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Strategies for Decarbonization Through Modal Shift in Logistic Transportation: Case Study of Tanah Abang Market

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Decarbonization; Sustainable Transportation; Modal Shift; Rail-Based Logistics

Abstract
The rapid growth of Indonesia's logistics sector, contributing 6.24% to GDP in 2024, has exacerbated greenhouse gas (GHG) emissions, with road transport accounting for 90% of the transportation sector's 27% national emissions share. Jakarta's Tanah Abang Market, Southeast Asia's largest textile hub, exemplifies this challenge, generating 8.33 tons CO_2e/day from freight activities dominated by diesel trucks (91% modal share). This study evaluates the decarbonization potential of shifting freight transport from road to rail via the proposed Tanah Abang Logistics Station. Using empirical freight flow data, vehicle emission factors, and scenario modeling (pessimistic, BAU, optimistic), we project emissions and externality cost reductions for 2025–2045. Results show rail-based logistics could reduce emissions by 5.6% (1.31 tons CO_2e/day) under pessimistic scenarios and 12.5% (7.68 tons CO_2e/day) under optimistic conditions by 2045. While impactful, these reductions fall short of Indonesia's 2030 NDC target (20% transport sector cuts). Economically, modal shift yields externality cost savings of IDR 423 million/year (optimistic scenario) through avoided emissions. The findings underscore rail's role in sustainable urban freight but highlight infrastructure and policy gaps limiting decarbonization speed. This study provides actionable insights for policymakers to accelerate rail integration, aligning logistics growth with Indonesia's 2060 net-zero commitment while improving air quality in Jakarta.

Introduction

Greenhouse gas (GHG) emissions are a critical global environmental issue, with land transportation identified as a major contributor. In Indonesia, the transportation sector accounts for approximately 27% of national GHG emissions, with 90% stemming from road-based transport (Agency, 2020; Environmental Protection Agency, 2019; EPA, 2020; Kumar, 2018; Woods et al., 2022). Trucks, which dominate the logistics sector, are heavily reliant on diesel and significantly contribute to urban air pollution—particularly in *Jakarta*, ranked as the most polluted city in Southeast Asia in 2023.

Despite the higher efficiency and lower emissions of rail-based freight, logistical challenges such as double handling and limited integration hinder its adoption (Justo & Bookstaver, 2014; Kartoglu et al., 2020; McLean et al., 2017; Soukup et al., 2022; Weber & Badenhorst-Weiss, 2018). Meanwhile, Indonesia's logistics sector is expanding rapidly, contributing 6.24% to the national GDP in Q2 2024. Yet, 91% of freight distribution still relies on trucks.

To support Indonesia's net-zero emissions target by 2060, strategic efforts are needed to decarbonize freight transport. One such initiative is the development of the *Tanah Abang Logistics Station* to support textile distribution from Southeast Asia's largest textile hub. This study investigates the potential for a modal shift from truck to rail for textile logistics and estimates the corresponding GHG emission reductions.

Previous studies have explored the potential of modal shift strategies to decarbonize freight transport. For instance, Zhou et al. (2017) demonstrated that intermodal rail freight in the United States could reduce CO_2 emissions by up to 75% compared to trucking for long-distance hauls. Similarly, Potti et al. (2019) highlighted the environmental benefits of urban rail logistics in European cities, emphasizing the need for policy interventions to overcome barriers like last-mile connectivity. However, these studies largely focused on developed economies with well-established rail networks, leaving a gap in understanding the applicability and impact of such strategies in emerging economies like Indonesia, where rail infrastructure is less developed and freight demand is rapidly growing.

This study addresses this gap by examining the potential for a modal shift from road to rail in *Tanah Abang Market*, Southeast Asia's largest textile hub. By integrating empirical data with scenario-based simulations, the research quantifies the GHG reduction potential and economic benefits of rail-based logistics in *Jakarta*'s urban context. The findings aim to inform policymakers and stakeholders on strategies to align Indonesia's freight sector with its climate commitments under the Nationally Determined Contributions (NDC), while also improving air quality and reducing externality costs. Ultimately, this study seeks to contribute to sustainable urban freight systems by providing actionable insights for decarbonizing logistics in rapidly growing cities.

Materials and Methods

The research integrates empirical data analysis—including current freight flows, vehicle emission factors, and logistics characteristics of *Tanah Abang Market*—with simulation-based forecasting across multiple time horizons (2025–2045). Emission calculations are derived using standardized emission coefficients ($kgCO_2e$) based on vehicle type and distance traveled, while projected freight growth is modeled under three distinct scenarios: pessimistic, business-as-usual (BAU), and optimistic. These scenarios account for varying levels of freight volume growth and modal shift success, enabling comparative evaluation of outcomes across a range of realistic future conditions. In addition, the study estimates external cost savings associated with emission reductions, applying monetary valuation techniques (based on carbon pricing references) to quantify the economic benefits of reduced carbon emissions. This methodological framework enables a comprehensive assessment of both environmental performance and economic viability of the rail-based logistics strategy.

1. Research framework

The research framework of this study is structured into four main phases to comprehensively assess the environmental and economic impacts of shifting freight transport modes from trucks to railways in *Tanah Abang*. Phase 1 begins with the formulation of the research foundation, including the identification of the core problem related to high greenhouse gas (GHG) emissions in freight transport, followed by the problem statement, research objectives, scope limitations, and a literature review to support the methodological approach. Phase 2 focuses on data preparation and traffic analysis, involving variable selection, data collection and validation, vehicle volume distribution analysis based on the origin-destination (O/D) matrix, and freight mode shift analysis to identify the potential for modal transition.

In Phase 3, the study estimates the current impacts of logistics activities through fuel-based GHG emissions calculations under existing conditions, speed reduction analysis due to congestion, and road user cost calculations. These assessments provide a baseline for comparison. Finally, Phase 4 consists of a decarbonization simulation based on a truck-to-rail modal shift strategy, followed by an evaluation of how such a shift correlates with changes in road user costs. This framework is designed to inform low-carbon freight policies by simulating the environmental benefits and externality reductions achievable through modal shift strategies.

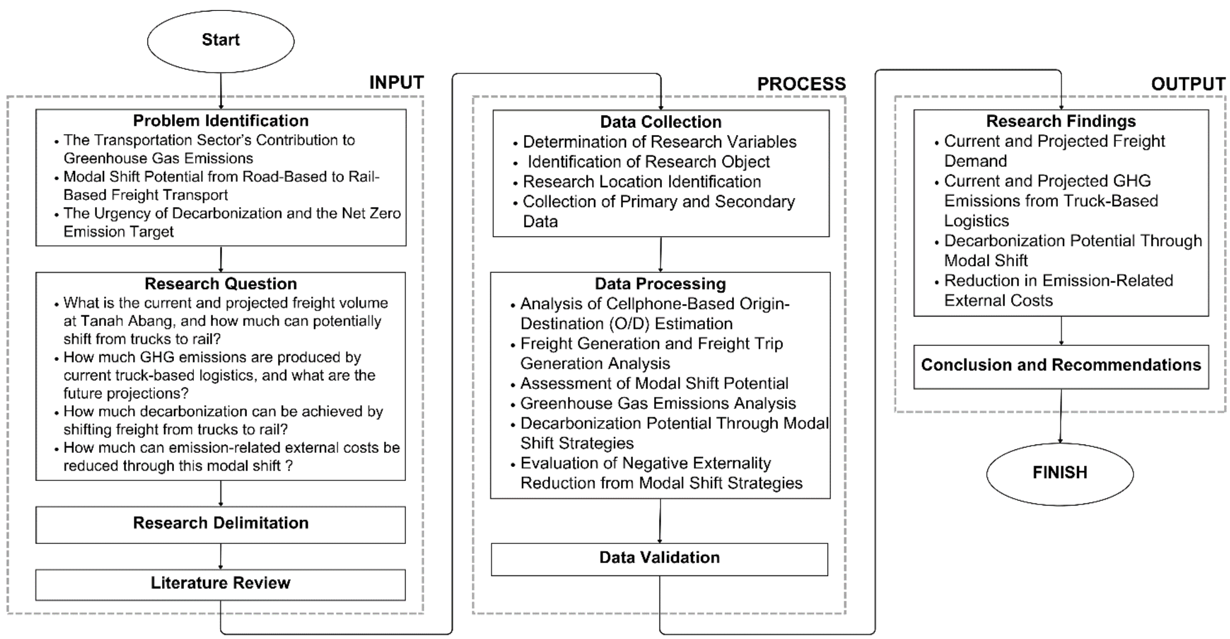

Fig. 1 Research workflow
Source: POLAR UI, 2024

Several notations are employed throughout this study to represent key variables and parameters used in the analysis. Table 1 summarizes the definitions and descriptions of these notations to ensure clarity and consistency in interpretation.

Table 1 Nomenclature section

Notation	Definition	Notation	Definition
FG	Freight Generation (Kg/day)	VT_4	Vehicle Type 4 (Pickup, Micro Truck, and Delivery Van)
FA	Freight Attraction (Kg/day)	VT_6A	Vehicle Type 6A (Two-Axle Light Truck)
FP	Freight Production (Kg/day)	VT_6B	Vehicle Type 6B (Two-Axle Medium Truck)
FTG	Freight Trip Generation (vehicle/day)	VT_7A	Vehicle Type 7A (Three-Axle Truck)
FTA	Freight Trip Attraction (vehicle/day)	VT_7B	Vehicle Type 7B (Full Trailer Truck)
FTP	Freight Trip Production (vehicle/day)	VT_7C	Vehicle Type 7C (Semi Trailer Truck)

Source: Data analysis, POLAR UI, 2024

2. Study area

Tanah Abang Market is one of the largest textile and garment wholesale centers in Southeast Asia, located in Central *Jakarta*, Indonesia. The market comprises several blocks (*A* to *G*) with approximately 13,000 retail units, managed by the regional enterprise *PD Pasar Jaya*. Its strategic position near *Tanah Abang Station* and direct access to major roads such as *K.H. Mas Mansyur* and *Jatibaru Raya* make it a key logistics node in the capital city. The high intensity of daily activities generates significant transport demand, leading to traffic congestion, inefficiencies in logistics, and increased environmental emissions. These issues underline the need for a sustainable transportation system to support market operations and minimize negative externalities.

The analysis of vehicle volume proportions was conducted along *Jalan K.H. Wahid Hasyim*, a secondary arterial roadway situated within a predominantly commercial zone of the *Tanah Abang District*, Central *Jakarta*, in the *Special Capital Region of Jakarta*, Indonesia. The selection of this corridor was informed by the significant concentration of freight forwarding companies operating along its length, underscoring its strategic importance in supporting regional freight mobility and urban logistics efficiency. The road is classified as a four-lane, two-way divided secondary arterial (4/2 D) and is characterized by consistently high traffic volumes and elevated transport demand. The traffic composition along this segment is predominantly dominated by motorcycles (*MC*), followed sequentially by light vehicles (*LV*), medium vehicles (*MV*), and heavy vehicles (*HV*). The selected observation segments (see Fig. 3) reflect typical urban traffic dynamics in *Jakarta*'s dense commercial corridors, making them suitable for analyzing freight-related vehicular interactions in highly urbanized environments.

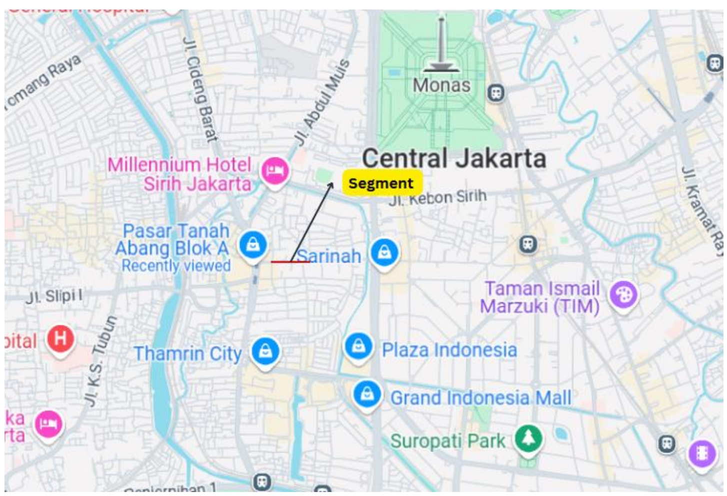

Fig. 2 Research location: Tanah Abang Market and Jalan K.H. Wahid Hasyim, Indonesia
Source: Data Map © Google, 2024

3. Research Object

In this study, the research object is the type of vehicles used for freight transport to and from Tanah Abang Market. Data sampling was conducted on Jl. K.H. Wahid Hasyim during weekdays to capture the vehicle volume proportions by type across different time periods.

4. Research Variables

Table 2 shows the variables used in this study.

Table 2 Research Variables

No	Objective	Independent Variables	Dependent Variable
1	To estimate GHG emissions from FTA and FTP	Vehicle Volume, Travel Distance, Energy Economic Factor, Emission Factor	GHG Emissions
2	To estimate decarbonization potential from truck-to-rail modal shift	Willingness to Shift (%), Vehicle Load, Vehicle Volume, Emission Factor, Energy Economic Factor	GHG Emissions (Reduced)
3.	To estimate the external cost reduction resulting from decarbonization	Carbon Tax, GHG Emissions	External Cost (IDR)

Source: POLAR UI, 2024

5. Commodity Characteristics

A field survey conducted by *POLAR UI* (2024) involving 170 retail units reveals that 92% of shops specialize in textiles and ready-made garments, while the remainder sell food products (6%) and other goods. Furthermore, 69% of traders engage in both retail and wholesale activities, 28% operate exclusively in retail, and 3% solely in wholesale. This mixed distribution model supports a multifaceted demand for logistics services and enables extensive freight movement both to and from the market.

6. Freight Generation Characteristic

Freight generation refers to the movement of goods from *Tanah Abang Market* to various destinations, including final consumers and intermediary distributors. Based on the survey conducted by *POLAR UI* (2024), approximately 24% of the overall freight activity in the *Tanah Abang Market* area. Around 85% of shops deliver goods within the Greater *Jakarta* area (*Jabodetabek*), while 27% also serve destinations beyond *Jabodetabek*, including inter-island deliveries. A majority of traders (82%) utilize freight forwarders for distribution, while 15% deliver goods independently and 3% use a combination of both. Among those handling their own deliveries, 85% use privately owned vehicles and 15% rely on rental transport. Additionally, 72% of traders deliver their goods to freight forwarder offices themselves, whereas 28% opt for goods to be picked up by the forwarders. The freight service providers are predominantly located around the *Tanah Abang* and *Kebon Kacang* areas.

7. Cellular Based for O/D Person Trip

Big data refers to large, complex, and rapidly growing datasets that exceed the capabilities of traditional data processing methods (Meher et al., 2023; Moorthy et al., 2015; Perera & Iqbal, 2021). It plays a key role in data-driven decision-making, particularly in transport and logistics, supported by technologies like *IoT*, sensors, and cloud computing (Yudistira, 2020). These enable real-time, continuous data collection from sources such as cellular signals, *GPS*, *CCTV*, and digital transactions. An *Origin–Destination (OD) matrix* captures travel flows between zones, typically shown in tabular form with rows and columns representing origins and destinations, and cell values indicating trip volumes (Ortúzar & Willumsen, 2011). This study uses *OD matrices* derived from mobile signal data, passively emitted by users' devices. Through big data processing and movement-tracking algorithms, inter-zonal travel patterns are estimated with high temporal resolution and large spatial coverage.

8. Shifting Modes

Modal shift refers to the strategic transition of travel demand or freight movement from one mode of transportation to another. This study specifically focuses on the potential for freight mode shift in the context of logistics movements originating from and destined to *Tanah Abang Market*, one of Southeast Asia's largest wholesale textile markets located in Central *Jakarta*, Indonesia. As a highly active commercial hub with a dense concentration of retail and wholesale textile trading, *Tanah Abang* generates significant freight activity that contributes to urban traffic congestion and carbon emissions. In freight logistics, shifting from road-based transportation (e.g., trucks) to rail is seen as a way to lower carbon emissions and improve long-distance distribution efficiency. According to Rodrigue et al. (2020), modal shift is a key element in decarbonizing transport systems, especially when moving toward lower-emission modes. Similarly, Banister (2008) highlights that achieving a sustainable transport system often involves demand management strategies that encourage a shift toward greener modes through investments in infrastructure, pricing mechanisms (e.g., carbon taxes), and regulatory frameworks.

9. Greenhouse Gas Emissions

Greenhouse gases (*GHGs*) are atmospheric components capable of absorbing and emitting infrared radiation, thus contributing to the greenhouse effect, a natural process that maintains Earth's habitable temperature. Key *GHGs* include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. The transport sector accounts for approximately 24% of global CO_2 emissions, mainly from fossil fuel combustion. Emissions vary by mode and are influenced by factors such as fuel type, vehicle type, engine efficiency, traffic volume, and travel distance. *WRI Indonesia* has developed a carbon footprint calculation method tailored to the specific conditions and travel behaviors in Indonesia. In this method, the emission value is obtained through the following equation.

$$\text{Total CO2ev} = \sum_{i=1}^{N} \left(\frac{D_i}{FCF_{ij}} \times \frac{EF_{sk}}{PT_i} \right) \tag{1}$$

Where i for number of trips, D_i for total distance (kilometers) for trip i, EF_sk for emission factor of fuel (kgCO_2eq per liter), FCF_ij for fuel consumption factor (km/liter) for transport mode j on trip i, PT_i for vehicle load weight (Kg).

10. Carbon Tax

A carbon tax is a fiscal instrument imposed on goods, services, or activities that generate carbon emissions, specifically measured in terms of carbon dioxide equivalent (CO_2e). It represents a market-based approach to internalize the external costs of greenhouse gas (*GHG*) emissions, thereby providing a price signal to emitters to reduce their carbon footprint. By assigning a cost to carbon emissions, the tax seeks to influence production and consumption behaviors, encouraging a transition towards low-carbon and renewable energy alternatives. In the context of Indonesia, the implementation of a carbon tax aligns with the country's commitment to the *Paris Agreement*, aiming to reduce national *GHG* emissions and support the development of a green economy. The tax is designed not only to mitigate environmental harm but also to serve as an instrument to mobilize public and private investment in renewable energy sources. The basis for the carbon tax in Indonesia is outlined in *Undang-Undang Nomor 7 Tahun 2021 tentang Harmonisasi Peraturan Perpajakan* (*UU HPP*). This provision establishes a minimum carbon tax rate of IDR 30 per kilogram of CO_2e, ensuring a consistent price floor regardless of fluctuations in the carbon market.

The carbon tax applies to both individuals and legal entities who consume carbon-intensive goods or engage in emission-producing activities. This includes major sectors such as energy, transportation, industry, and manufacturing. By imposing a financial cost on carbon emissions, the tax creates an incentive for actors across the economy to reduce their carbon footprint, adopt cleaner technologies, and optimize operational efficiency. It also helps level the playing field between conventional, fossil-based energy sources and cleaner, renewable alternatives.

Results and Discussions

This section provides valuable insights into how road damage affects travel behavior and costs. By revealing the relationship between road damage length, vehicle speed, travel time, traffic volume, and road repair delays, the study highlights the need for prompt repairs to minimize inconvenience to road users. In addition, the associated cost analysis emphasizes the importance of proactive maintenance strategies. These findings guide policymakers to prioritize timely repairs and improve the overall efficiency of the road network, making travel more seamless for road users.

1. Cellular-Based Big Data Analysis of Person Trip Origin-Destination Patterns

Based This dataset presents an estimate of the number of daily person trips originating from or destined to Central Jakarta and various other cities or regencies, both within the Greater Jakarta area (Jabodetabek) and beyond. The data represent daily human mobility patterns based on recorded cellular signal locations. According to data obtained from the Ministry of Transportation (2024), individual movement information is available in units of person trips per day, derived from the mobile signal data of a single telecommunications operator. To provide a more comprehensive picture, a data expansion method was employed to extrapolate the findings to the wider population.

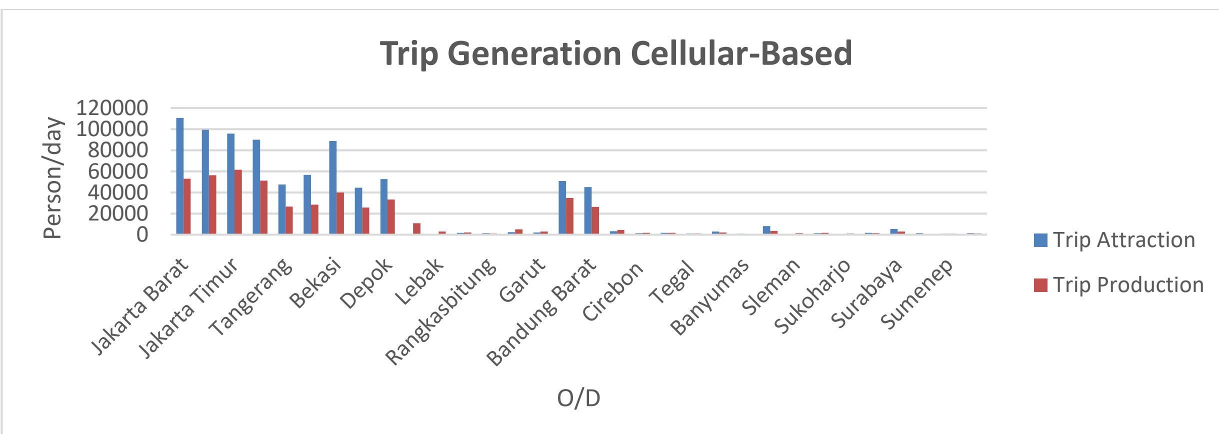

Fig. 3 Trip Generation Cellular Based
Source: Ministry of Transportation, 2024

The data reveal high levels of daily mobility, both within the internal administrative boundaries of Jakarta and extending to surrounding regions and across provinces. The highest concentration of trips originates within Jakarta itself, indicating a high intensity of inter-district movements within the capital. This reflects the centrality of Jakarta in terms of economic activity, governmental functions, and residential density.

Outside Jakarta, cities within the Jabodetabek region, such as Bekasi, South Tangerang, Depok, Tangerang, and Bogor also demonstrate significant trip volumes, suggesting a strong pattern of daily commuting between Jakarta's urban core and its surrounding suburban areas.

Moreover, major cities beyond Jabodetabek, such as Bandung and West Bandung, also report a high number of trips, highlighting the strong connectivity between Jakarta and the Greater Bandung area. This inter-city linkage is likely supported by key transportation infrastructure, particularly toll roads. Other cities such as Karawang, Purwakarta, Garut, and Sumedang are also involved in daily mobility flows, although to a lesser extent.

At a broader scale, the data also capture trips from cities in Central Java, Yogyakarta, and East Java, such as Yogyakarta, Surakarta, and Surabaya. Although the volumes are relatively smaller, these flows suggest the presence of long distance intercity and interprovincial mobility, potentially related to business travel, official duties, or regular intercity transport services.

2. Vehicle Volume Distribution Based on Traffic Counting

This analysis was conducted through a traffic counting survey on Jalan K.H. Wahid Hasyim, one of the main corridors with a high concentration of logistics service activities around the Tanah Abang area. The road is classified as a secondary collector road with a 4/2 D typology (four lanes, two directions), serving to connect primary arterials with surrounding neighborhoods and to distribute local and logistics traffic. According to the POLAR FTUI report (2024), 82% of businesses in the Tanah Abang area utilize expedition services for both delivery and receipt of goods. This indicates that Jalan K.H. Wahid Hasyim plays a strategic role as a primary logistics distribution route linking market trade activities with the city's transportation network. Therefore, conducting a traffic count on this road section provides a relevant and comprehensive representation of the intensity and movement patterns of logistics vehicles serving the inbound and outbound distribution needs of Tanah Abang Market. The following presents the traffic counting results on Jalan K.H. Wahid Hasyim.

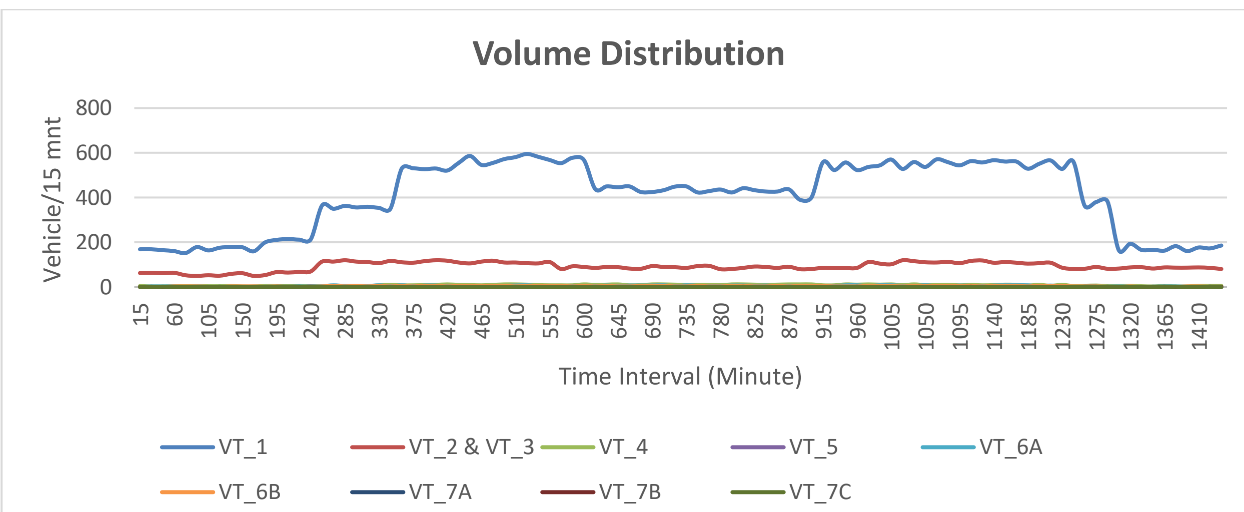

Figure. 4 Volume Distribution
Source: Results of the POLAR UI field survey on Jalan K.H. Wahid Hasyim, 2024

Based on the vehicle volume data chart recorded at 15 minute intervals, it is evident that Class 1 vehicles dominate traffic flow throughout the day, particularly during the morning and evening hours. This pattern indicates peak commuting periods and reflects that personal mobility remains the dominant factor in road usage.

In contrast, logistics activities represented by heavy and commercial vehicles such as vehicle type 4, 6a, 6b, 7a, 7b, and 7c display a different pattern. Between 00:00 and 04:45, the volume of these vehicle classes remains relatively low, suggesting minimal goods distribution or freight movement during the night. However, starting at 05:00, there is a noticeable increase in the volume of logistics vehicles. This pattern suggests that logistics activities in the area typically commence in the early morning, with a significant surge occurring between 05:00 and 07:00. This may be linked to the start of distribution operations from warehouses to markets and retail shops, aligning with business opening hours and the onset of economic activity. Overall, the data reflects a distinct temporal separation between individual mobility and logistics activities in road usage.

3. Freight Trip Generation

Based on the data processing conducted through the spatial disaggregation method and visualized in Fig. 3, an estimate of daily person trips to and from the Tanah Abang area was obtained. These person trip data were then converted into an estimate of daily vehicle trips by applying vehicle occupancy rates according to predetermined parameters. After calculating the total vehicle volume, a proportional approach was applied based on vehicle types, referring to the previously analyzed origin-destination (O/D) distribution. This approach aims to estimate the contribution of each vehicle type to the total volume of logistics movements to and from the Tanah Abang area.

The proportional estimation process was carried out using vehicle distribution data obtained from the traffic counting survey and linked with the spatial distribution of O/D zones, as illustrated in Fig. 4. The presented FTA and FTP data illustrate the distribution pattern of goods movement across various cities and regencies within the Greater Jakarta (Jabodetabek) region and surrounding areas, classified by types of freight vehicles.

The analysis results indicate that West Jakarta, South Jakarta, and East Jakarta are the primary destinations, recording the highest volume of freight trips across almost all vehicle categories—particularly for Class 4 and Class 6A vehicles, which showed the highest trip volumes. This reflects the high intensity of logistics activities and distribution demand in these areas, consistent with their role as centers of economic, commercial, and industrial activity. Additionally, several surrounding cities such as Bandung, Tangerang, Bekasi, and Depok also demonstrate significant contributions to the freight trip volume, reinforcing their strategic roles in supporting the regional logistics system.

Conversely, large-capacity vehicles such as VT_7A and VT_7C recorded relatively low trip volumes. This is likely due to limited accessibility and regulatory restrictions on heavy vehicles in densely populated urban areas, which may influence mode preferences in freight distribution activities.

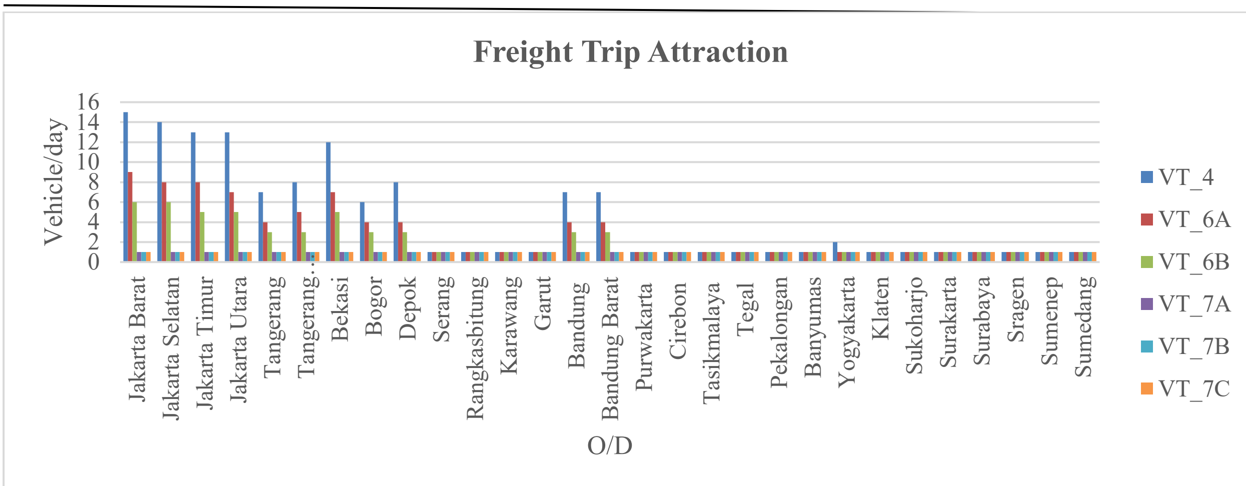

Fig. 5 Freight Trip Attraction

Source: Results of data analysis of goods movement based on the POLAR UI survey and processing of the Origin-Destination matrix, 2024

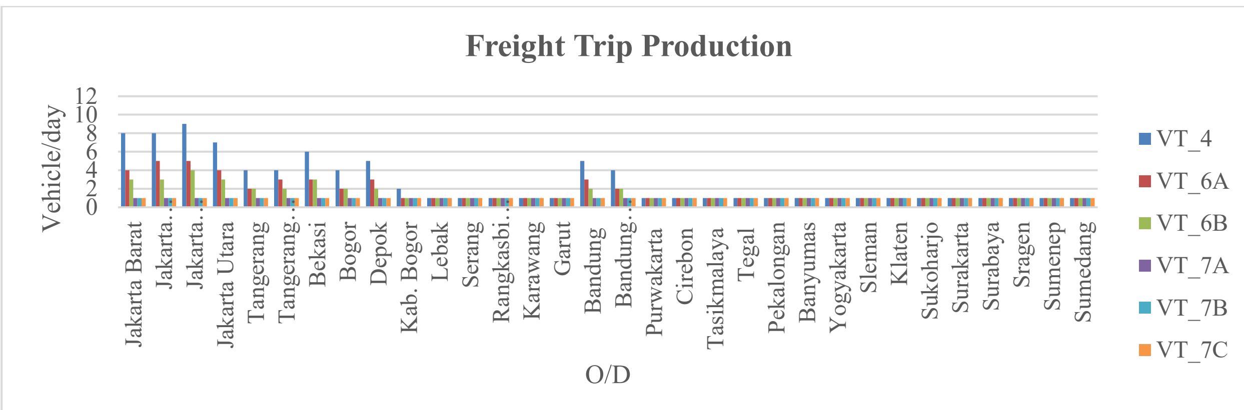

Fig. 6 Freight Trip Production

Source: Results of analysis of the distribution of goods movements from Tanah Abang Market based on POLAR UI data, 2024

4. Freight Generation

Based on Fig. 5 and Fig. 6, an estimation of freight demand between Tanah Abang Market and major destination cities across Java Island was developed. The data encompass the volume of goods transported to and from each city, serving as the foundation for projecting long-term logistics demand. To capture the gradual dynamics of modal shift from truck-based freight to rail transport, the projections are structured across five distinct time periods. The first period represents the baseline condition in 2024. The subsequent projections are divided into the short-term period (2025–2030), mid-term period I (2031–2035), mid-term period II (2036–2040), and the long-term period (2041–2045).

To accommodate economic growth fluctuations and transport system development, two distinct scenarios pessimistic and optimistic, are formulated, each reflecting different assumptions regarding future growth trajectories:

a. Business as Usual (BAU) Scenario: This scenario adopts a 5% annual growth rate, derived from the average increase in rail freight volume observed along the Central and Northern Java corridors in 2024. The BAU scenario serves as the analytical baseline, illustrating the implications of maintaining current operational patterns. It assumes no significant intervention in transport mode shifts, energy efficiency improvements, or emissions reduction strategies.

b. Pessimistic Scenario: Similar to the BAU scenario, this projection applies a 5% annual growth rate, reflecting the actual historical trend in rail freight without any substantial policy intervention or shifts in logistics user behavior. It represents a continuation of the current trajectory under conservative planning assumptions.

c. Optimistic Scenario: This scenario assumes a more aggressive annual growth rate of 9.87%, based on the average increase in Gross Regional Domestic Product (GRDP) for the wholesale and retail trade; repair of motor vehicles and motorcycles sector in Central Jakarta during the 2021–2023 period. This sector is considered a key driver of logistics demand in the Tanah Abang area. The optimistic scenario thus reflects the potential impact of enhanced economic activity and strategic investments in logistics infrastructure and modal shift efforts.

Table 3 presents the freight demand associated with Tanah Abang Market, illustrating that the freight attraction (FA) significantly exceeds the freight production (FP). This indicates that Tanah Abang functions primarily as a major goods-receiving hub rather than a dispatching center. The scenarios developed for this study are based on the growth rate assumptions outlined in Subsection 2.2. Under the optimistic scenario, freight attraction is projected to reach approximately 328.8 tons per day during the 2041–2045 period, while freight production is estimated at 195.5 tons per day. This imbalance reflects the strategic and economic importance of Tanah Abang as a key urban logistics node with high inbound freight activity. The substantial volume of goods being transported into the area necessitates a corresponding increase in logistics vehicle operations, which in turn contributes significantly to greenhouse gas (GHG) emissions. Therefore, there is a critical need to implement measures that support a modal shift in freight transportation particularly from road-based trucking to more sustainable alternatives such as rail freight.

Table 3 Freight Demand

Generator	***Freight Generation***	***Scenario***	***Freight Demand* (Kg/day)** 2024	2025-2030	2031-2035	2036-2040	2041-2045
Tanah Abang Market	*Attraction*	*BAU*	44435.68	59548.07	76000.10	96997.52	123796.15
		Pessimistic	44435.68	59548.07	76000.10	96997.52	123796.15
		Optimistic	44435.68	78720.52	126780.19	204180.77	328835.16
	Production	BAU	26421.65	35407.54	45189.99	57675.15	73609.73
		Pessimistic	26421.65	35407.54	45189.99	57675.15	73609.73
		Optimistic	26421.65	46807.57	75384.06	121406.78	195526.83

Source: Scenario simulation results, 2024

5. Estimation of Freight Modal Shift from Road to Rail

Based on the results of the freight demand forecasting analysis in Table 3, it is evident that the trade and industrial sectors in the Tanah Abang area generate a significant demand for freight transport. This analysis serves as the basis for projecting the volume of freight demand that has the potential to shift from road transport to rail transport.

The projection considers two categories of origin-destination (O/D) areas:

a. Cities located more than 300 km from Tanah Abang, and
b. Cities within a 300 km radius that exhibit high freight demand and are supported by the presence of active freight terminals.

The results indicate that the total volume of freight with potential to shift to rail transport from these cities amounts to approximately 12.5 tons per day. The cities included in this projection are: Karawang, Garut, Bandung, West Bandung, Purwakarta, Cirebon, Tasikmalaya, Tegal, Pekalongan, Banyumas, Yogyakarta, Sleman, Klaten, Sukoharjo, Surakarta, Surabaya, Sragen, Sumenep, and Sumedang. To estimate the volume of freight transport that could potentially shift from trucks to rail, a stated preference (SP) approach was applied. This is due to the fact that modal shift decisions are not determined solely by technical characteristics such as capacity or distance, but also by the preferences and perceptions of logistics actors regarding service attributes offered by each mode.

To quantify the willingness to shift, this study utilized findings from POLAR UI (2024), which applied the stated preference method, an approach in behavioral economics used to understand individual preferences under controlled hypothetical scenarios. The variables considered include service cost, travel time, reliability, and ease of access. The study found that, under a scenario in which rail transport offers equivalent service time and cost as road transport (trucking), 19.16% of respondents expressed a willingness to shift to rail.Error! Not a valid link. In the optimistic scenario for the 2041–2045 period, the projected modal shift indicates that up to 10.7 tons of freight per day entering Tanah Abang Market and 7.1 tons per day exiting the area could be transferred from truck-based transport to rail. This represents a significant volume of logistics activity that could potentially be decarbonized.

The higher the volume of freight shifted from road to rail, the lower the emissions generated by logistics operations. Rail transport produces substantially fewer greenhouse gas (GHG) emissions per ton-kilometer compared to trucks, particularly for long-distance haulage. As such, this projected shift could lead to a considerable reduction in carbon emissions associated with freight movement to and from Tanah Abang Market. In addition to mitigating environmental impacts, this transition supports the development of a more sustainable and resilient urban freight system aligned with national decarbonization targets.

6. Emission Produced by Freight Trip Generation

Table below presents the hourly carbon emissions (in KgCO_2eq) generated by various categories of freight vehicles operating within the Tanah Abang area. These vehicle categories range from light to heavy-duty transport modes, each contributing differently to levels of urban air pollution.

In estimating emissions, the analysis distinguishes between freight trip attraction (FTA) and freight trip production (FTP). As shown in Fig. 7, the inbound freight volume FTA to Tanah Abang Market is higher than the outbound volume FTP. This imbalance directly affects the number of freight vehicles entering the area, thereby increasing the corresponding emissions. The higher volume of inbound trips reflects the intense delivery activity supporting commercial operations in the market area, which subsequently contributes more significantly to total freight-related emissions.

a. Freight Trip Attraction

The following table shows the total emissions generated based on the origin locations.

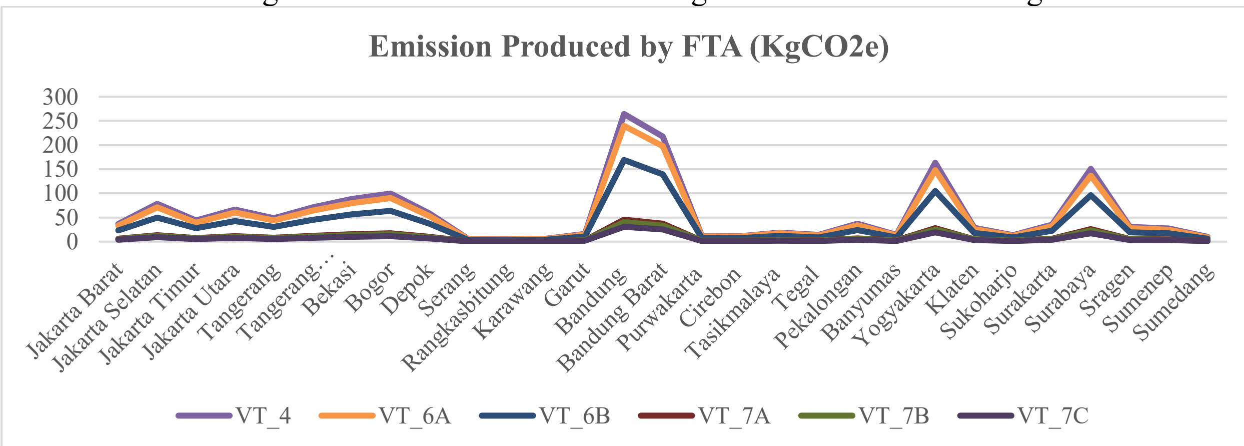

Figure. 7 Emission Produced by FTA

Source: Calculation of carbon emissions based on transport vehicle emission factors and freight travel volume data, 2024

Based on Fig. 7, Bandung and West Bandung are identified as the highest emitters, with total emissions of 789,9 $KgCO_2e$ and 650,8 $KgCO_2e$, respectively. Although the Greater Jakarta (Jabodetabek) area has a higher overall freight demand, factors such as travel distance and the mode of transport used play a significant role in determining emission levels. Other cities with notably high emissions include Yogyakarta in Central Java and Surabaya in East Java, both of which are located more than 500 kilometers from Tanah Abang. It can also be observed that light trucks are the largest contributors to emissions, as freight activity for textile commodities is predominantly carried out using these vehicles rather than heavy trucks. This reflects the operational preference for smaller, more flexible vehicles in urban distribution, particularly within the Tanah Abang are. These findings highlight the substantial impact of long distance freight transport on carbon emissions, especially when road-based modes are predominantly used.

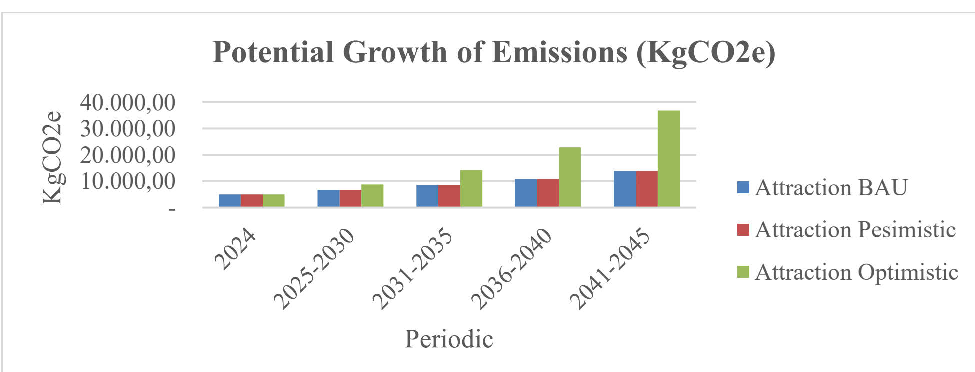

Figure. 8 Potential Growth of Emissions

Source: Projected GHG emissions in the Business-as-Usual (BAU) scenario based on logistics demand growth, 2024

Under the business-as-usual (BAU) scenario, daily emissions are projected to reach 13,9 tons of CO_2e per day during the 2041–2045 period. This figure represents a substantial environmental burden if no efforts are made to promote a modal shift as part of broader decarbonization strategies. Without intervention, continued reliance on road-based freight transport will lead to unsustainable emission levels, underscoring the urgent need for transitioning to lower-emission modes such as rail.

b. Freight Trip Production

The following table shows the total emissions generated based on the destination locations.

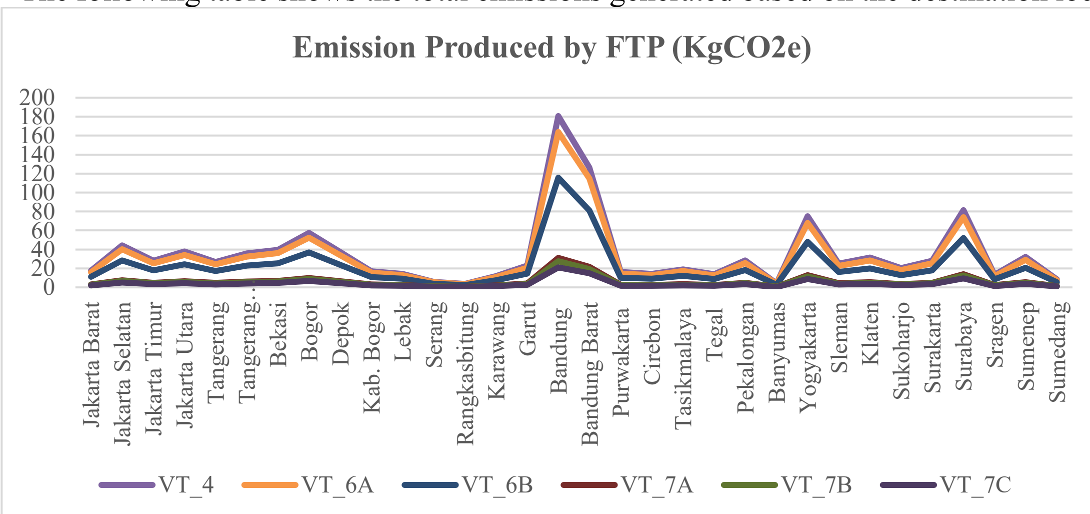

Figure. 9 Emission Produced by FTP

Source: Analysis of carbon emissions from Freight Trip Production activities using WRI Indonesia's calculation method, 2024

Based on Fig. 9, Bandung and West Bandung are identified as the highest emitters, with total emissions of 539,7 CO_2e and 378 $KgCO_2e$, respectively. With the same dominance pattern as observed in the Freight Trip Attraction (FTA), light trucks, represented by VT_4, continue to be the primary mode used for freight transport.

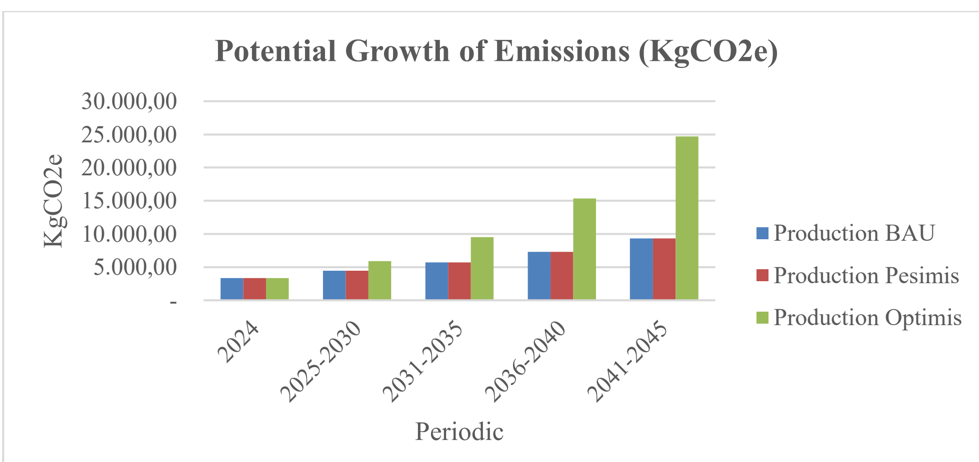

Fig. 10 Potential Growth of Emissions FTP

Source: Simulation of increased emissions from Freight Trip Production in the period 2025–2045, 2024

Under the business-as-usual (BAU) scenario, daily emissions are projected to reach 9,3 tons of CO_2e per day during the 2041–2045 period. In line with the higher freight demand from Freight Trip Attraction (FTA), the emissions generated from FTA are also greater than those from Freight Trip Production (FTP). This reflects the larger volume of inbound logistics activity to Tanah Abang Market, which contributes more significantly to total freight-related emissions compared to outbound flows.

7. Decarbonization through Modal Shift from Truck to Rail

Based on the estimated emissions from Freight Trip Generation (FTG), as presented in Table 5.19, a further analysis was carried out using a scenario-based approach to evaluate the potential modal shift of freight transport from trucks to railways. Subsequently, the potential reduction in greenhouse gas (GHG) emissions resulting from this modal shift was calculated. Although there is a slight increase in emissions from the rail mode due to the additional freight load, the total emissions still show a notable decrease compared to the FTG-based emissions under the business-as-usual scenario for the 2041–2045 period. This indicates a net reduction in emissions, underscoring the decarbonization potential that can be achieved by shifting freight transport from road-based to rail-based systems.

1) Freight Trip Attraction

The following table presents the total decarbonization potential based on Freight Trip Attraction (FTA) under both pessimistic and optimistic scenarios.

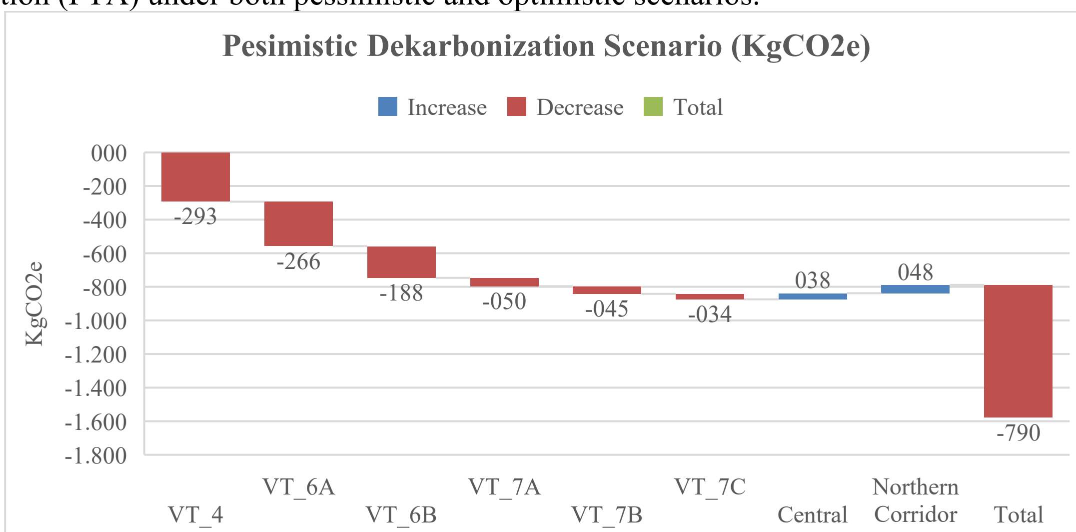

Figure. 11 Pessimistic Decarbonization Scenario FTA

Source: Simulation of GHG emission reduction from truck-train mode switching in a pessimistic scenario, 2024

Based on the Fig. 11, Under the pessimistic scenario of FTA, the modal shift of freight transport from trucks to railways can achieve a decarbonization effect of up to 789.74 $KgCO_2e$ per day compared to the business-as-usual condition. This reduction occurs despite a slight increase in emissions from rail transport, which results from the additional freight load due to the modal transition.

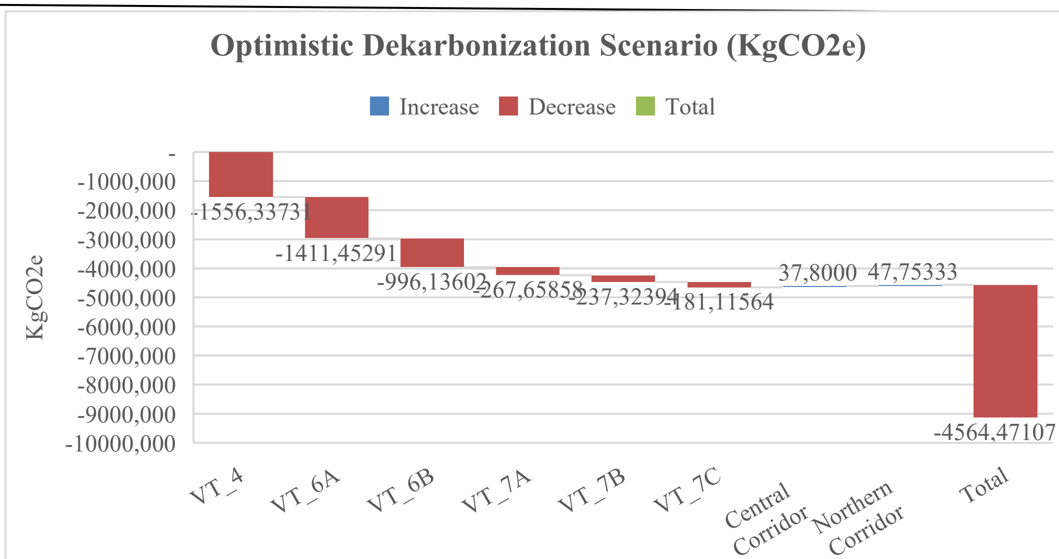

Figure. 12 Optimistic Decarbonization Scenario FTA
Source: Projected GHG emission reduction in an optimistic scenario assuming economic growth of 9.87% per year, 2024

Under the optimistic scenario for Freight Trip Attraction (FTA) during the 2041–2045 period, the estimated reduction in emissions can reach up to 4,564.5 $KgCO_2e$ per day. Although there is an increase in emissions resulting from the additional load on the rail mode, the cumulative outcome still reflects a greater net decarbonization effect compared to the baseline scenario.

2) Freight Trip Production

The following table presents the total decarbonization potential based on FTP under both pessimistic and optimistic scenarios.

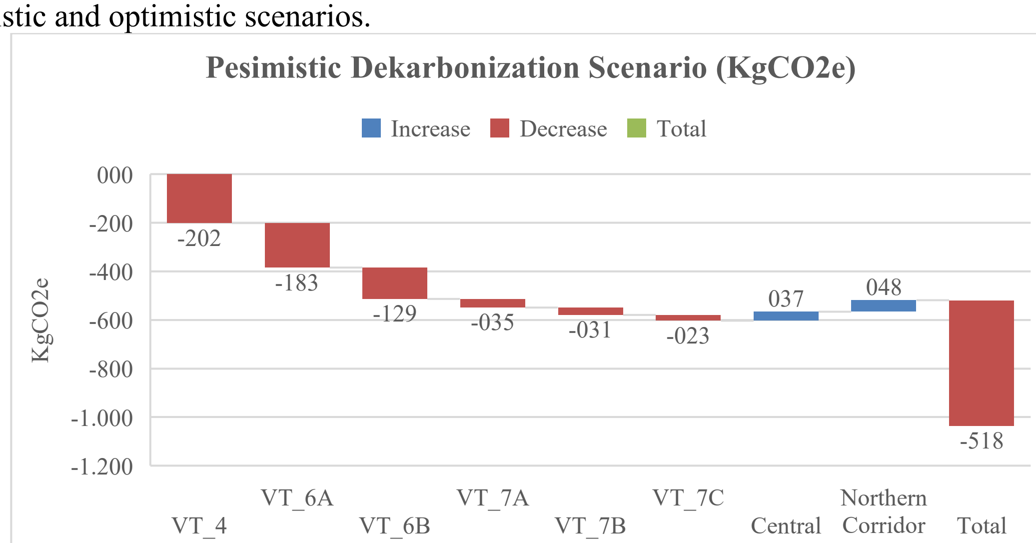

Figure. 13 Pessimistic Decarbonization Scenario FTP
Source: Results of analysis of the impact of mode switching on emission reduction in *Freight Trip Production* (pessimistic scenario), 2024

During the 2041–2045 period, the FTP under pessimistic scenario is projected to yield an emissions reduction of up to 518.3 $KgCO_2e$ per day. Despite the rise in emissions attributed to the increased load on the railway system, the overall impact remains positive, as the total emissions are still lower than those in the baseline (business-as-usual) scenario demonstrating a net decarbonization benefit from the modal shift.

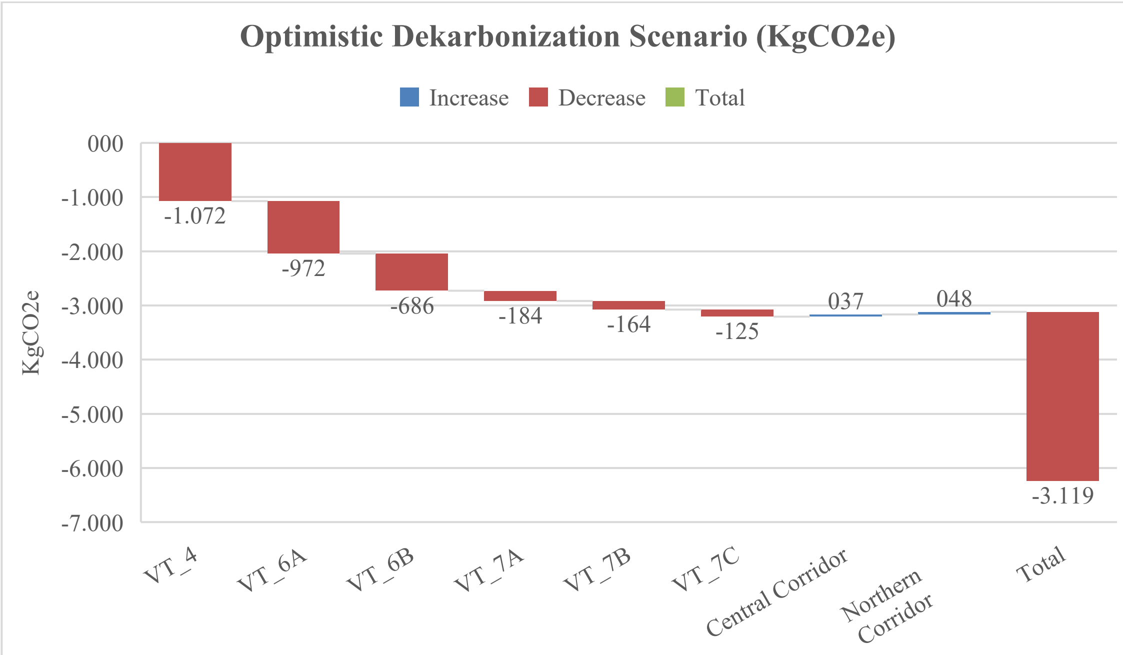

Figure. 14 Optimistic Decarbonization Scenario FTP
Source: POLAR UI simulation data analysis based on optimistic scenarios, 2024

During the 2041–2045 period, the FTP under the optimistic scenario is projected to yield an emissions reduction of up to 3119,14 $KgCO_2e$ per day. The emission reduction under Freight Trip Production (FTP) is smaller compared to Freight Trip Attraction (FTA), which corresponds to the lower volume of freight demand shifting in the FTP scenario. As a result, the quantity of logistics transport transferred to rail is also less significant, leading to a smaller decarbonization impact.

8. Reduction of Negative Externalities through Decarbonization Efforts

Externalities refer to the economic consequences arising from production or consumption activities that are not fully reflected in market prices, thereby imposing costs or benefits on third parties who are not directly involved in the transaction. To quantitatively assess and value these external impacts, a commonly used approach is to monetize carbon emissions through carbon pricing mechanisms. In Indonesia, the implementation of carbon pricing has a legal foundation established by Undang-Undang No. 7 Tahun 2021 on the Harmonization of Tax Regulations, and is further reinforced by Peraturan Presiden No. 98 Tahun 2021 on Carbon Economic Value. Within this policy framework, the government has set an initial carbon tax rate of IDR 30 per kilogram of CO_2e. Furthermore, to analyze the projected economic value of externality reduction over the long term, an estimated increase in carbon pricing was applied, based on the assumption of Indonesia's Gross Domestic Product (GDP) growth rate of 5% per year. This assumption aligns with the actual national economic growth realized in 2024.

Table 4 Externality Cost Reduction

Generator	Scenario	Externality Cost (IDR/Year)			
		2025-2030	**2031-2035**	**2036-2040**	**2041-2045**
Tanah Abang Market	Pessimistic	631,433.20	5,309,275.45	15,310,393.68	39,904,350.60
	Optimistic	7,157,278.89	25,165,198.24	83,352,473.82	234,398,323.15

Source: Calculation of external costs based on Law No. 7 of 2021 concerning the Harmonization of Tax Regulations and projected GDP growth of 5% per year, 2024

Based on Table 4, it is estimated that under the pessimistic scenario in the 2041 to 2045 period, potential cost savings from reduced externalities could reach up to IDR 39,904 million per year. In comparison, under the optimistic scenario for the same period, the savings could reach as much as IDR 234,398 million per year. These results indicate a positive economic impact, as the reduction in external costs contributes significantly and indirectly to decreasing the overall economic burden of negative externalities.

Conclusion

Tanah Abang Market currently functions as a major freight distribution hub, with a daily freight attraction of 44.44 tons, exceeding its freight production of 26.42 tons. This highlights its strategic role as a primary receiving point for goods before redistribution at smaller scales. Long-term projections for the 2041 to 2045 period indicate substantial growth in logistics demand. Under the pessimistic scenario, demand is estimated to reach 197.41 tons/day with a potential modal shift of 3.47 tons/day, while the optimistic scenario projects 524.36 tons/day, with a shift potential of 18.43 tons/day. Freight distribution activities to and from *Tanah Abang Market* generate substantial greenhouse gas emissions, with 4.99 tons CO_2e/day from freight trip attraction and 3.34 tons CO_2e/day from freight trip production. The largest contributors are light and medium trucks, specifically category 4 (33.5%), 6a (30.4%), and 6b (21.4%), while heavy trucks (categories 7a, 7b, 7c) account for only 14.8%. This composition indicates that over 85% of daily emissions originate from light and medium freight vehicles. With rising logistics demand, emission projections for 2041 to 2045 show a sharp increase, reaching 23.2 tons CO_2e/day under the business-as-usual/pessimistic scenario and up to 61.62 tons CO_2e/day under the optimistic scenario. In the pessimistic scenario, *GHG* emission reductions show a gradual increase in line with the growing shift of freight to rail. Reductions range from 43.03 kgCO_2e/day (0.4%) in 2025–2030 to 1,308.07 kgCO_2e/day (5.6%) by 2041–2045. Under the optimistic scenario, emission cuts are significantly higher, reaching 7,683.61 kgCO_2e/day (12.5%) in 2041–2045. While the modal shift contributes positively to transport decarbonization, the achieved reductions remain insufficient to meet Indonesia's 2030 *NDC* target of a 20% reduction, as outlined in the *NDC* (2022) and *LTS-LCCR* (2022) documents. The strategy of shifting freight transport from trucks to rail in the *Tanah Abang Market* area demonstrates a clear contribution to reducing greenhouse gas (*GHG*) externality costs. Under the pessimistic scenario, annual savings increase from IDR 15.3 million (2025–2030) to IDR 39.9 billion (2041–2045). In the optimistic scenario, the impact is more substantial, with savings rising from IDR 83.3 million to IDR 234.4 million per year over the same period.

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