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# INVENTORY OF CARBON EMISSIONS FOR NET ZERO EMISSION POLICIES IN THE TRANSPORTATION SECTOR IN THE NEW CITY CENTER OF BANDA ACEH, ACEH, INDONESIA

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## Abstract

Carbon emissions, a major cause of global warming, predominantly originate from the transportation sector. Countries worldwide, including Indonesia, are committed to achieving Net Zero Emissions (NZE) by targeting a 29% to 41% reduction in emissions by 2030. As Aceh Province's capital, Banda Aceh strives to become a low-carbon city through various mitigation strategies. This study focuses on Mr Teuku Muhammad Hasan Street in the New City Center area of Banda Aceh, a high-traffic zone that significantly contributes to carbon emissions. The research aims to (1) measure vehicular CO2 emissions using traffic counting methods and (2) assess the CO2 absorption capacity of roadside vegetation along this route. Employing the IPCC 2019 Guidelines Tier 1 methodology, the study adopts a quantitative approach with spatial and descriptive analysis supported by field surveys and literature review. Findings indicate a residual emission of 2,676.17 tons of CO2 per year, unabsorbed by existing vegetation. Two key policies are proposed to support NZE goals: (1) increasing vegetation to enhance carbon sequestration and (2) optimizing public transportation, particularly the Trans Koetaradja bus service. Scenario analysis suggests that implementing these policies could reduce residual emissions by up to -114.29 tons CO2 per year, potentially transforming the area into a carbon-negative zone and advancing Banda Aceh's transition toward a low-carbon city.

***Keywords***: CO2, Net Zero Emission, Policy, Transportation, Vegetation

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# INTRODUCTION

Global warming has become a prominent issue over the past few decades. The significant increase in the earth's average temperature is heavily influenced by the greenhouse gas (GHG) effect. Carbon dioxide ($CO_2$) is responsible for over 75% of GHG emissions and is the largest contributor to global warming (Labiba & Pradoto, 2018). Urban areas generate approximately 60-70% of these emissions, with the transportation sector, particularly motor vehicles, being a major source (Albuquerque et al., 2020; Kim, 2018).

The 2015 Paris Agreement saw nations commit to maintaining the earth's average temperature below 2°C to mitigate climate change impacts. This commitment led to the rise of Net Zero Emission (NZE) policies. The Indonesian government has pledged to reduce GHG emissions by 29% independently and 41% with international support by 2030. This commitment is reinforced through local initiatives, such as Banda Aceh City's Regional Action Plan for GHG Reduction (RAD-GRK Kota Banda Aceh 2020-2025).

As the capital of Aceh Province, Banda Aceh has expanded southward, particularly into the New City Center in Batoh area, following the 2004 tsunami. Consequently, traffic has surged along main arteries like Mr Teuku Muhammad Hasan Street. $CO_2$ emissions from the transportation sector in Banda Aceh have risen from 242,577 tCO2eq in 2011 to 285,321 tCO2eq in 2019 (RAD GRK Kota Banda Aceh 2020-2025). This increase underscores the need for effective emission reduction strategies to ensure future quality of life.

In this context, Low Carbon Development (LCD) and NZE have become essential frameworks for promoting sustainable growth with lower energy and carbon usage. For Banda Aceh, particularly in the New City Center area, these frameworks provide a pathway to address pollution and reduce emissions through effective policies. Compared to the more congested Old City Center, the New City Center offers greater flexibility for implementing low-carbon initiatives, such as (1) Expanding green open spaces (GOS) to enhance $CO_2$ absorption and (2) Enhancing public transportation, specifically the Trans Koetaradja bus system. These strategies support the NZE goal of balancing $CO_2$ emissions with absorption, ultimately aiming to transform the New City Center into a carbon-negative zone and advancing Banda Aceh's aspiration to become a low-carbon city.

To achieve these goals effectively, conducting an emission inventory—a detailed record of air pollutants within a specific area and timeframe—is crucial. This inventory aligns with international standards, such as the 2019 IPCC Guidelines for GHG Inventories (Purwanto et al., 2015), and serves as an essential step in managing urban air quality. It ensures Banda Aceh's strategies meet national and global emissions reduction benchmarks.

# LITERATURE REVIEW

## Indonesia's Principles in Implementing the NZE Concept

To reduce its carbon footprint and achieve Net-Zero Emissions (NZE), the Indonesian government adheres to five main principles:

1. Increasing the use of renewable energy replacing fossil fuels with renewable energy sources.
2. Reducing fossil energy consumption.
3. Promoting the use of electric vehicles.
4. Enhancing electricity utilization.
5. Implementing Carbon Capture and Storage (CCS) technology to capture industrial carbon emissions.

This research focuses on principles 2 and 5, referencing the Resilience Development Initiative (RDI) & Greenpeace Indonesia (2022) study on Jakarta's transportation transformation, which implemented emission reduction policies by improving public transportation services and efficiency to reduce private vehicle use. While CCS technology is beneficial, plant-based carbon absorption is more cost-effective and environmentally beneficial.

## Carbon Absorption Capacity of Vegetation

Planting vegetation is an effective strategy for reducing $CO_2$ emissions (RAD-GRK Kota Banda Aceh 2020-2025). The $CO_2$ absorption capacity varies by tree species. The list of vegetation along the Mr. Teuku Muhammad Hasan Street and its absorption ability is shown in the following table.

**Table 1:** CO2 Absorption Capability Based on Tree Species

| No. | Name | Scientific Names | $CO_2$ Absorption (kg/tree/year) |
|---|---|---|---|
| 1 | Trembesi (1) | *Samanea Saman* | 28,448.39 |
| 2 | Tabebuya Kuning (1) | *Tabebuia aurea* | 135.27 |
| 3 | Flamboyan (1) | *Delonix regia* | 42.2 |
| 4 | Tanjung (1) | *Mimusops elengi* | 34.29 |
| 5 | Angsana (1) | *Pterocarpus indicus* | 11.12 |
| 6 | Asam (1) | *Tamarindus indica* | 1.49 |
| 7 | Ketapang Kencana (2) | *Terminalia mantaly* | 23.48 |
| 8 | Glodokan Tiang (3) | *Polyalthia longifolia* | 602.03 |
| 9 | Palem Raja (3) | *Roystonea regia* | 31.87 |
| 10 | Mimba (4) | *Azadirachta indica* | 126.51 |
| 11 | Ketapang (5) | *Terminalia catappa* | 105.87 |
| 12 | Palem (6) | *Arecaceae* | 52.52 |
| 13 | Cemara (6) | *Casuarinaceae* | 394.2 |
| 14 | Pohon Kuda-Kuda (7) | *Lannea coromandelica* | 60.00 |

*Source : (1) Dahlan (2007); (2) Febriansyah et al. (2022); (3) Trisandy (2018); (4) Setyowati et al. (2020); (5) Milantara & Gustin* (2023)*; (6). Suryaningsih et al. (2015); (7) Trisetio (2022)*

## RESEARCH METHODOLOGY

This study was conducted in the new city center in Batoh area, Banda Aceh City, specifically along the 2.49 km stretch of Mr. Teuku Muhammad Hasan Street, from Surabaya Intersection to Batoh Bus Station. This road was divided into six segments (**Figure 1**) based on signalized and non-signalized intersections, significantly affecting traffic movement in each segment.

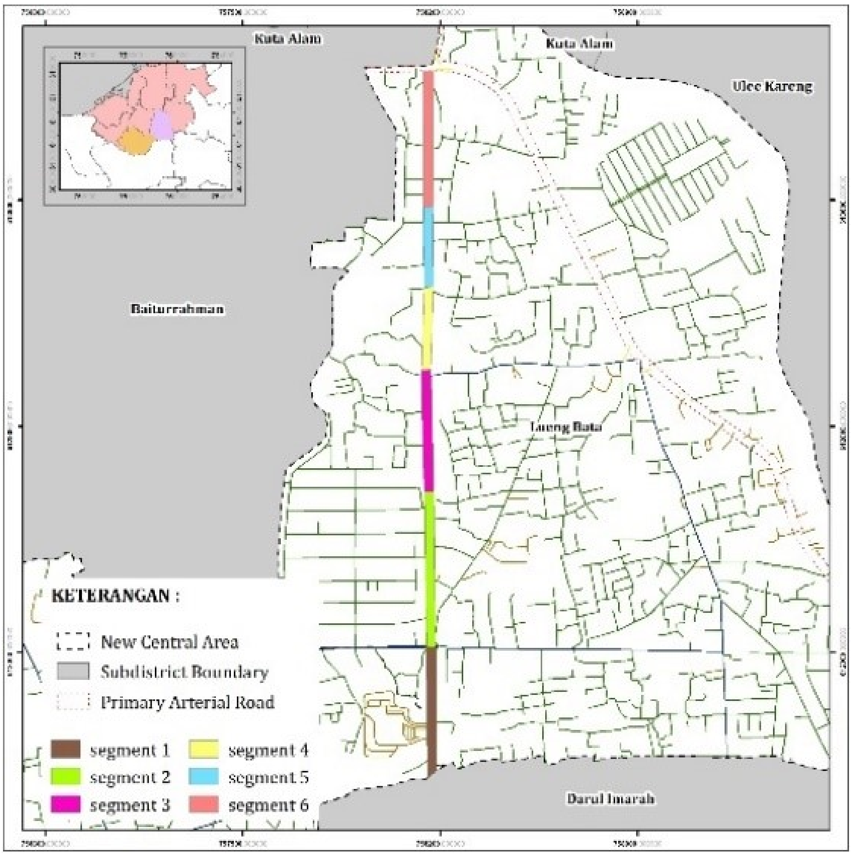



**Figure 2.** Map of The Mr. Teuku Muhammad Hasan Street Segment
*Source: Map elaborated from The Regional Development Planning Agency of Banda Aceh*

Surveys were conducted to collect data on traffic and vegetation on weekdays and weekends during four peak periods: 8-9 AM, 12-1 PM, 4-6 PM, and the evening peak at 8-10 PM. The research employed a quantitative approach with descriptive analysis to summarize data and formulate $CO_2$ emission reduction policies and spatial analysis to understand the distribution patterns.

**$CO_2$ Emission Calculation**

The emission calculation used the Tier 1 approach, leveraging activity data from global sources and default emission factors:

*Em= n x l x Kes x KE x EF* (1)
Description:
*Em*= Emission per hour (kg)
*n* = Number of vehicles
*l* = Length of road segment (km)
*Kes* = Specific energy consumption (liter/km)
*KE* = Energy conversion (MJ/liter)
*EF*= Emission factor (kg/MJ)

**Table 2:** Specific Energy Consumption of Vehicles

| Vehicle Type | Specific Energy Consumption (liters/Km) |
|---|---|
| Car | 0.118 |
| Bus | 0.169 |
| Mini Bus | 0.118 |
| Taxi | 0.109 |
| Truck | 0.158 |
| Pick-Up | 0.081 |
| Motorcycle | 0.027 |

*Source: Kusuma (2010)*

Emission factors represent the weight of pollutants produced by fuel combustion of a certain amount of fuel over a specific period (Rohman, 2018).

**Table 3:** Energy Conversion Units and Emission Factors by Fuel Type

| Fuel Type | Energy Content (MJ/liter) | Default Emission Factor (kg/Mj) |
|---|---|---|
| Gasoline | 33 | 0.0693 |
| Diesel | 36 | 0.0741 |

*Source: Kementerian Lingkungan Hidup (2012)*

The results obtained represent emissions in kg/hour. Data on the number of active vehicles per day was required to calculate the total emissions in kg/year. Based on observations, active driving hours ranged from 6 AM to midnight or 18 hours/day. Therefore, the following formula was used to calculate annual emissions (Milantara & Gustin, 2023).

*M= Em x 18 x 365*(2)

Description:
M = Total emissions (kg/year)
Em= Emissions (kg/hour)

**Absorption Capacity**
Based on Rawung (2015), vegetation absorption capacity is calculated as:

$AC = n \; x \; AC_{rate}$ (3)

Description:
AC= Absorption capacity (ton/year)
n= Number of trees
$AC_{rate}$= Absorption rate (ton/tree/year)

Unabsorbed emissions are derived from:

$E_{unabsorbed} = E_{total} - AC$ (4)

Description:
$E_{unabsorbed}$ = Unabsorbed emissions (ton/year)
$E_{total}$= Total Emissions (ton/year)
AC= Absorption capacity (ton/year)

**Formulation of $CO_2$ Emission Reduction Policies**
*Vegetation Addition Scenario*
Emission reduction from vegetation planting followed Rohman (2018):

$E_{total} = N \; x \; A_{co2}$ (5)
$E_{total} = \frac{L_{land}}{D_{plant}} \; x \; Aco2$

Description:
$E_{total}$ = Total $CO_2$ emission reduction (ton/year)
N = Number of trees planted
$A_{co2}$ = $CO_2$ absorption rate per tree (ton/year)
$L_{land}$ = Land area required
$D_{plant}$ = Planting distance per tree

The planting distance adhered to the Regulation of Minister of Public Works of Indonesia Number 05/PRT/M/2012), which categorized the planting distance as follows:

- Large trees : 6 meters
- Small trees (shrubs) : 2 meters
- Bushes : 0.3 meters
- Vine bushes : No specific distance

***Optimization Scenario of BRT-Trans Koetaradja Usage***

This study proposed an optimization scenario for BRT by increasing the bus arrival frequency to every 10 minutes. With a maximum capacity of 80 passengers per bus, 6 buses would operate every hour, accommodating up to 480 passengers per hour. Assuming that, on average, one private vehicle carries one passenger, the reduction in private vehicles was calculated:

$$RPV = \%RPV_{usage} \times 480 \quad (6)$$

Description:
RPV = Reduction in private vehicles (units)
$\%RPV_{usage}$ = Percentage of private vehicle usage

Next, calculate the reduction in $CO_2$ emissions from private vehicles:

$$T_{reduction} = RPV \times l \; x \; Kes \; x \; KE \; x \; EF \quad (7)$$

Description:
$T_{reduction}$= Total emission reduction (ton/year)
RPV = Reduction in private vehicles (units)
*l* = Road Length (km)
*Kes* = Specific energy consumption (liter/km)
*KE* = Energy conversion (MJ/liter)
*EF*= Emission Factor (kg/MJ)

## RESULT AND DISCUSSION

The Batoh Area, designated as Banda Aceh's New City Center in the city's Spatial Masterplan, serves as a commercial, residential, and office hub with a type 1 main terminal. Dominated by trade and services in the first layer and residential zones in the second, this mixed land-use configuration drives high traffic volumes along Mr Teuku Muhammad Hasan Street.

### Traffic Flow on Mr. Teuku Muhammad Hasan Street

The average vehicle counts per segment along Mr Teuku Muhammad Hasan Street is displayed in **Figure 2**.

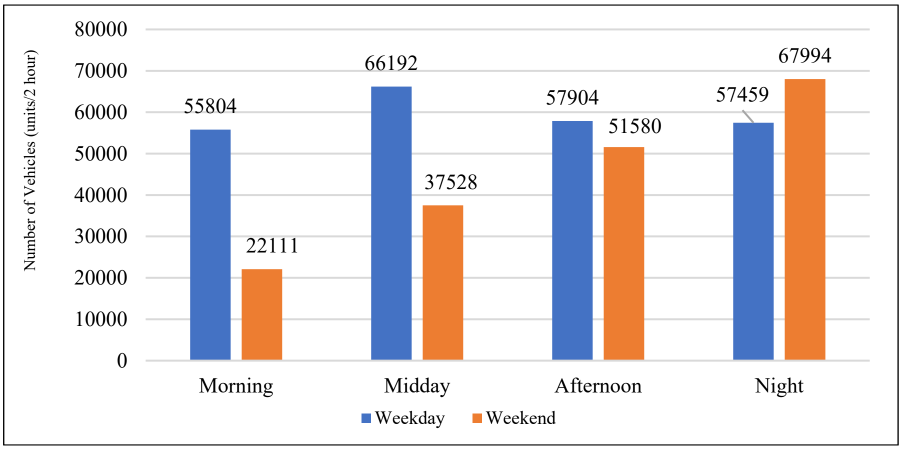



**Figure 3.** Traffic Flow Graph of Mr. Teuku Muhammad Hasan Street

Based on the graph above, traffic flow along Mr. Teuku Muhammad Hasan Street varies between weekdays and weekends. On weekdays, traffic fluctuates during four peak periods, reflecting daily activity patterns in the area. The morning period (8-9 AM) shows increased traffic flow as people begin daily activities such as commuting to work or school, though this increase is less pronounced than during midday. The midday period (12-1 PM) reaches peak traffic volumes due to commercial, business, and social activities, including lunch breaks and shopping. These weekday patterns demonstrate how regular schedules and routines influence traffic movement dynamics.

Weekend traffic patterns differ significantly, with smoother morning flow as residents begin activities later in the day. However, from midday through the evening, a substantial increase occurs, peaking between 8-10 PM due to heightened commercial and recreational activities. When commercial activity peaks, this results in greater road congestion during afternoon and nighttime hours. While initial weekend traffic appears lighter, vehicle numbers ultimately surpass weekday volumes. Analysis shows personal vehicles, particularly motorcycles, dominate all segments, with segment 6 recording the highest count at 6,959 units. The average number of vehicles per segment on Mr Teuku Muhammad Hasan Street is displayed in **Figure 3**.

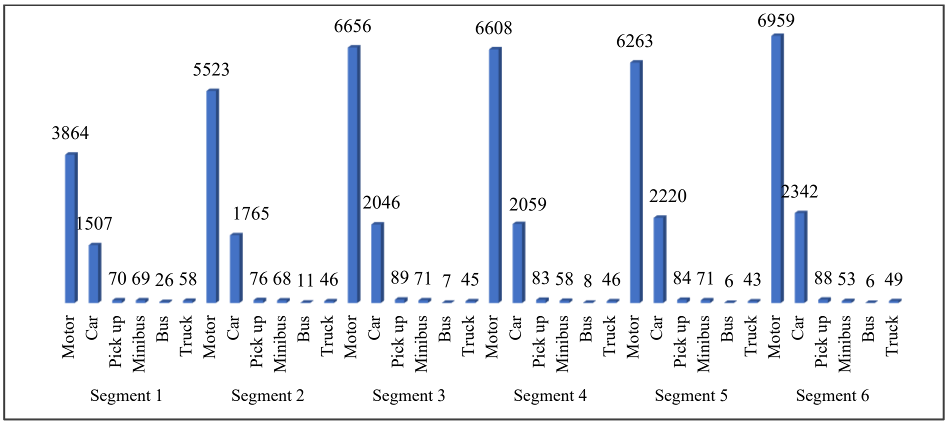



**Figure 4.** Vehicle Volume Graph for Each Segment

## $CO_2$ Emission and Absorption Inventory

The relationship between traffic flow and $CO_2$ emissions is direct and proportional, with increased traffic volume generating higher emissions.

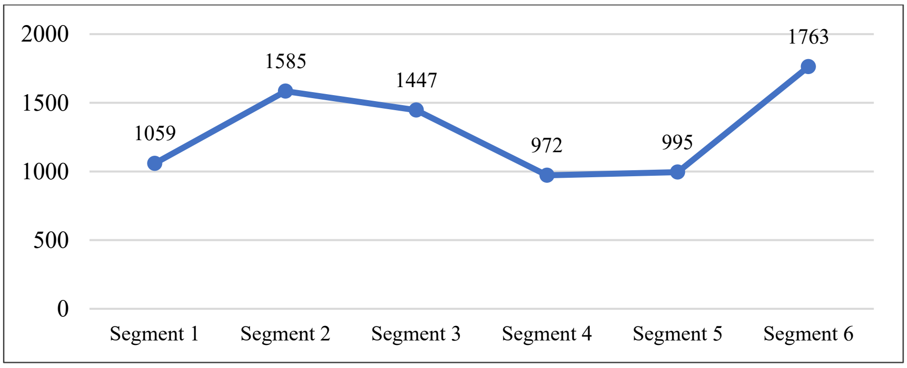
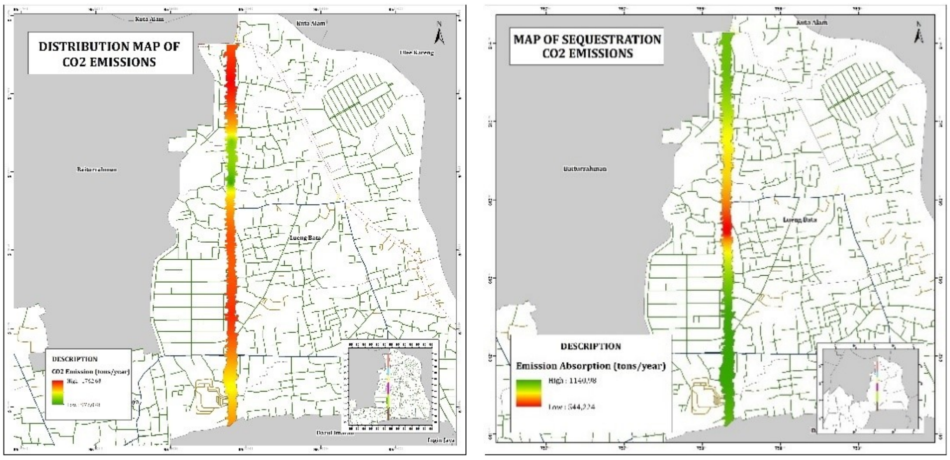



**Figure 5.** Annual CO2 Emissions Production Graph

**Figure 4** reveal significant variation in emissions production across different road segments. Segment 6 produces the highest emissions at 1,762.91 tons/year, while segments 4 and 5 show the lowest levels at 88.9 tons/year and 995 tons/year, respectively. These disparities suggest that emission levels are influenced by factors beyond simple vehicle counts, including vehicle type, fuel type, and segment length. Total $CO_2$ emissions for the study area amount to 7,820 tons/year, as illustrated in **Figure 5a**.




a b

**Figure 6.** a) CO2 Emissions Distribution Map; b) CO2 Absorption Distribution Map

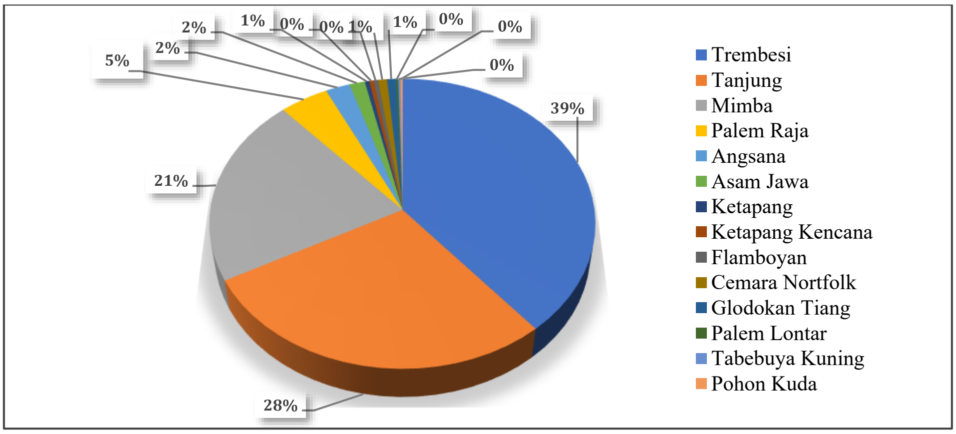



**Figure 7.** Percentage of Trees in the Green Belt of Mr. Teuku Muhammad Hasan Street

Urban vegetation, particularly roadside trees, plays a crucial role in $CO_2$ absorption, helping to mitigate air pollution and improve urban air quality (Milantara & Gustin, 2023). The analysis of the green belt along Mr Teuku Muhammad Hasan Street identified 14 different plant species totaling 491 individual trees. By multiplying the quantity of each tree species as shown in **Figure 6** by its specific absorption rate (Rohman, 2018), the total $CO_2$ absorption capacity was calculated. Segment 1 shows the highest absorption at 1,140.2 tons/year, with the entire study area vegetation absorbing 5,143.71 tons/year collectively, as shown in **Figure 5b**.

However, a significant gap remains between emissions production and vegetative absorption capacity. The unabsorbed emissions, or residual emissions, amount to 2,676.17 tons/year, as illustrated in **Figure 7**, indicating that the green belt in this area is not fully effective in offsetting vehicle emissions.

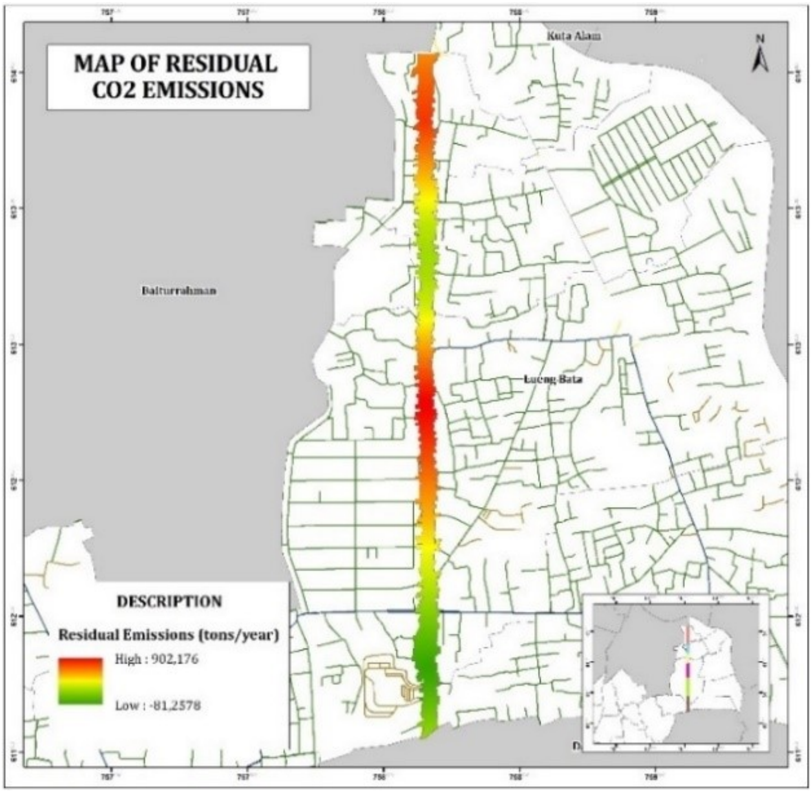



**Figure 8.** Residual Emissions Distribution Map

This finding aligns with Milantara and Gustin's (2023) research in Padang City, where green belts along Khatib Sulaiman Street absorbed only 0.06% of $CO_2$ emissions. These consistent results underscore the limitations of urban green belts as standalone solutions and highlight the need for comprehensive mitigation strategies in urban planning frameworks.

### $CO_2$ Emission Reduction Policies

#### *Increasing Vegetation in District-Level Green Open Spaces (GOS)*

The study results show that the role of green belts in $CO_2$ absorption is not optimal, with residual emissions of 2,676.17 tons/year unabsorbed. Based on these results, additional tree vegetation is needed to reduce $CO_2$ emissions from transportation activities. The choice of tree species is based on the highest absorption capacity and suitability for planting in the location, referring to the Regulation of Minister of Public Works of Indonesia Number 05/PRT/M/2012), and previous study from Pratiwi (2020) and Rohman (2018). Five types of vegetation are recommended for planting in the GOS of the New City Center area: glodokan (*Polyalthia longifolia*), kenanga (*Canangium odoratum*), flamboyan (*Delonix regia*), mahoni (*Swietenia mahagoni*), and angsana (*Pterocarpus indicus*).

The planting of these five vegetation types is aligned with the GOS development plan in Lueng Bata District by 2029, as mentioned in the Banda Aceh City Green Open Space Masterplan 2029 document, specifically in Blang Cut, Batoh, and Lueng Bata villages. The addition of 23,05 hectares of city parks and 17,8 hectares of green belts is planned for green open space development in Lueng Bata District. The following is the scenario calculation for reducing CO2 emissions by increasing vegetation in developing green belts and city parks.

**Table 4:** Recommendations for Vegetation Enhancement to the Green Belt

| Tree Type | Area for GOS Development (Ha) | Land Requirement (Ha) | Planting Distance (Ha) | Total Trees | $CO_2$ Absorption Capacity (kg/tree/ year) | Total $CO_2$ Absorption (tons/year) |
|---|---|---|---|---|---|---|
| a | b | c | d | e = c/d | f | g = e x f |
| Glodokan | 12,46 | 5.0 | 0,0036 | 1,384 | 602.03 | 833.48 |
| Flamboyan | | 3.7 | | 1,038 | 42.2 | 43.82 |
| Mahoni | | 2.5 | | 692 | 295.73 | 204.71 |
| Angsana | | 1.2 | | 346 | 11.12 | 3.85 |
| **TOTAL** | | | | **3,461** | | **1,085.85** |

*Source: Analysis Result (2024)*

**Table 5:** Recommendations for Vegetation Enhancement to City Parks

| Tree Type | Area for GOS Development (Ha) | Land Require ment (Ha) | Planting Distance (Ha) | Total Trees | $CO_2$ Absorption Capacity (kg/tree/year) | Total $CO_2$ Absorption (tons/year) |
|---|---|---|---|---|---|---|
| a | b | c | d | e = c/d | f | g = e x f |
| Flamboyan | 18.44 | 9.2 | 0,0036 | 2,561 | 42.2 | 108.08 |
| Kenanga | | 6.1 | | 1,707 | 756.59 | 1,291.81 |
| Angsana | | 3.1 | | 854 | 11.12 | 9.49 |
| **TOTAL** | | | | **640** | | **1,409.38** |

*Source: Analysis Result (2024)*

The recommendations for expanding green open space for city parks and green roadways at the district level follow the Ministerial Regulation of ATR/BPN Number 14 of 2022. This regulation stipulates that district park green cover should be 80%, and green roadways should have 70% green cover. The planting distance is adjusted according to the Regulation of Minister of Public Works Number 5/PRT/M/2012, recommending that large trees be planted 6 meters apart, requiring a land area of 36 m² or 0.0036 hectares per tree.

The scenario of GOS development through vegetation enhancement in the study area is estimated to absorb 2,495.23 tons of $CO_2$ annually. Nevertheless, a residual emission of 180.93 tons of $CO_2$ per year remains. These results indicate that the GOS development alone is insufficient to fully mitigate transportation-related emissions. Therefore, additional mitigation strategies are essential to achieve the zero-emission target within the area.

### *Optimization of Trans Koetaradja Public Transportation*

Personal vehicles, such as motorcycles and cars, are the largest contributors of emissions in the New City Center Area. The greenhouse gas (GHG) emission reduction strategy for the transportation sector in Banda Aceh, as outlined in the 2020-2025 Regional Action Plan for GHG Reduction, can be optimized by developing the Bus Rapid Transit (BRT) system. According to Anisah (2022), BRT is a strategic public policy designed to reduce reliance on private vehicles and support of low-carbon initiatives. Similarly, Abdullah et al. (2024) emphasized that public transportation serves as a governmental policy to decrease carbon emissions and preserving environmental quality, especially in urban areas.

The Government of Aceh Province operated Trans Koetaradja, a BRT-lite system, in 2016 to reduce private vehicles use. However, the system has yet to effectively curb the growth of personal vehicles, especially motorcycles. Optimizing the system, coupled with strategic land use management in the Batoh area, could significantly lower GHG emissions in Banda Aceh. The following scenario estimates the reduction in private vehicles use and corresponding emissions along Mr Teuku Muhammad Hasan Street, assuming optimal operation of Trans Koetaradja system based on the average vehicle count data.

**Table 6:** Reduction in Private Vehicle Numbers

| **Vehicle Type** | **Private Vehicle Usage (units/hour)** | **%** | **Trans Koetaradja BRT Units (units/hour)** | **Passengers per Bus** | **Passengers per Hour** | **Total Reduction in Private Vehicles (units/ hour)** |
|---|---|---|---|---|---|---|
| a | b | c | d | e | f = d x e | g = c x f |
| Motorcycles | 2.989 | 73 % | 6 | 34 | 204 | 149 |
| Cars | 995 | 24 % | | | | 49 |
| **TOTAL** | | | | | | **198** |

*Source: Analysis Results (2024)*

**Table 7:** Reduction in CO2 Emissions

| Vehicle Type | Reduction in Private Vehicles (units/ hour) | Road Length (km) | Fuel Consumption (l/km) | Energy Conversion (MJ/l) | Emission Factor (kg/MJ) | Total $CO_2$ Reduction (kg/jam) |
|---|---|---|---|---|---|---|
| a | b | c | d | e | f | g |
| Motorcycles | 149 | 2,49 | 0,027 | 33 | 0,0693 | 22,91 |
| Cars | 49 | | 0,118 | | | 32,92 |
| TOTAL | | | | | | 55,83 |

*Source: Analysis Results (2024)*

According to Ryansyah (2018), Trans Koetaradja buses arrives at the stop every 10 minutes or six busses per hour with a maximum capacity of 80 passengers per bus. However, this figure is considered overestimated under real operating conditions. A more realistic figure of 34 passengers per bus reflects the average active ridership during peak periods. Based on traffic analysis during weekdays and holidays, the average number of motorcycles is 73% of 4,087 total vehicles or 2,989 units, while the average number of cars is 24.3% or 995 units. Assuming each private vehicle (motorcycle or car) carries only one passenger, 204 bus passengers per hour could replace an equivalent number of private vehicles on the road.

The Trans Koetaradja system operates 14 hours daily, from 6:00 AM to 8 PM, amounting to 5,110 operating hours annually. With the optimization of BRT use along Mr. Teuku Muhammad Hasan Street, it is estimated that annual $CO_2$ emissions reduced by approximately 285,29 tons $CO_2$/year. Previous analysis indicates that the remaining emissions in the area are about 181 tons per year. However, with further optimization of BRT Koetaradja operations, these remaining emissions could be reduced to a negative value of -114.29 tons $CO_2$ per year.

## CONCLUSIONS

The results indicate that motorized transportation in the New City Center area in Batoh, Banda Aceh, generates 7,820 tons $CO_2$ annually. In contrast, the existing greenway vegetation absorbs only 5,143.71 tons $CO_2$ per year, leaving 2,676.17 tons/year of unabsorbed emissions. To mitigate the residual emission, it is recommended to enhance vegetation in district-scale Green Open Spaces (GOS) and optimize the use of Trans Koetaradja public transportation system. These combined measures could reduce emissions by up to -114.29 tons/year, with the negative value indicating that $CO_2$ absorption exceeds the generated emissions. This outcome aligns with the Net Zero Emission target of the 2015 Paris Agreement, establishing the New City Center area as a negative carbon zone.

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