Enhancing Sustainable Urban Mobility: The TARIK Program for Carbon Emission Reduction in Bogor, Indonesia

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Abstract— The paper discusses the impact of transportation on carbon emissions in Bogor, Indonesia, and introduces the TARIK program to boost public transportation usage and decrease the carbon footprint. It presents calculations of carbon emissions before and after the TARIK implementation, demonstrating a reduction in emissions. The TARIK program comprises a mobile app for convenient access to public transportation details and payments, along with an Intelligent Transportation System to optimize fleet size and cut emissions. The program's introduction in Bogor City is anticipated to lower the carbon footprint by 11.02% to 29.02% weekly. Recommendations for supporting facilities include enhancing sidewalks, building bike lanes, improving shelter facilities, and incorporating green open spaces to encourage public transportation use and emission reduction, aligning with Sustainable Development Goals.

Keywords— Net Zero Emission, Sustainable Development Goals, Green Transportation, Carbon Emissions, Carbon Footprint Reduction, Intelligent Transportation System, Public Transportation Usage

1 Introduction

Greenhouse gas emissions (GHG) have become a serious concern in efforts to address global-scale climate change [1]. Currently, the Earth's surface temperature is approximately 1.1°C warmer than the late 1800s, and it is expected to continue rising [2]. To prevent more detrimental effects of climate change, the

Intergovernmental Panel on Climate Change (IPCC) has released a special report highlighting the necessity of keeping the rise in global temperatures to less than 1.5°C above pre-industrial levels [3]. The outcomes of the Paris Agreement (UNFCCC COP 21) established a target of 45% emission reduction by 2030 and Net Zero Emission by 2050 as a means of accomplishing this challenging goal [2].

Indonesia is the fifth-highest emitter of CO2 in the world between 1850 and 2021, accounting for 4.1% of the total emissions over that time, or 102.5 billion tonnes CO2 [4]. As one of the countries that ratified the Paris Agreement, Indonesia emitted 1,050,413 Gg CO_2 equivalent from all sectors in 2020 [5]. Based on these figures, transportation accounts for about 5% of total emissions in Indonesia. In the Nationally Determined Contribution (NDC) target, transportation generates approximately 26% of total emissions from the energy sector [6]. This data is supported by the Institute for Transportation and Development Policy (ITDP), which states that the transportation sector plays a significant role in carbon emissions production and energy consumption.

In the context ofithe SustainableiDevelopment Goals (SDGs) outlined by the UN, specifically goal 11 on Sustainable Cities and Communities and goali13 oniClimate Action, the implementation of sustainable transport is an effort to achieve these goals [7]. In its implementation, three crucial aspects must be considered in the application of sustainable cities: economic, social, and environmental [8].

As a support for reducing carbon footprint, social and economic aspects also need to be focused on through the concept of inclusive city development, which includes universal accessibility and inclusive infrastructure for all city residents [9]. A transportation system that prioritizes social-economic aspects, such as inclusive, affordable, and beneficial public transportation, can increase interest in public transportation use and have a positive impact on the environment [10].

The close relationship between the transportation system and the resulting carbon footprint can be observed in the city of Bogor. Transportation on the roads of Bogor contributes significantly to CO_2, SO_2, NMVOC, and PM2.5 emissions, accounting for 60-86% of the total emissions [11]. This is related to commuting activities, especially between Bogor and Jakarta. Steps taken to address this issue include improving public transportation facilities in Bogor, including the KRL Commuter Line [12]. The enhancement of supporting facilities for KRL in Bogor tends to have a significant impact on KRL users. It is estimated that KRL passengers from Bogor Station could reach 182,647,716 passengers per year by 2024 [13].

Although KRL passengers from Bogor Station have experienced rapid growth, this increase has not been supported by good first-mile connection facilities. Based on a survey

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TABLE 1.
Emission Factors and Energy Economic Factors

Modes of Transportation	Fuel Type	Emission Factor (kg CO_2/liter)	Energy Economic Factors (km/liter)
Car	Petrol (100% mineral petrol)	2.339	9.8
	Diesel (average biofuel blend)	2.558	10.3
Motorcycle	Petrol (100% mineral petrol)	2.339	28
Angkot (Public Transportation)	Petrol (100% mineral petrol)	2.339	7.5
Bus	Diesel (average biofuel blend)	2.558	3.5

TABLE 2.
Sample Calculation Results of Actual Carbon Footprint Emissions to Bogor Station

Modes of Transportation	**Total Carbon Footprint (kg CO_2eq/week)**	**Average Carbon Footprint (kg CO_2eq/week-person)**	**n**
Car	70,283	2,510	28
Motorcycle	40,464	2,310	31
Angkot (Public Transportation)	22,460	3,198	5
Bus	12,563	1,871	23
Total	**145,770**	**9,889**	**87**

conducted in 2023 as shown in Figure 1, only 10.34% of KRL users heading to Bogor Station use public transportation, and 8.05% use public transportation with private vehicles interchangeably. The most used public transportation by the public is Angkot (public minivans) and Trans Pakuan Buses. However, the public perceives Angkot to lack comfort and safety [14], and Trans Pakuan Buses have deficiencies in terms of speed, fleet size, and route information clarity [15]. Additionally, improving walkability and bikeability is also needed in first-mile connection facilities [16].

This scientific work aims to design an optimal public transportation program in Bogor, accompanied by an analysis of the reduction in carbon footprint that can be achieved with a case study of the first-mile connection to Bogor Station. Furthermore, recommendations are provided to stakeholders regarding steps that can be taken to support the success of the proposed program.

2 Literature Review

2.1 Mobility as a Service (MaaS)

MaaS, or mobility as a service, is a game-changing idea in transportation that aims to combine several means of transportation into a user-centric service for expedited trip planning and payment [17]. Its potential benefits span societal, economic, and environmental dimensions, but successful implementation hinges on prioritizing user needs and fostering seamless integration among various transportation options. Public- private collaboration is crucial to overcoming challenges and driving innovation [18]. In terms of fleet management, MaaS integration offers opportunities for optimizing resource allocation, reducing costs, and gaining insights into user behavior [19]. Collaboration between MaaS providers and fleet operators can enhance service provision and overall transportation efficiency [20]. MaaS holds the potential to revolutionize the way people move within and between cities. By providing a seamless and interconnected network of transportation options, MaaS can significantly reduce congestion, carbon emissions, and the overall environmental impact of individual travel [21]. This user-centric approach to mobility also has the potential to improve accessibility, especially for underserved communities and individuals with limited mobility options.

Furthermore, successful implementation of MaaS relies on robust data analytics and intelligent fleet management [22]. By collecting and analyzing user behavior and travel patterns, MaaS providers and fleet operators can optimize service offerings, identify areas for infrastructure improvement, and enhance the overall user experience [21]. This data-driven approach also presents opportunities for proactive maintenance and resource allocation, ultimately leading to more efficient and reliable transportation services.

TABLE 3.

Comparative Analysis of Emissions for Each Mode of Transportation

Modes of Transportation	**Passenger (Person)**	**Emission Factors/Economic Factors**	**Number of Vehicles with LCM (n=700/p)**	**Total Emission (kg CO_2) (TE=f×n)**	**Emissions Comparison**
Car	4	0.239	175	41,780	2.04
Motorcycle	1	0.084	700	58,493	2.86
Angkot (Public Transportation)	7	0.312	100	31,196	1.52
Bus	25	0.731	28	20,463	1.00
Least Common Multiple (LCM)	700				

TABLE 4.

Calculation Of Carbon Footprint After Tarik Implementation

Modes of Transportation	**Total Carbon Footprint (kg CO_2eq/week)**	**Average Carbon Footprint (kg CO_2eq/week-person)**
Car	12,665	1,055
Motorcycle	16,578	1,174
Angkot (Public Transportation)	46,178	2,674
Bus	41,169	2,403
Total	116,591	7,307

2.2 Decarbonization

To advance the aim of reaching net-zero emissions by the middle of the century, it is imperative that the transport sector reduce its greenhouse gas emissions. This is known as "transport decarbonisation." [23]. Given transportation's substantial role in exacerbating climate change as the global second-largest source of GHG and CO2 emissions (about 24%) [24], decarbonization initiatives are indispensable for alleviating its detrimental effects on the environment and public well-being. This transformation entails deploying diverse strategies, such as bolstering public transportation infrastructure and advocating for active modes of transport like walking and cycling [25]. Decarbonization of the transportation sector requires a multifaceted approach that goes beyond simply switching to cleaner fuels or more efficient vehicles. It involves a holistic transformation of the entire transportation system, including infrastructure, regulations, and individual behaviors [26]. This transformation also involves reshaping urban planning to prioritize walking and cycling, as well as innovating public transportation systems to make them more accessible, affordable, and environmentally friendly [27].

Decarbonization initiatives should also address other environmental and social effects of mobility, such as noise and air pollution and the unequal distribution of the costs and benefits of transport. These should not be limited to reducing greenhouse gas emissions. [28]. This comprehensive approach is crucial for ensuring that decarbonization efforts result in a truly sustainable and equitable transportation system for all [27].

2.3 First & Last Mile (FLM) Connection

First and last mile (FLM) connections play a pivotal role in transit planning endeavors, striving to enhance accessibility to public transportation networks [29]. Strategies aimed at improving FLM connections encompass various approaches such as spatial analysis, integrating emerging mobility services, implementing innovative funding models, and advancing infrastructure development [30]. These initiatives are geared towards boosting ridership, tackling transportation equity concerns, and aligning with regional emissions reduction targets. Through the enhancement of FLM connections, public transportation can elevate the overall transit experience, attract a larger ridership base, and foster sustainability and equity in urban transportation systems. Their focus remains on implementing strategies to enhance transit accessibility, encourage multimodal options, and ensure the overall viability of public transportation [31].

2.4 Movement & Place

The correlation between movement and place stands as a fundamental aspect of urban planning and transportation

Fig 3. Features in the Tarik On Line Application

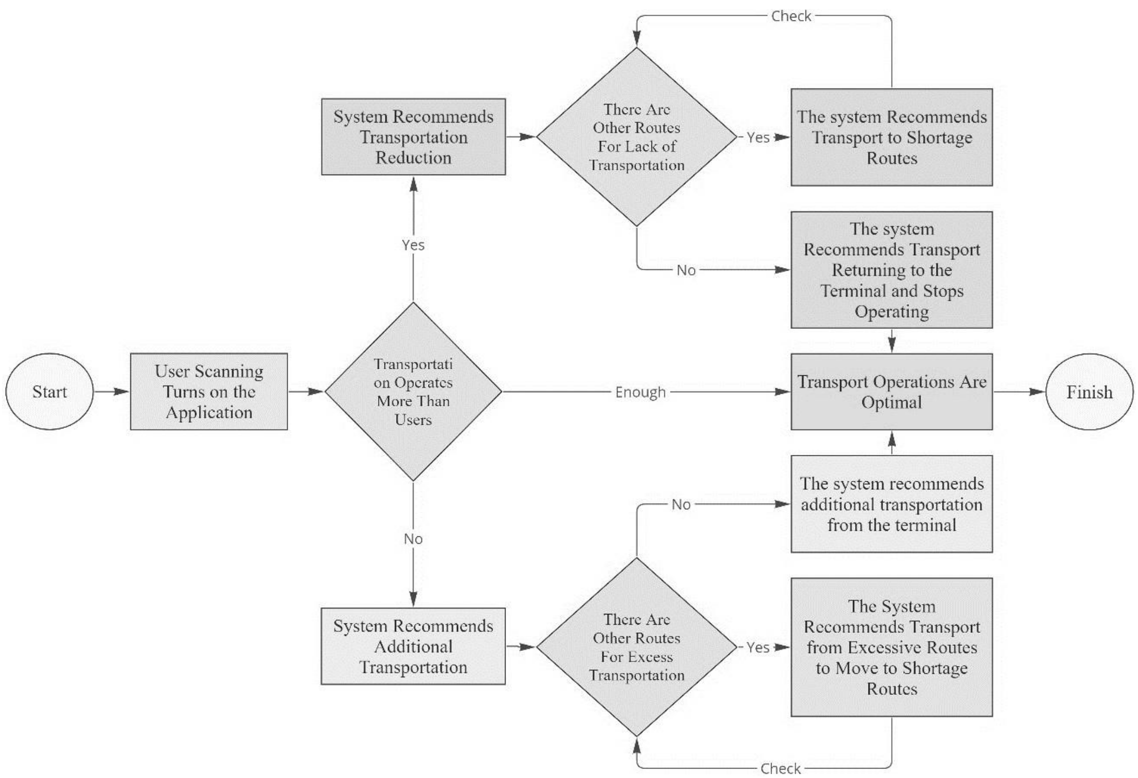

Fig 4. TARIK Intelligent Fleet Management System Logic and Algorithm Flow

policies, significantly influencing individual well-being, behavior, and community cohesion [32]. Public space quality plays a crucial role in determining the duration individuals spend in these areas and can yield positive outcomes, including heightened environment satisfaction and enhanced mental health and community unity [33]. Policies aimed at enhancing place quality, such as street redesign initiatives, theestablishment of pedestrian-friendly zones, and the reduction of motorized traffic volumes, are vital for cultivating sustainable and livable urban environments [32]. Recognizing the intricate relationship between movement and place quality is essential for crafting transportation policies that prioritize livability and address societal concerns like personal safety, visual clutter, community fragmentation, and social inclusion[34]. By emphasizing improvements in trip quality, place quality, and time utilization within transportationand public spaces, cities can foster more dynamic and sustainable living conditions for their residents [35].

3 Research Methodology

3.1 Data Collection

Rapid motorization, low usage of public transportation, excessive travel distances, and massive vehicledensity are

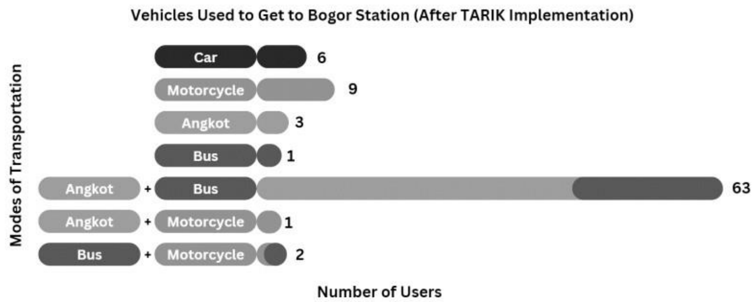

Fig 5. Prediction of KRL Users Regarding Modes After TARIK Implementation

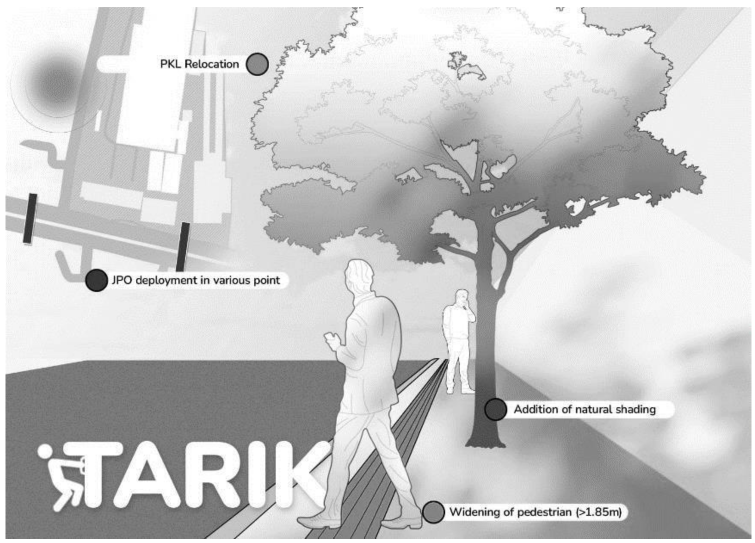

Fig 6. Recommendations for Walkable Facilities Supporting Solutions for the TARIK Program Illustration

the primary reasons that have led the transportation sector to become one of the major contributors to emissions and air pollution in Indonesia [36]. The calculation of the carbon footprint due totransportation in Bogor aims to demonstrate the extent of transportation's impact on air quality. This can serve as a relevant basis for considering environmental solutions by considering sociodemographic characteristics, the country's economy, and emission factors for Bogor's environmental policies. The methods used in the carbon footprint calculation process and the factors influencing CO_2 can be seen in Figure 1.

The carbon footprint calculation method is categorized as a bottom-up approach, involving the calculation of characteristics and the number of trips for Bogor residents. The calculation of Bogor's carbon footprint requires two parts: determining the characteristics of trips through survey data from Bogor KRL users and calculating carbon footprint emissions towards Bogor Station.

In the first part, data processing related to the characteristics of Bogor residents' trips to Bogor Station is essential, such as the mode of transportation used, the number of transfers, travel distance, travel frequency per week, and the number of people traveling together on the used transportation. Therefore, random sampling on residents of Bogor who use the KRL Commuter Line service regarding the usual mode of transportation used as the first mile, frequency of travel per week, and the origin location of the journey to determine mileage is conducted. Random sampling was conducted through a questionnaire survey of 87 respondents from the Bogor residents who use the KRL Commuter Line service, and the distribution of options for transportation modes as shown in Figure 2 was obtained. Additionally, based on the survey conducted, it is known that the distance traveled by each respondent and the frequency of travel per week are on average 5.75 km and 4 trips per week, respectively.

3.2 Carbon Emissions Calculation

The second part utilizes a fuel-based method andidistance calculations to determine carbon footprint emissions [37]. This method considers emission factors (EF) in Indonesia, namelyfuel emission factors (kg CO_2/liter) and energy economic factors (km/liter) as fuel efficiency calculations [38]. The mode of transportation used will influence both factors. Emission and energy economic factors represent the ratio between greenhouse gas emissions produced and activity data, such as fuel consumption and travel distance. The carbon footprint calculation using fuel-based and distance calculation methods can be expressed by the following equation [37]:

$$Total\ emission\ per\ person\ (TEP_p) = \sum_{I=1}^{N} \frac{Di}{FCFij} \times \frac{EFsk}{PTi}$$

Information:

i = number of trips (i = 1,2, …, N) taken

D_i = distance traveled for the i-th trip (km)

FCF_{ij} = energy economic factors for transportation modes (j) on trip i (km/liter)

EF_{sk} = fuel emission factor

PT_i = number of people traveling together ontrip I

Determinants in the calculation of greenhouse gas (GRK) carbon footprint emissions are obtained from the recommendations of theiIPCC (2006) and national average figures provided by the Ministry of Environment and Forestry of Indonesia (KLHK) (2010) (see Table 1). After conducting calculations based on the method of measuring the impact of greenhouse gas (GRK) emissions in carbon dioxide equivalent (CO_2 eq), it was found that the total carbon footprint emissions per week towards Bogor Station amounted to 145,770 kg CO_2 eq, with an average carbon footprint of 9,889 kg CO_2 eq per person.

To determine the significance of carbon footprint emissions from transportation to Bogor Station in 2024, the sample carbon footprint calculation from the survey was processed according to the population data projection of KRL passengers from Bogor Station, which is 182,647,716 people per year [13]. Therefore, the total carbon footprint towards Bogor Station in 2024 is 6,375,612.862 kg CO_2 eq/week with an average of 432,519.967 kg CO_2 eq/week per person.

4 Discussion

4.1 Mode of Transportations Emissions Comparison

Comparative analysis in the carbon footprint calculation method is used to present a comparison of carbon footprint emission results from various modes of transportation used towards Bogor Station. Through the least common multiple method among passenger capacities in a vehicle, it is found that if the same population with the same travel distance uses the same type of vehicle as the sole mode of transportation, private vehicles such as motorcycles and cars can produce significantly larger emissions compared to public transportation, such as minivans and buses.

Based on Table 3, the conclusion is drawn that public transportation, which has a higher passenger capacity than private vehicles, has emissions that are nearly twice as small compared to private vehicles. The more passengers transported in one vehicle, the fewer motorized vehicle mobilizations, and the lower carbon emissions per passenger. Greenhouse gas emissions produced from collective transportation footprints will have a comprehensive and hazardous environmental impact on global temperature rise.

Therefore, effective solutions are needed to encourage the concept of carpooling or the use of group transportation such as public transportation to optimize vehicle capacity, which influences the overall reduction of carbon footprint emissions.

4.2 Strategies for Increasing Public Trasport Users with TARIK

TARIK, Transportasi Aman, Ramah Lingkungan, Inklusif (in Indonesia) or Safe, Environmentally Friendly, Inclusive Transportation, is a program aimed at transforming connectivity and increasing the useof public transportation in the city of Bogor. The goal is to reduce the negative impacts of private motor vehicle usage. The TARIK program is accessible through the mobile application "Tarik On Line." This initiative aims to provide information about the availability of public transportation in the city of Bogor.

Features within the Tarik Online application include easy searching for public transportation and optimal routes through "TarikRide," as well as convenient payment options and promotional coupons for KRL (Commuter Line) users through "TarikPay," as illustrated in Figure 3. TarikRide utilizes GPS (Global Positioning System) technology to map the location of passengers and vehicles, displaying the nearest public transportation options within a certain radius by evaluating distance, arrival time, level of service (LoS), and travel time for the route.

TarikPay employs a historical track payment method to integrate fares between different modes of public transportation. This innovation tracks user activities and facilitates daily transactions through a digital wallet. Tarik On Line also provides an article section covering the latest news and action steps to support the environment, collaborating with the Environmental Agency of Bogor City. This is intended to disseminate information and raise awareness among application users about the impact of public transportation on the climate crisis and environmental sustainability. Additionally, the application allows users to report criminal activity indicators and driver violations within public transportation as a safety feature for users.

In addition to efforts aimed at increasing public transportation usage, the excess number of public transportation vehicles exceeding demand on specific routes and times can contribute to a high carbon footprint. Therefore, TARIK incorporates the concept of an Intelligent Transportation System by designing a system capable of real-time observation of supply and demand for transportation. This system provides recommendations for the optimal fleet size to operate every two hours, utilizing Reinforcement Machine Learning mechanisms.

The algorithm begins by monitoring passenger demand when passengers activate the "Tarik On Line" feature. Subsequently, the system actively monitors passenger distribution at specific times on each route and suggests the appropriate fleet size for operation during those times. By implementing this system, the frequency and operational fleet size of public transportation can be reduced, as illustrated in Figure 4.

The concept of the main features offered by TARIK was presented to respondents to gauge the level of community interest in using this system. The results indicated that 70.11% of respondents were interested, while29.89% were not yet interested in using public transportation if TARIK were implemented. Most respondents who were not interested mentioned that public transportation is still challenging to access from their homes due to insufficient walking access to the nearest transportation routes.

4.3 Predicting Carbon Footprint Reduction After Implementation of TARIK

The reduction in carbon footprint is closely related to the frequency and usage of transportation modes per week. The solutions offered in the TARIK features are predicted to decrease the frequency of private vehicle usage and the operational frequency of public transportation, ultimately leading to a reduction in carbon footprint. The prediction of carbon footprint reduction is made by comparing the weekly carbon footprint per person traveling to Stasiun Bogor before and after the implementation of TARIK. To determine the community's interest in switching to public transportation after the implementation of this program, additional questions were given to the initial 87 respondents regarding their interest in using public transportation if TARIK program were to be implemented. Based on the conducted survey, public transportation usage is expected to increase after the implementation of TARIK, as illustrated in Figure 5.

The method for calculating the carbon footprint after the implementation of TARIK involves a similar iteration process as the calculation method for the existing condition's carbon footprint towards Stasiun Bogor. However, this time, the calculation utilizes input data as indicated in Figure 5. The data represents the predicted distribution of first- mile connection mode usage after the implementation of TARIK towards Stasiun Bogor. The results of the carbon footprint calculation after the implementation of TARIK are presented in Table 4. According to these results, areduction in carbon footprint is observed after the implementation of TARIK.

After predicting the reduction in carbon footprint resulting from the implementation of TARIK, accuracy calculations for random sample data are performed using the Cochran equation, as follows:

$$n = \frac{z^2 p\,(1-p)}{e^2}$$

Information:
n = number of samples
p = standard deviation
e = margin of error
z = level of confidence

By calculating from 87 samples out of 182,647,716 passengers at Stasiun Bogor per year [13], a margin of error of ±9% with a confidence level of 90% is obtained. Thus, it can be concluded that the predicted carbon footprint reduction after the implementation of TARIK can range from 1,161,376.3 $kgCO_2$ eq (11.02%) to 1,391,099.085 $kgCO_2$ eq (29.02%) per week.

4.4 Additional Physical Facilities Upgrade to Support TARIK Implementation

In addition to the introduction and innovation development of the TARIK program, supporting facilities are a crucial necessity in promoting the efficiency ofipublic transportation utilization in the city of Bogor [26]. The Bogor City Government has made various efforts to design the optimization of public vehicle usage through development focused on Transit Oriented Development (TOD) [13]. The Institute for Transportation and Development Policy (ITDP) has outlined several fundamental TOD principles, one of which is the enhancement of walking activities [38] [32]. Referring to the significance of these activities, recommendations as steps to support the TARIK program in the Stasiun Bogor area with the aim of safety and comfort can be seen in Figure 6, including:

1. Renewing and improving sidewalks around Stasiun Bogor
2. Constructing bike lanes integrated with pedestrian paths around Stasiun Bogor
3. Enhancing the quality of shelter facilities around Stasiun Bogor, including adding seating, adequate lighting, clear travel information through wayfinding, and protection from weather conditions.
4. Adding Green Open Spaces by expanding and beautifying city park areas and adding green spaces around stations and bus stops. Additionally, Green Open Spaces can be integrated with bike lanes and pedestrian pathways to enhance accessibility and comfort for public transportation users.

5 Conclusions

Optimizing the public transportation system in Bogor City is a step that can increase public interest in using public transportation. The increase in public transportation usage has been proven to be effective in theory and statistically towards reducing carbon footprint, as outlined in Sustainable Development Goals (SDGs) points 11 and 13. In the discussion of this scientific work, it has been demonstrated that the increase in the use of public transportation, with a case study of the first-mile connection to Stasiun Bogor, can reduce carbon footprint by 1,161,376.3 $kgCO_2$ eq (11.02%) to 1,391,099.085 $kgCO_2$ eq (29.02%).

The TARIK program is designed to support the increased use of public transportation by the residents of Bogor City, with pillars of safety, environmental friendliness, and inclusivity. This program is expected to enhance public transportation usage and raise awareness among the community about the importance of environmental steps and community participation. Additionally, improving facilities that support the implementation of the first-mile connection is crucial for the comfort of transportation users, pedestrians, and cyclists. Thus, the TARIK solution can be a significant step in reducing emissions in Bogor City and supporting the achievement of Sustainable Development Goals (SDGs) indicators.

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