitasari, 2017). However, the result also indicates that the average percentage of the bike sharing demand ranging from 15.39% to 16.67% with MC and MC RH users remaining to be the most contributor shares.

The changes of attributes combination were expected to be determinant factors in affecting bike sharing demand. This study aligns with previous research that investigated socio-economic and travel characteristics influencing the intention to use bike sharing systems (Adnan et al., 2019; Zhao & Li, 2017). In the context of Yogyakarta City, a mixed-logit study confirmed that availability of proper bicycle facilities could increase probability of cycling (Irawan, Andani, Hasanah, & Bastarianto, 2023). Conversely, with respect to bicycle facilities, a pivotal finding from prior research in developed countries indicates that bike-friendly infrastructure can substantially increase cycling activity in densely populated areas (Ito, Bansal, & Biljecki, 2024).

Table 3. Shifting Rate from Existing Motorized Vehicle to Bike Sharing (N=157)

Scenario	Car to bike sharing	MC to bike sharing	Car RH to bike sharing	MC RH to bike sharing	Cumulative bike sharing share
S1	3.85%	18.59%	4.49%	21.15%	48.08%
S2	2.56%	17.95%	3.21%	19.23%	42.95%
S3	2.56%	8.34%	3.85%	10.26%	25.01%
S4	1.28%	7.70%	1.28%	6.41%	16.67%
S5	0.64%	6.41%	3.21%	6.41%	16.67%
S6	1.28%	8.98%	0.64%	4.49%	15.39%
S7	0.64%	9.62%	1.28%	5.13%	16.67%
S8	1.28%	8.34%	1.92%	4.49%	16.03%

MC = Motorcycle

Car RH = Car ride-hailing

MC RH = Motorcycle ride-hailing

3.2 Emission Reduction Results

Table 4 presents the example results of the potential emissions reduction from Scenario 1 with different ridership scenarios. Along with the result, the assumption data used for estimating the potential emissions reduction are also presented in the table. On the other hand, the cumulative potential emission reduction based on combined demand and ridership scenario, within the period of 2024 – 2030, is presented in Table 5. As expected, the results were reasonable which revealed that the higher demand for bike sharing as the egress mode, the higher the potential for avoided emission.

Table 4. The Example Results of The Emission Reduction from The Avoided Motorized Trips Based on Scenario 1 in 2024 (Commuter Line Passengers: Baseline = 1,634,423 passengers/year/direction; Development = 1,683,455 passengers/year/direction)

	Car	MC	Car RH	MC RH
Avoided motorized trips by bike sharing	3.85%	18.59%	4.49%	21.15%
Vehicle occupancy rate[a]	1.52	1.27	1.76	1.42
Fuel type	Gasoline	Gasoline	Gasoline	Gasoline
Energy economy factor (km/liter)[b]	9.8	28	8.7	28
Emission factor (kgCO_2/liter)[b]	2.39	2.39	2.39	2.39
Average one-way trip distance by mode based on survey (km/trip)	2.94	3.3	3.25	3.01
Operating days	365	365	365	365
Annual avoided a motorized trip				
Baseline scenario[c]	62,925	303,839	73,386	345,680
Development scenario[d]	64,813	312,954	75,587	356,051
Baseline scenario				
Daily avoided emission per person (kg CO_2e)	0.47	0.22	0.51	0.18
Annual avoided emission per person (kg CO2e)[e]	172.34	80.95	185.16	66.05
Annual avoided emission (kg CO_2e)[f]	10,844,645	24,597,257	13,587,917	22,832,092
Annual avoided emission (tons CO_2e)	10,844.65	24,597.26	13,587.92	22,832.09
Development scenario				
Daily avoided emission per person (kg CO_2e)	0.47	0.22	0.51	0.18
Annual avoided emission per person (kg CO_2e)[e]	172.34	80.95	185.16	66.05
Annual avoided emission (kg CO_2e)[f]	11,169,984	25,335,174	13,995,554	23,517,055
Annual avoided emission (tons CO_2e)	11,169.98	25,335.17	13,995.55	23,517.05

[a] The value of vehicle occupancy rate was obtained based on the earlier study from YUA, assuming the number of people traveling together by mode (Rusdiyanto et al., 2021)

[b] The value of the energy economy factor and emission factor were obtained based on WRI Indonesia's report (Noor et al., 2020)

[c] Calculated by multiplying annual commuter line passengers from the baseline scenario with the avoided motorized trips rate

[d] Calculated by multiplying annual commuter line passengers from the development scenario with the avoided motorized trips rate

[e] Calculated by multiplying daily avoided emission per person with the operating days

[f] Calculated by multiplying annual avoided emission per person with the annual avoided motorized trip

This study assessed the result of potential contribution of emission reduction shown in Table 5 to both national and provincial targets regarding the emission reduction by 2030. To conduct the assessment, first we need to adjust those targets to derive the assumed value of emissions reduction targets only from motorized transport vehicles. Along with the value of both targets, the assumptions used for the adjustment are presented in Table 6.

The national emission reduction target was obtained from Presidential Decree of Republic of Indonesia Number 98 Year 2021 about National Determined Target on Green House Emission, whereas the provincial emission reduction target was obtained from the YSR Provincial Medium-Term Development Plan 2022 – 2027. The study assumed that the provincial emission reduction target in the period 2030 is equal with the target written in medium-term development plan at the end of 2027. After the adjustment, the emissions reduction target for both national and provincial targets, particularly from motorized vehicles are 116,543,032 tons CO_2e and 354,223 tons CO_2e respectively.

Table 5. Summary Results of Potential Emission Reduction

Bike sharing demand scenario	CL ridership scenario	Avoided emissions in the one-way trip (tons CO_2e)							Cumulative
		2024	2025	2026	2027	2028	2029	2030	
S1	Baseline	71,861.91	71,861.91	71,861.91	71,861.91	71,861.91	71,861.91	71,861.91	503,033.37
S1	Development	74,017.77	76,238.30	78,525.45	80,881.21	83,307.65	85,806.88	88,381.09	567,158.35
S2	Baseline	61,435.12	61,435.12	61,435.12	61,435.12	61,435.12	61,435.12	61,435.12	430,045.85
S2	Development	63,278.18	65,176.52	67,131.82	69,145.77	71,220.14	73,356.75	75,557.45	484,866.63
S3	Baseline	40,973.11	40,973.11	40,973.11	40,973.11	40,973.11	40,973.11	40,973.11	286,811.79
S3	Development	42,202.31	43,468.38	44,772.43	46,115.60	47,499.07	48,924.04	50,391.76	323,373.57
S4	Baseline	24,587.12	24,587.12	24,587.12	24,587.12	24,587.12	24,587.12	24,587.12	172,109.83
S4	Development	25,324.73	26,084.47	26,867.01	27,673.02	28,503.21	29,358.30	30,239.05	194,049.80
S5	Baseline	26,918.20	26,918.20	26,918.20	26,918.20	26,918.20	26,918.20	26,918.20	188,427.41
S5	Development	27,725.75	28,557.52	29,414.25	30,296.67	31,205.57	32,141.74	33,105.99	212,447.49
S6	Baseline	22,271.23	22,271.23	22,271.23	22,271.23	22,271.23	22,271.23	22,271.23	155,898.64
S6	Development	22,939.37	23,627.55	24,336.38	25,066.47	25,818.46	26,593.02	27,390.81	175,772.07
S7	Baseline	23,943.01	23,943.01	23,943.01	23,943.01	23,943.01	23,943.01	23,943.01	167,601.06
S7	Development	24,661.30	25,401.14	26,163.17	26,948.07	27,756.51	28,589.20	29,446.88	188,966.27
S8	Baseline	25,298.04	25,298.04	25,298.04	25,298.04	25,298.04	25,298.04	25,298.04	177,086.26
S8	Development	26,056.98	26,838.69	27,643.85	28,473.16	29,327.36	30,207.18	31,113.40	199,660.61

The potential contributions of the bike sharing initiatives to emission reduction targets both at the national and provincial levels are presented in Table 7. Each combination of bike sharing demand scenario and commuter line ridership scenario were compared. The contribution (in percent) was generated by dividing the potential emission reduction based on Table 5 with both national and provincial target presented in Table 6. The results show that implementing Scenario 1 with all positive attributes, or in other words, the rental tariff is cheap with the availability of integrated payment and information apps as well as the final docking station is near to end destination trip, contribute nationally to 0.432% and 0.487% in reducing CO_2 emissions from baseline and development scenarios respectively. It is important to note that those contributions were estimated with the assumption that bike sharing is used for egress mode that is conducted in one-way trips, or in other words, heading to the passenger's destination from one of three commuter line stations within YUA. Moreover, implementing bike sharing integration with Scenario 1 could contribute within the provincial level to 142.010% and 160.113% in reducing CO_2 emissions from baseline and development scenarios, respectively. Ultimately, the implementation of policies that facilitate intermodal integration within urban areas can significantly enhance public transportation ridership, thereby yielding co-benefits, particularly in fostering environmental sustainability (Devi, Pramana, & Safitri, 2022; Dirgahayani, 2013).

Table 6. The Assumption of National and YSR Province Emission Reduction Targets by 2030

Indicator	National	YSR Province
Emission reduction target by 2030 (tons CO_2e)	914,924,100[a]	2,603,336[b]
Transportation sector contribution to CO_2 emission	22%[c]	23.5%[d]
Private motorized vehicle contribution to emission in Indonesia[e]	57.9%	57.9%
Emission reduction target from private vehicle transport (only car and motorcycle) in Indonesia by 2030 (tons CO_2e)[f]	116,543,032	354,223

[a] Based on national target unconditionally worth 31.89% in Enhanced Nationally Determined Contribution (E-NDC) Republic of Indonesia multiplied with baseline GHG emission by 2030 worth 2,869,000,000 (tons CO_2e) according to Presidential Decree of Republic of Indonesia Number 98 Year 2021 concerning National Determined Target on GHG Emission
[b] According to YSR Provincial Medium-Term Development Plan 2022 – 2027
[c] Transportation sector contribution ratio to emission in Indonesia was obtained from SLOCAT (SLOCAT, 2023)
[d] According to Yogyakarta City Environmental Agency (Pustral UGM, 2017)
[e] Private motorized vehicle contribution ratio to emission in Indonesia was obtained from IESR (IESR, 2023)

[f] Calculated by multiplying emission reduction target by 2030 with the percentage of transport sector contribution and private vehicle motorized transport contribution to emission in Indonesia

Table 7. Potential Contribution of Bike Sharing Initiative to Emission Reduction Targets by Determined Targets Both National and Provincial Level in 2030

Bike sharing demand scenario	CL ridership scenario	Potential contribution to the national emission reduction target	Potential contribution to the YSR Province emission reduction target
S1	Baseline	0.432%	142.010%
S1	Development	0.487%	160.113%
S2	Baseline	0.369%	121.405%
S2	Development	0.416%	136.882%
S3	Baseline	0.246%	80.969%
S3	Development	0.277%	91.291%
S4	Baseline	0.148%	48.588%
S4	Development	0.167%	54.782%
S5	Baseline	0.162%	53.195%
S5	Development	0.182%	59.976%
S6	Baseline	0.134%	44.011%
S6	Development	0.151%	49.622%
S7	Baseline	0.144%	47.315%
S7	Development	0.162%	53.347%
S8	Baseline	0.152%	49.993%
S8	Development	0.171%	56.366%

4. CONCLUSION

As the global environmental issue regarding CO_2 emission is escalating, the implementation of sustainable transportation in urban areas is more critical. Moreover, the transportation sector was identified as one of the major contributors to global carbon emissions. To cope with this issue, the idea of advancing urban micro-mobility service by integrating bike sharing schemes with commuter rail stations, in terms of environmental benefit perspective, was proposed through this study. In addition, there have been little studies examining environmental benefits of micro-mobility service, namely integrated bike sharing with commuter rail stations, especially in urban areas characterized with less cycling demand in the context of developing countries.

To address these gaps, this study took commuter line services within YUA as the case study. The paper aims to examine the environmental benefits of bike sharing programs regarding the potential CO_2 emission reduction. The environmental benefits were generated by considering the avoided motorized trips which shifted to bike sharing. This result indicates that bike sharing implementation could contribute to reducing CO_2 emissions by 0.487% and 160.113% both for national and provincial targets, respectively. It can be concluded that implementing Scenario 1 could be a potential contribution to exceeding the provincial target.

Based on the findings of this study, it is recommended that stakeholders in YUA should actively promote the integration of bike sharing with public transportation. This initiative holds significant potential for environmental benefits, particularly in terms of substantial emission reductions. However, the implementation of this bicycle-oriented initiative in the policy-making process faces two potential primary challenges. Firstly, there are institutional challenges, including the need for inter-stakeholder cooperation and securing infrastructure financing. Secondly, there are cultural challenges related to cycling, as the population has become heavily reliant on motorized vehicles. Changing this entrenched habit poses a significant difficulty. It is well-documented that many cities and metropolitan areas, including YUA, are predominantly characterized by motorized vehicle usage for various trip purposes, including commuting and leisure. Consequently, developing a robust cycling culture will require considerable time and effort.

The present findings hold promise for the implementation of sustainable transportation solutions to enhance urban mobility. Future research should explore alternative sustainable modes to assess their environmental benefits comprehensively. Additionally, further studies should aim to gather a larger dataset to more accurately estimate the potential reduction in CO_2 emissions.

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