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# CARBON EMISSION REDUCTION WITH GREEN OPEN SPACE DEVELOPMENT IN JAGORAWI TOLL ROAD, INDONESIA

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## ABSTRACT

**Objective:** The objective of this study is to conduct a Green Open Space (GOS) planning that meets ecological, socio-cultural, economic, and aesthetic functions in the context of carbon capture, and assess the capability of the GOS in capturing CO2.

**Theoretical Framework:** This research supports SDG 13 by means of the development of GOS that are capable of capturing carbon while keeping the aesthetic aspects. The approaches used are the integration of landscape planning aspects into the development of green infrastructures, the calculation of emissions produced by vehicles driving through the toll road, and the calculation of the carbon capture capacity of the vegetation.

**Method:** The research is conducted through two stages of research: 1.) The GOS Planning on the Jagorawi toll road that can fulfill ecological, socio-cultural, economic, and aesthetic functions, specifically the CO2 emission absorption, and 2.) Assessment of the GOS' capability in absorbing carbon.

**Results and Discussion:** The results of the study are: 1). The total number of trees to be planted in the GOS area is 10,917, and 2). The capability of the GOS to absorb CO2 emissions, as high as 30% of the total CO2 emitted by vehicles driving through the research area.

**Research Implications:** Efficient policies for combating climate change and reducing emissions to prevent future warming while also adapting to the unavoidable effects of climate change.

**Originality/Value:** Originality/Value: This research supplements the list of literature on the development of GOS based on carbon capture that are optimized in decreasing CO2 emissions.

**Keywords:** green open space, planting plan, CO2 absorption, vehicle emission, green infrastructure, Sustainable Development Goals (SDGs).

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## 1 INTRODUCTION

Indonesia has shown commitment to reducing carbon emissions to tackle climate change issues. This commitment is shown through the ratification of the Paris Agreement through Law No.16/2016 concerning The Ratification of the Paris Agreement to the United Nations Framework Convention on Climate Change in which the law contains the obligation of the government to conduct efforts and contributions in the reduction of greenhouse gas emissions. Environmental Regulations aim to stabilize greenhouse gases through the industrial emission limit policy that has been in existence since the Kyoto Protocol (Sitawati *et.al*, 2022).

One means to address the greenhouse gas emissions problem is Green Open Spaces (GOS). A GOS are urban areas that take the form of open spaces or corridors without buildings filled with naturally occurring or cultivated vegetation (Hardiansyah *et al.*, 2024). When it comes to carbon absorption, GOS serves an ecological purpose of carbon capture where vegetation planted within the GOS absorb carbon emitted. The role of GOS when it comes to urban planning has become more important than ever. This considers the fact that the rapid increase in urbanization and industrialization linked to the rapid increase in population growth has led to the increased pollution and has decreased the environmental capability of a city (Arifin & Nakagoshi, 2011).

This research aligns with SDG-13, which calls for urgent action to combat climate change and its impacts. The goal of SDG 13, "Climate Action," is to mitigate the negative effects of climate change, limit global temperature rise to below 1.5°C by the century's end, and develop low-carbon strategies (Küfeoğlu, 2020). Effective climate policies must focus on reducing emissions to prevent further warming while simultaneously adapting to the unavoidable impacts of climate change.

Moreover, carbon absorption is carried out by certain types of vegetation. These plantations are a part of biotic components that live in certain habitats such as forests, grasslands, bushes, and other places. (Dian *et al.*, 2018). Each type of vegetation has a different carbon absorption capacity which depends on the morphology of its leaves. Meanwhile, the rate of carbon absorption is affected by the age and the position of the leaves. Some of the vegetation that carry out high carbon absorption are Rain Tree (Samanea saman), 22,488.39 kg/year) and Cassia (Cassia sp, 5,295.47 kg/year).

This study focuses on the development of GOS along the Jagorawi Toll Road. The Jagorawi Toll Road is a 59 km expressway that connects Jakarta-Bogor-Ciawi. The Toll Road experiences a high volume of traffic and possesses a fairly large area of GOS. While this GOS is purposeful for absorbing carbon emitted from vehicles driving through the Toll Road, based on plantations planted within the GOS, it appears that the design of the Jagorawi Toll Road.

GOS is still aesthetically focused rather than emphasizing its function as a carbon absorber. This strengthens the result of the research conducted by Nur & Nizar (2013) which shows that the development planning of the GOS along the Jagorawi Toll Road is still focused on aesthetical aspects instead of the carbon absorption ones. The Carbon Capture approach is a relatively new concept that integrates aesthetic elements with climate change mitigation. However, it is often overlooked by Public Open Space (POS) planners, as most Green Open Space (GOS) development plans continue to prioritize aesthetic aspects over environmental benefits.

The “green belts” in the Jagorawi Toll Road has a diverse range of plants such as acacia (Acacia mangium), butterfly flower (Bauhinia purpurea), and royal palm (Roystonea regia) among others. Despite the diversity of plants planted on the green belt, the plants are not considered those with a high carbon absorption.

There is still a lack of observations that calculate how much a GOS can absorb $CO_2$ in detail, hindering the achievement of the national target of greenhouse gas emissions reduction by 29%. One example is the observation on the GOS planning along the roadsides in Medan conducted by Hilma *et al.*, (2023) which aims to improve air quality and to reduce rainwater. Despite the study does consider air quality improvement in the city, the research lacks the emphasis on the carbon capture by the vegetation settling within the GOS.

As GOS is heavily connected to the government of Indonesia's program in reducing greenhouse gas emission, this research is designed to realize the development of sustainable green infrastructure in form of carbon capture-based GOS development planning within the toll road area. Therefore, the research question is "how carbon capture-based green open spaces development can reduce emissions in Jagorawi toll road?". Following the Carbon Capture concept, this research focuses on the GOS development planning which takes place in Jagorawi Toll Road that emphasizes the capability of carbon absorption and combines the element with aesthetical aspects.

## 2 THEORETICAL FRAMEWORK

### 2.1 PLANTING PLAN

The landscaping of toll road corridors is an integral part of toll road development. Various criteria are considered for the landscaping plan along the Jagorawi Toll Road corridor, such as:

1. Vegetation should effectively absorb $CO_2$. This criterion aligns with SDG 13, "Climate Action," aiming to mitigate greenhouse gas (GHG) emissions. In this study, the reduction of GHG is approached naturally by selecting specific vegetation. This method also supports the Indonesian government's commitment to lowering GHG emissions as per Government Regulation No. 16/2016, which ratifies the Paris Agreement under the United Nations Framework Convention on Climate Change;
2. The landscape plan must prioritize safety (Urban Design Roads and Waterways, 2023). The landscape should ensure safety during construction, maintenance, and use. It should also promote safer driving behavior by incorporating elements such as:

a) Ensuring safe sight distances in line with design speed;
b) Protecting fast-moving vehicles from tree collisions through separation or barriers;

c) Enhancing road safety;
d) Using median strip planting to reduce headlight glare;
e) Employing ground cover plants to suppress weeds in visible areas;
f) Offering visual cues to drivers to signal road alignment and appropriate speeds;
g) Improving driver behavior and alertness through thoughtful planting;

3. The landscape plan should be ecologically responsible (Urban Design Roads and Waterways, 2023). The design aims to restore and strengthen local habitats, manage stormwater runoff by shaping the terrain, select appropriate species, and reduce waste and pollution during construction and maintenance. Vegetation choices are guided by considerations like topography (Booth, 1983), available space, adequate light and water, suitable temperatures, and soil type (Iles, 2001).
4. The landscape should enhance the character and value of the built environment (Urban Design Roads and Waterways, 2023). People spend significant time traveling, and their impression of a destination is influenced by the journey, including road conditions. Thus, the landscape should elevate the environmental quality and enhance the travel experience;
5. The landscape plan should be cost-effective (Urban Design Roads and Waterways, 2023). Plant selections take into account sustainable maintenance costs, with the aim of reducing long-term operational expenses for the management.

## 2.2 GHG EMISSION IN THE TOLL ROAD

Greenhouse gases (GHGs) are atmospheric gases that trap solar heat, contributing to the warming of the earth. The trapping of the solar heat leads to the greenhouse effect which occurs in a natural manner and has an essential role in keeping the planet warmer for the survival of human beings.

Some of the GHGs are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide (N2O), and fluorinated gases. These gases lead to the increase of the temperature of the earth, becoming contributors to global warming and eventually climate change. As such, there is a call for actions to reduce emissions from these gases to mitigate environmental impacts and to support environmental sustainability.

According to McGrath *et al.,* (2023), GHGs emitted into the Earth's atmosphere can create a "greenhouse effect," whereby heat is trapped, resulting in a rise in global temperatures. Although emissions can arise from natural sources, the predominant contributors are human activities, especially the burning of fossil fuels for energy and transportation. A significant source of $CO_2$ emissions comes from mobile vehicles. However, the extent of these emissions is influenced by the type of fuel utilized in the vehicles (Miwa, 2006).

### 2.3 $CO_2$ ABSORPTION

There are several types of $CO_2$ absorption methods used for carbon capture, among others (1) Biological absorption. This natural process involves plants, trees, and other photosynthetic organisms capturing $CO_2$ from atmosphere (Prajapati *et al.,* 2023), (2) Chemical absorption. This method uses chemical solvents to capture $CO_2$ from industrial emissions (Kothandaraman, 2010), (3) Physical absorption. This technique relies on the solubility of $CO_2$ in a liquid solvent without a chemical reaction. It is typically used in high-pressure environments where $CO_2$ has a higher solubility in the solvent (Zhenhong *et al.*, 2014), (4) Adsorption. This method uses solid materials, such as activated carbon or zeolites, to capture $CO_2$ from gas streams (Debbie Soo, 2024), and 5) Mineral sequestration. This involves reacting $CO_2$ with minerals to form stable carbonates. This process can permanently store $CO_2$ in solid form, such in underground geological formations (Molahid, at.al., 2022).

This research plans the arrangement of plants planted within the Jagorawi Toll Road GOS, enabling the toll road to absorb $CO_2$ optimally. Naturally, carbon absorption can be done by vegetation consisting of specific plants. Each plant has a different carbon absorption capacity, depending on the morphology of its leaves (Yohanes *et al.,* 2023). The rate of $CO_2$ absorption is also influenced by the age and the location of the leaves. In this research, plants that will be planted within the GOS are those that possess a high absorption capacity. (Yohanes *et al.*, 2023).

## 3 METHODOLOGY

### 3.1 RESEARCH AREA

The study takes place in Jagorawi Toll Road. Specifically, the study is conducted in the Cibinong-Bogor segment (Segment 3 – Segment 6) of the toll road at STA 26,500 – 43,500. The segment has a total length of 17 Km. The research area is shown in Figure 1 as follows.

**Figure 1**

*Research area location*


Inaugurated on March 9th, 1978, the Jagorawi Toll Road is the first highway built in Indonesia and connects Jakarta-Bogor-Ciawi. The highway is regarded as a busy roadway with around 9,000 vehicles making a 37-mile journey/day (or a 25 mile journey/day during congestion) (USAID, 2024).

## 3.2 DATA COLLECTION

The data collected is categorized into two types: primary data and secondary data.

### 3.2.1 Primary Data

The primary data is obtained from the observation of the current conditions of (i) types and quantities of the vegetation that settle within the GOS and their quantities (Table 1) and (ii) data on daily traffic within the research area (Table 2) Based on observation, it was reported that there are 9,588 trees settled within the GOS, consisting of 24 species. The detailed information on the types and the quantities of the existing vegetation can be seen on Table 1.

**Table 1**

*Types and quantities of existing vegetation in 2024*

| No. | Species | Quantity |
|---|---|---|
| 1 | *Acacia mangium* | 150 |
| 2 | *Pterocarpus indicus* | 28 |
| 3 | *Dracaena* | 446 |
| 4 | *Cerbera odollam* | 646 |
| 5 | *Casuarina equisetifolia* | 33 |
| 6 | *Erythrina crista-galli* | 263 |
| 7 | *Tectona grandis* | 67 |
| 8 | *Leucosyke capitellata* | 17 |
| 9 | *Plumeria* | 75 |
| 10 | *Caesalpinia pulcherrima* | 129 |
| 11 | *Hibiscus rosa-sinensis* | 33 |
| 12 | *Terminalia mantaly* | 3,130 |
| 13 | *Bauhinia purpurea* | 558 |
| 14 | *Leucaena leucocephala* | 37 |
| 15 | *Swettiana mahagoni* | 374 |
| 16 | *Pometia pinnata* | 50 |
| 17 | *Caesalpinia pulcherrima* | 400 |
| 18 | *Maniltoa grandiflora* | 58 |
| 19 | *Duranta erecta* | 17 |
| 20 | *Spathodea campanulata* | 116 |
| 21 | *Brugmansia (yellow)* | 643 |
| 22 | *Brugmansia (rosea)* | 1,377 |
| 23 | *Cordyline fruticosa* | 300 |
| 24 | *Samanea saman* | 643 |

The research takes a place in Segment 3 – Segment 6. The observed segments reportedly generated 235,000 trips per day in June 2024. Detailed information on the daily traffic within the research area can be seen on Table 2 below:

**Table 2**

*Daily traffic within the research area in June 2024*

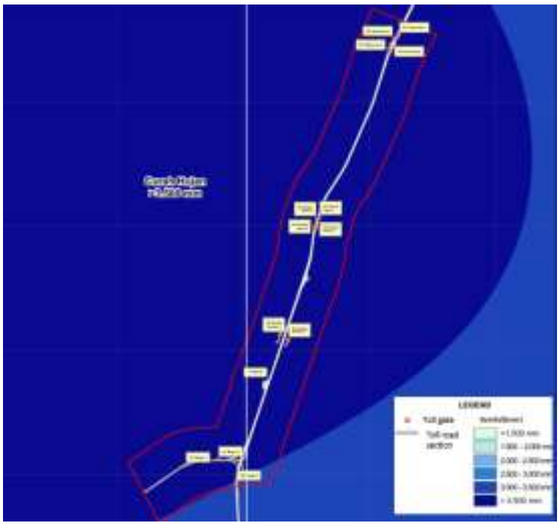
| No. | Segment | Distance (Km) | Daily Average Traffic |
|---|---|---|---|
| 1 | Segment 3: G.Putri-Citeureup<br>(Km. 23+800 s.d Km. 27+100) | 3,300 | 22,456 |
| 2 | Segment 4: Citeureup -Sentul<br>(Km. 27+100 s.d 32+800) | 5,700 | 27,119 |
| 3 | Segment 5: Sentul-Sentul Selatan<br>(Km. 32+800 s.d Km. 36+700) | 3,900 | 56,614 |
| 4 | Segment 5: Sentul Selatan-Ciawi Gadog/Bogor<br>(Km. 36+700 s.d Km. 44+500) | 7,800 | 129,139 |
| Total | | 20,700 | 235,329 |

### 3.2.2 Secondary Data

The study uses secondary data on rainfall conditions (Fig. 2), types of soils (Figure.3), topography conditions (Figure 4), and other aspects. The secondary data is purposeful to explain current land physical characteristics, on which the quality and the land use of the land observed are assessed.

**Figure 2**

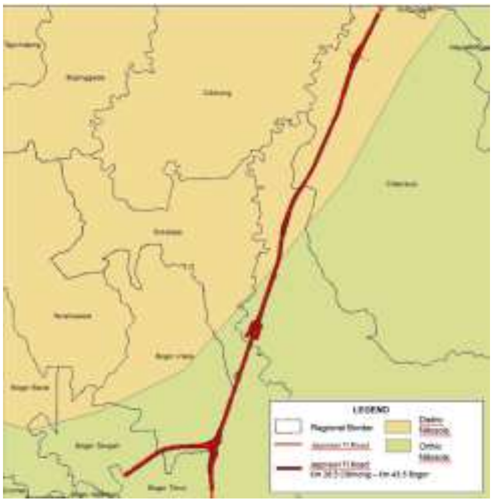
*Rainfall conditions*



The rainfall occurs in the research area at an average 3,500 mm per year. Therefore, the most suitable plants for this environment are those that can withstand high humidity and are resilient to diseases associated with excessive moisture.

**Figure 3**

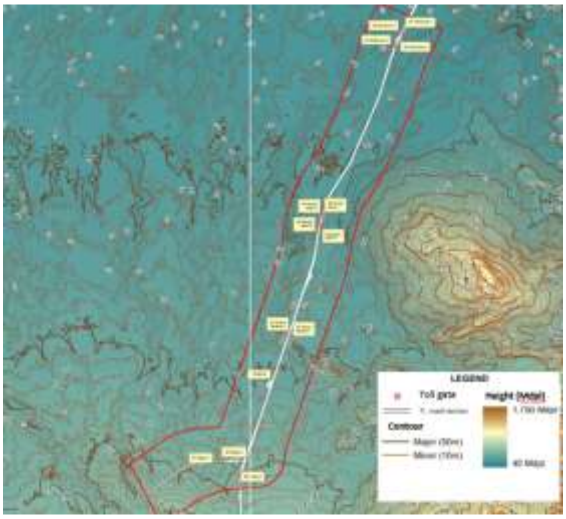
*Soil conditions*




From the soil map, it was observed that the Jagorawi Toll Road from the KM 26,500 Cibinong – Km 43,500 Bogor is developed on two types of soils: Acrisols and Nitosol. During dry season, these types of soils often accumulate, resulting in both less fertile and fertile soils. These soils are often referred to as Red-Yellow Podzolic Soils. The Red-Yellow Podzolic Soils have a crucial role in agricultural and plantation businesses as well as the purpose of greening such as the development of the green belts in the toll road area.

**Figure 4**

*Topography conditions*




As observed from the topography and the soil conditions in Jagorawi KM 26,500 – KM 43,500, lowlands still exist within the observed area. In such conditions and lands, a sizable number of vegetation can grow with an exception of swamp-coastal vegetation such as Mangrove.

3.3 RESEARCH STAGES

This research consists of two main stages: 1.) The GOS Planning on the Jagorawi toll road that can fulfill ecological, socio-cultural, economic, and aesthetic functions, specifically the $CO_2$ emission absorption (planning stage), and 2.) Assessment on the GOS' capability in absorbing carbon. Each stage fits the objectives of this research (assessment stage).

The planning stage is done by assessing the suitability of various plants with their respective criteria with the physical characteristics of the planning area. The planning stage is expected to result in a landscape design map along with a list of suitable vegetation and quantities of vegetation to be planted within the GOS.

The assessment is carried out by collecting primary and secondary data through data gathering. The assessment is carried out by calculating: (1) Trees' $CO_2$ absorption capacity, (2) $CO_2$ emitted by vehicles driving through the 26,500-43,500 km section of the Jagorawi Toll Road.

### 3.3.1 Planning Stage

In this stage, researchers select suitable types of vegetation to be planted on the Jagorawi Toll Road green belts. The criteria are as follows:

1) Possesses medium and high absorption;
2) Suits soil physical characteristics including topography, climate, types of soils, and other characteristics;
3) Functions as the corridor builder and improves road aesthetic aspects;
4) The vegetation can be planted on roadsides and other green areas based on the diameter of the canopy (big, medium, and small).

### 3.3.2 Calculation Stage

In this stage, researchers will assess the absorption capabilities of vegetation. The stage is conducted as follows:

**Stage I: Calculation Stage ($CO_2$ Absorption)**

In this stage, researchers will calculate the $CO_2$ absorption of the trees that will be planted within the research area.

**Stage II: Calculation Stage ($CO_2$ Emission)**

In this stage, researchers will calculate the quantities of $CO_2$ emitted by vehicles driving through the research area.

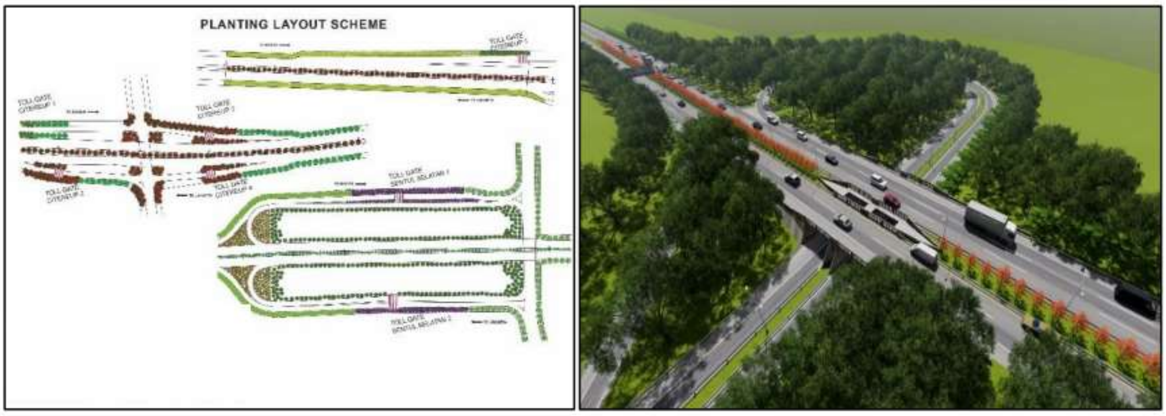
## 4 RESULTS AND DISCUSSION

### 4.1 PLANNED LAYOUT

Based on the criteria which describe that the vegetation that will planted within the research area is plants that possess medium-high absorption, suit soil physical characteristics including topography, climate, types of soils, and other characteristics, function as the corridor builder and improve road aesthetic aspects, and can be planted on roadsides and other green areas based on the diameter of the canopy (big, medium, and small), the quantities of planted trees are set at 10,197 trees. The planned plant layout can be seen in Figure 5 below.

**Figure 5**

*Planned layout scheme*




The 2D render The 3D render

The plant plan also considers the aesthetic aspects and the formation of road corridor spaces. Small trees are placed in the green junction lane so as not to obstruct the driver's line of sight. On the other hand, large-sized trees are placed in the outermost roadside of the green belts and arranged in gradient. Lastly, medium-sized trees and small-sized plants are planted closer to the roadside shoulder.

The list of tree species, along with their $CO_2$ absorption capacity (annual and daily), can be seen in Table 3 below.

**Table 3**

*Tree species with their $CO_2$ absorption capacity (annual and daily)*

| No. | Species | Annual $CO_2$ Absorption Capacity (kg/tree/year) | Daily $CO_2$ Absorption Capacity (kg/tree/year) |
|---|---|---|---|
| 1 | *Acacia mangium* | 15.19 [a] | 0.04 |
| 2 | *Pterocarpus indicus* | 11.12 [a] | 0.03 |
| 3 | *Dracaena* | 0.39 [b] | 0.001 |
| 4 | *Cerbera manghas* | 27.91 [c] | 2.32 |
| 5 | *Casuarina equisetifolia* | 45.00 [b] | 0.12 |
| 6 | *Erythrina crista-galli* | 4.55 [a] | 0.01 |
| 7 | *Tectona grandis* | 135.27 [a] | 0.37 |
| 8 | *Leucosyke capitellata* | 1.03 [d] | 0.003 |
| 9 | *Plumeria* | 44.00 [b] | 0.12 |
| 10 | *Caesalpinia pulcherrima* | 30.95 [a] | 0.08 |
| 11 | *Tilipariti tiliaceum* | 1.61 [e] | 0.05 |
| 12 | *Terminalia mantaly* | 23.48[b] | 0.06 |
| 13 | *Bauhinia purpurea* | 1,280.68 [e] | 3.56 |
| 14 | *Leucaena leucocephala* | 1,425.60 [g] | 3.96 |
| 15 | *Swettiana mahagoni* | 295.73 [a] | 0.82 |
| 16 | *Pometia pinnata* | 329.76 [a] | 0.91 |
| 17 | *Caesalpinia pulcherrima* | 30.95 [a] | 0.08 |
| 18 | *Maniltoa grandiflora* | 8.26 [a] | 0.02 |
| 19 | *Duranta erecta* | 0.25[b]) | 0.001 |
| 20 | *Spathodea campanulat* | 211.64 [f] | 0.59 |
| 21 | *Tabebuia rosea* | 209.09 [g] | 0.58 |
| 22 | *Tabebuia rosea* | 209.09 [g] | 0.58 |
| 23 | *Cordyline fruticosa* | 0.25 [b] | 0.001 |
| 24 | *Samanea saman* | 28,448.39 [a] | 79.02 |
| 25 | *Cassia fistula* | 5,295.47 [a] | 14.71 |
| 26 | *Oleana syzyygium* | 123.87 [b]) | 0.34 |
| 27 | *Adenanthera pavoniana* | 221.18 [a] | 0.61 |
| 28 | *Schima wallichii* | 63.31 [a] | 0.17 |
| 29 | *Filicium decipiens* | 404.83 [a] | 1.12 |
| 30 | *Michelia champaca* | 8,280.00 [h] | 23.00 |
| 31 | *Manilkara kauki* | 36.19 [a] | 0.10 |
| 32 | *Canarium SP* | 8,280.00 [h] | 23.00 |
| 33 | *Bougainvillea spectabills* | 0.25 [b] | 0.001 |
| 34 | *Mimusops elengi* | 34.29 [a] | 0.09 |
| 35 | *Polyalthia longifolia* | 6,304.92 [f] | 17.51 |
| 36 | *Ficus benjamina* | 1,255.40 [b] | 3.49 |

Source: Dahlan, 2007 [a], Febriansyah *et al.*, 2022 [b], Aindo *et al.*, 2023 [c], Wikansari & Nurjani, 2018 [d], Nursyahbandi *et al.*, 2020 [e], Marisha, 2018 [f], Roshintha & Mangkoedihardjo, 2016 [g]

The types of species and quantities of vegetation to be planted within the research area are seen in Table 4.

**Table 4**

*Planned types and quantities of vegetation to be planted within the research area.*

| No. | Species | Quantity | Percentage |
|---|---|---|---|
| 1 | *Oleana syzyygium* | 2,266 | 22% |
| 2 | *Caesalpinia pulcherrima* | 1,648 | 16% |
| 3 | *Samanea saman* | 1,241 | 12% |
| 4 | *Cassia fistula* | 1,210 | 12% |
| 5 | *Terminalia mantaly* | 1,033 | 10% |
| 6 | *Bauhinia purpurea* | 869 | 9% |
| 7 | *Schima wallichii* | 380 | 4% |
| 8 | *Cerbera manghas* | 324 | 3% |
| 9 | *Bougainvillea* | 320 | 3% |
| 10 | *Filicium decipiens* | 229 | 2% |
| 11 | *Pometia pinnata* | 201 | 2% |
| 12 | *Erythrina crista-galli* | 197 | 2% |
| 13 | *Canarium Sp.* | 172 | 2% |
| 14 | *Mimusops elengi* | 73 | 1% |
| 15 | *Polyalthia longifolia* | 34 | 0% |
| Total | | 10,197 | 100% |

Quantities of species that will be planted within the research area are 15 types or equal to 10,197 trees. There are 5 trees that possesses above 10% percentage: Oleana syzyygium (22%), Caesalpinia pulcherrima (16%), Samanea saman (12%), Cassia fistula (12%), and Terminalia mantaly (10%). These five trees possess adequately high $CO_2$ absorption. In addition to the capacity of absorbing $CO_2$, other factors that are topography, climate suitability, and types of soils are also considered. Selection of the vegetation is also based on criteria such as enhancing the road visual aesthetics, acting as a composition for the roadside tree strata, forming the road corridor spaces, acting as the road guidance, and etc. as seen in Table 5.

**Table 5**

*Criteria for the selection of vegetation.*

| No. | Species | Function |
|---|---|---|
| 1 | *Caesalpinia pulcherrima, Bougainvillea sp.* | Flowering plant. Enhancing the road visual aesthetics |
| 2 | *Oleana syzyygium, Schima wallichii* | Foilage plant. Enhancing the road visual aesthetics |
| 3 | *Erythrina crista-galli* | Flowering tree. Acting as a composition for the roadside tree strata. |
| 4 | *Cerbera manghas* | Acting as a composition for the roadside tree strata. |
| 5 | *Pometia pinnata, Cassia fistula* | Large-sized tree, Forming the road corridor spaces. |
| 6 | *Bauhinia purpurea* | Flowering tree. Acting as a composition for the roadside tree strata. |
| 7 | *Terminalia mantaly* | Pyramid-shaped tree. Acting as the road guidance. sebagai pengarah jalan |
| 8 | *Polyalthia longifolia* | Columnar-shaped tree. Forming the road corridor spaces. |
| 9 | *Canarium sp.* | Large-sized tree. Bogor's landmark. |
| 10 | *Filicium decipiens, Mimusops elengi* | Forming the road corridor spaces. |
| 11 | *Samanea saman* | Large-sized tree. Acting as a shade tree capable of creating a microclimate. |

## 4.2. ASSESSMENT STAGE

### 4.2.1 Calculation of Trees' Absorption Capacity

The total $CO_2$ absorption capacity of the trees is obtained by calculating the results of multiplying the quantities of trees by the absorption capacity of each tree (Equation 1) (Febriansyah *et al.*, 2022):

$$\sum_{i}^{n} = V_i \, xCAC_i \qquad (1)$$

where:

Vi= quantities of vegetation settled;

CACi= carbon ($CO_2$) absorption capacity.

Referring to the planned plant, the number of trees to be planted within the research area consists of 15 species, meaning 10.197 trees in total (Table 4). As such, the total $CO_2$ absorption capacity of the trees in the GOS within the research area reaches 125,769.839 kg/day. The $CO_2$ absorption capacity of each tree is seen in Table 6 as follows.

**Table 6**

*Trees' absorption capacity*

| No. | Species | Quantity | Annual $CO_2$ Absorption kg/tree/day | Daily $CO_2$ Absorption kg/day | |
|---|---|---|---|---|---|
| | | | | Kg/day | % |
| 1 | *Caesalpinia pulcherrima* | 1,648 | 0.08 | 141.68 | 0.11 |
| 2 | *Oleana syzyygium* | 2,266 | 0.34 | 779.69 | 0.62 |
| 3 | *Schima wallichii* | 380 | 0.17 | 66.83 | 0.05 |
| 4 | *Bougainvillea* | 320 | 0.001 | 0.22 | 0.00 |
| 5 | *Erythrina crista-galli* | 197 | 0.013 | 2.49 | 0.00 |
| 6 | *Cerbera manghas* | 324 | 2.32 | 753.49 | 0.60 |
| 7 | *Pometia pinnata* | 201 | 0.91 | 184.11 | 0.15 |
| 8 | *Cassia fistula* | 1,210 | 14.71 | 17,798.7 | 14.15 |
| 9 | *Bauhinia purpurea* | 869 | 3.56 | 3,091.42 | 2.46 |
| 10 | *Terminalia mantaly* | 1,033 | 0.06 | 67.37 | 0.05 |
| 11 | *Polyalthia longifolia* | 34 | 17.51 | 595.46 | 0.47 |
| 12 | *Canarium Sp.* | 172 | 23.00 | 3.95 | 3.15 |
| 13 | *Filicium decipiens* | 229 | 1.12 | 257.52 | 0.20 |
| 14 | *Mimusops elengi* | 73 | 0.09 | 6.95 | 0.01 |
| 15 | *Samanea saman* | 1,24 | 79.02 | 98,067.93 | 77.97 |
| Total | | 10,197 | | 125,769.84 | 100% |

Table 6 shows that the total $CO_2$ absorbed by the green belts within the research area is amounted at 125,769.84 kg/day. From the table, the Samanea saman possesses the highest absorption percentage of 77.97%.

### 4.2.2 Calculation Of $CO_2$ Emitted by Vehicles

Mobile sources such as vehicles are known to emit direct greenhouse gas emissions such as carbon dioxide ($CO_2$), methane ($CH_4$), and nitrogen oxide (N2O). These gas emissions result the combustion of various fuels and other pollutants such as carbon monoxide (CO), Non-methane Volatile Organic Compounds (NMVOC), sulfur dioxide ($SO_2$), particulates (PM) and nitric oxide (NOx), all contributing to local/regional air pollution.

This research is focused on the calculation of one greenhouse gas emission of carbon dioxide ($CO_2$) which can be assumed by fuel consumption or the distance covered by vehicles. The amount of $CO_2$ emitted by vehicles driving through the research area is obtained by multiplying the fuel sold with the emission factor as shown in equation 2 as suggested by Miwa (2006) as follows:

$$\boxed{Emission = \sum_a [Fuel_a \bullet EF_a]} \qquad (2)$$

where:

Emission= Emission of $CO_2$ (kg)
$Fuel_a$= Fuel sold (TJ)
$Ef_a$= Emission factor (kg/TJ)
A = Type of fuel

Based on the calculation using the equation 2, the amount of $CO_2$ emitted by vehicles crossing the study area can be seen in Table 7.

**Table 7**

*Trees' absorption capacity*

| Segment | Vehicle Quantity (Unit) | Road Length (Km) | Fuel Consumed (L) | Energy Conversion (TJ) | $CO_2$ Emission Factor (Kg/TJ) | Total $CO_2$ Emitted (Kg) |
|---|---|---|---|---|---|---|
| Segment 3 G.PUTRI - CITEUREUP | 22,456 | 3.30 | 9,263.25 | 0.30 | 69,300 | 21,184 |
| Segment 4 CITEUREUP -SENTUL | 27,119 | 5.70 | 19,322.54 | 0.64 | 69,300 | 44,189 |
| Segment 5 SENTUL - SOUTH SENTUL | 56,614 | 3.90 | 27,599.14 | 0.91 | 69,300 | 63,116 |
| Segment 6 S. SENTUL - CIAWI GADOG/ BOGOR | 129,139 | 7.80 | 125,910.88 | 4.15 | 69,300 | 287,946 |
| TOTAL | 235,329 | 20.7 | 182,095.83 | 6.00 | | 416,435 |

The total $CO_2$ emissions produced by as high as 235,000 vehicles driving through the research area daily reach as high as 416,000 Kg/day. The highest emissions are produced by vehicles driving through the South Sentul area towards Gadog/Bogor. Assumptions used in the calculation of $CO_2$ emitted by vehicles driving through the research area are as follows:

1) The average vehicle driving through the research area is a minibus;
2) The average vehicle uses gasoline as fuel;

3) The fuel consumption for the minibus type is 8 Km/Liter (Suhardi & Febrina, 2013).

## 5 CONCLUSION

The carbon absorption-based GOS planning within the Jagorawi Toll Road corridors results in a plan to plant 10,197 trees settled in the GOS with the total trees' carbon absorption capacity reaching 125,769/83 kg/day. From the emission calculation, it appears that the vehicles driving through the Segment 3-6 of the Jagorawi Toll Road emit a total 416,436 kg/day of $CO_2$. Comparing both calculations, the GOS is capable of absorbing as high as 33% of the total $CO_2$ emissions emitted by the vehicles driving through segment 3-6 of the Jagorawi Toll Road. Based on the results, the planned GOS is expected to contribute to the Government program in the GHG emission reduction as stipulated in Law No.16/2016 concerning The Ratification of the Paris Agreement to the United Nations Framework Convention on Climate Change in which the Government has set a commitment to reduce GHG emissions to 29% in 2030.

In addition, the total $CO_2$ absorbed by the green belts within the research area happens to be larger than that of the existing trees. As seen in Table 1, the quantity of trees currently planted within the research area is 9,558. By using the same equation as the previous (Equation 1), the total $CO_2$ absorbed by the existing trees settled in the research area reaches 56,342.004 kg/day. Comparing with the total $CO_2$ emitted by the vehicles driving through the research area, the existing trees only absorb 13.53% of the total emissions. As such, the planting layout scheme proposed in this research is assumed to be capable of absorbing $CO_2$ emitted by the vehicles driving through the research area twice higher than that of the existing layout.

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# Journal of Lifestyle & SDGs Review

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# CARBON EMISSION REDUCTION WITH GREEN OPEN SPACE DEVELOPMENT IN JAGORAWI TOLL ROAD, INDONESIA

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## ABSTRACT

**Objective:** The objective of this study is to conduct a Green Open Space (GOS) planning that meets ecological, socio-cultural, economic, and aesthetic functions in the context of carbon capture, and assess the capability of the GOS in capturing $CO_2$.

**Theoretical Framework:** This research supports SDG 13 by means of the development of GOS that are capable of capturing carbon while keeping the aesthetic aspects. The approaches used are the integration of landscape planning aspects into the development of green infrastructures, the calculation of emissions produced by vehicles driving through the toll road, and the calculation of the carbon capture capacity of the vegetation.

**Method:** The research is conducted through two stages of research: 1.) The GOS Planning on the Jagorawi toll road that can fulfill ecological, socio-cultural, economic, and aesthetic functions, specifically the $CO_2$ emission absorption, and 2.) Assessment of the GOS' capability in absorbing carbon.

**Results and Discussion:** The results of the study are: 1). The total number of trees to be planted in the GOS area is 10,917, and 2). The capability of the GOS to absorb $CO_2$ emissions, as high as 30% of the total $CO_2$ emitted by vehicles driving through the research area.

**Research Implications:** Efficient policies for combating climate change and reducing emissions to prevent future warming while also adapting to the unavoidable effects of climate change.

**Originality/Value: Originality/Value:** This research supplements the list of literature on the development of GOS based on carbon capture that are optimized in decreasing $CO_2$ emissions.

**Keywords:** Green Open Space, Planting Plan, $CO_2$ Absorption, Vehicle Emission, Green Infrastructure, Sustainable Development

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## 1 INTRODUCTION

Indonesia has shown commitment to reducing carbon emissions to tackle climate change issues. This commitment is shown through the ratification of the Paris Agreement through Law No.16/2016 concerning The Ratification of the Paris Agreement to the United Nations Framework Convention on Climate Change in which the law contains the obligation of the government to conduct efforts and contributions in the reduction of greenhouse gas emissions. Environmental Regulations aim to stabilize greenhouse gases through the industrial emission limit policy that has been in existence since the Kyoto Protocol (Sitawati *et.al*, 2022).

One means to address the greenhouse gas emissions problem is Green Open Spaces (GOS). A GOS are urban areas that take the form of open spaces or corridors without buildings filled with naturally occurring or cultivated vegetation (Hardiansyah *et al.*, 2024). When it comes to carbon absorption, GOS serves an ecological purpose of carbon capture where vegetation planted within the GOS absorb carbon emitted. The role of GOS when it comes to urban planning has become more important than ever. This considers the fact that the rapid increase in urbanization and industrialization linked to the rapid increase in population growth has led to the increased pollution and has decreased the environmental capability of a city (Arifin & Nakagoshi, 2011).

This research aligns with SDG-13, which calls for urgent action to combat climate change and its impacts. The goal of SDG 13, "Climate Action," is to mitigate the negative effects of climate change, limit global temperature rise to below 1.5°C by the century's end, and develop low-carbon strategies (Küfeoğlu, 2020). Effective climate policies must focus on reducing emissions to prevent further warming while simultaneously adapting to the unavoidable impacts of climate change.

Moreover, carbon absorption is carried out by certain types of vegetation. These plantations are a part of biotic components that live in certain habitats such as forests, grasslands, bushes, and other places. (Dian *et al.*, 2018). Each type of vegetation has a different carbon absorption capacity which depends on the morphology of its leaves. Meanwhile, the rate of carbon absorption is affected by the age and the position of the leaves. Some of the vegetation that carry out high carbon absorption are Rain Tree (Samanea saman), 22,488.39 kg/year) and Cassia (Cassia sp, 5,295.47 kg/year).

This study focuses on the development of GOS along the Jagorawi Toll Road. The Jagorawi Toll Road is a 59 km expressway that connects Jakarta-Bogor-Ciawi. The Toll Road experiences a high volume of traffic and possesses a fairly large area of GOS. While this GOS is purposeful for absorbing carbon emitted from vehicles driving through the Toll Road, based on plantations planted within the GOS, it appears that the design of the Jagorawi Toll Road.

GOS is still aesthetically focused rather than emphasizing its function as a carbon absorber. This strengthens the result of the research conducted by Nur & Nizar (2013) which shows that the development planning of the GOS along the Jagorawi Toll Road is still focused on aesthetical aspects instead of the carbon absorption ones. The Carbon Capture approach is a relatively new concept that integrates aesthetic elements with climate change mitigation. However, it is often overlooked by Public Open Space (POS) planners, as most Green Open Space (GOS) development plans continue to prioritize aesthetic aspects over environmental benefits.

The “green belts” in the Jagorawi Toll Road has a diverse range of plants such as acacia (Acacia mangium), butterfly flower (Bauhinia purpurea), and royal palm (Roystonea regia) among others. Despite the diversity of plants planted on the green belt, the plants are not considered those with a high carbon absorption.

There is still a lack of observations that calculate how much a GOS can absorb $CO_2$ in detail, hindering the achievement of the national target of greenhouse gas emissions reduction by 29%. One example is the observation on the GOS planning along the roadsides in Medan conducted by (Hilma *et al.*, 2023) which aims to improve air quality and to reduce rainwater. Despite the study does consider air quality improvement in the city, the research lacks the emphasis on the carbon capture by the vegetation settling within the GOS.

As GOS is heavily connected to the government of Indonesia’s program in reducing greenhouse gas emission, this research is designed to realize the development of sustainable green infrastructure in form of Carbon Capture-based GOS development planning within the Toll Road area. Following the Carbon Capture concept, this research focuses on the GOS development planning which takes place in Jagorawi Toll Road that emphasizes the capability of carbon absorption and combines the element with aesthetical aspects.

## 2 THEORETICAL FRAMEWORK

### 2.1 PLANTING PLAN

The landscaping of toll road corridors is an integral part of toll road development. Various criteria are considered for the landscaping plan along the Jagorawi Toll Road corridor, such as:

1. Vegetation should effectively absorb $CO_2$. This criterion aligns with SDG 13, "Climate Action," aiming to mitigate greenhouse gas (GHG) emissions. In this study, the reduction of GHG is approached naturally by selecting specific vegetation. This method also supports the Indonesian government's commitment to lowering GHG emissions as per Government Regulation No. 16/2016, which ratifies the Paris Agreement under the United Nations Framework Convention on Climate Change.
2. The landscape plan must prioritize safety (Urban Design Roads and Waterways, 2023). The landscape should ensure safety during construction, maintenance, and use. It should also promote safer driving behavior by incorporating elements such as:
   a) Ensuring safe sight distances in line with design speed;
   b) Protecting fast-moving vehicles from tree collisions through separation or barriers;
   c) Enhancing road safety;
   d) Using median strip planting to reduce headlight glare;
   e) Employing ground cover plants to suppress weeds in visible areas;
   f) Offering visual cues to drivers to signal road alignment and appropriate speeds;
   g) Improving driver behavior and alertness through thoughtful planting.
3. The landscape plan should be ecologically responsible (Urban Design Roads and Waterways, 2023). The design aims to restore and strengthen local habitats, manage stormwater runoff by shaping the terrain, select appropriate species, and reduce waste and pollution during construction and maintenance.

Vegetation choices are guided by considerations like topography (Booth, 1983), available space, adequate light and water, suitable temperatures, and soil type (Iles, 2001).

4. The landscape should enhance the character and value of the built environment (Urban Design Roads and Waterways, 2023). People spend significant time traveling, and their impression of a destination is influenced by the journey, including road conditions. Thus, the landscape should elevate the environmental quality and enhance the travel experience.
5. The landscape plan should be cost-effective (Urban Design Roads and Waterways, 2023). Plant selections take into account sustainable maintenance costs, with the aim of reducing long-term operational expenses for the management.

## 2.2 GHG EMISSION IN THE TOLL ROAD

21 Greenhouse gases (GHGs) are atmospheric gases that trap solar heat, contributing to the warming of the earth. The trapping of the solar heat leads to the greenhouse effect which occurs in a natural manner and has an essential role in keeping the planet warmer for the survival of human beings.

Some of the GHGs 15 are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide (N2O), and fluorinated gases. These gases lead to the increase of the temperature of the earth, becoming contributors to global warming and eventually climate change. As such, there is a call for actions to reduce emissions from these gases to mitigate environmental impacts and to support environmental sustainability.

According to McGrath *et al.*, (2023), GHGs emitted 18 into the Earth's atmosphere can create a "greenhouse effect," whereby heat is trapped, resulting in a rise in global temperatures. Although emissions can arise from natural sources, the predominant contributors 10 are human activities, especially the burning of fossil fuels for energy and transportation. A significant source of $CO_2$ emissions comes from mobile vehicles. However, the extent of these emissions is influenced by the type of fuel utilized in the vehicles (Miwa, 2006).

## 2.3 $CO_2$ ABSORPTION

There are several types of $CO_2$ absorption methods used for carbon capture, among others (1) Biological absorption. This natural process involves plants, trees, and other photosynthetic organisms capturing $CO_2$ from atmosphere (Prajapati *et al.*, 2023), (2) Chemical absorption. This method uses chemical solvents to capture $CO_2$ from industrial emissions (Kothandaraman, 2010), (3) Physical absorption. This technique relies on the solubility of $CO_2$ in a liquid solvent without a chemical reaction. It is typically used in high-pressure environments where $CO_2$ has a higher solubility in the solvent (Zhenhong *et al.*, 2014), (4) Adsorption. This method uses solid materials, such as activated carbon or zeolites, to capture $CO_2$ from gas streams (Debbie Soo, 2024), and 5) Mineral sequestration. This involves reacting $CO_2$ with minerals to form stable carbonates. This process can permanently store $CO_2$ in solid form, such in underground geological formations (Molahid, at.al., 2022).

This research plans the arrangement of plants planted within the Jagorawi Toll Road GOS, enabling the toll road to absorb $CO_2$ optimally. Naturally, carbon absorption can be done by vegetation consisting of specific plants. Each plant has a different carbon absorption capacity, depending on the morphology of its leaves (Yohanes *et al.*, 2023). The rate of $CO_2$ absorption is also influenced by the age and the location of the leaves. In this research, plants that will be planted within the GOS are those that possess a high absorption capacity. (Yohanes *et al.*, 2023).

## 3 METHODOLOGY

### 3.1 RESEARCH AREA

The study takes place in Jagorawi Toll Road. Specifically, the study is conducted in the Cibinong-Bogor segment (Segment 3 – Segment 6) of the toll road at STA 26,500 – 43,500. The segment has a total length of 17 Km. The research area is shown in Figure 1 as follows.

**Figure 1.**
*Research area location*


Inaugurated on March 9th, 1978, the Jagorawi Toll Road is the first highway built in Indonesia and connects Jakarta-Bogor-Ciawi. The highway is regarded as a busy roadway with around 9,000 vehicles making a 37-mile journey/day (or a 25 mile journey/day during congestion) (USAID, 2024).

## 3.2 DATA COLLECTION

The data collected is categorized into two types: primary data and secondary data.

### 3.2.1 PRIMARY DATA

The primary data is obtained from the observation of the current conditions of (i) types and quantities of the vegetation that settle within the GOS and their quantities (Table 1) and (ii) data on daily traffic within the research area (Table 2) Based on observation, it was reported that there are 9,588 trees settled within the GOS, consisting of 24 species. The detailed information on the types and the quantities of the existing vegetation can be seen on Table 1.

**Table 1.**

*Types and quantities of existing vegetation in 2024*

| No. | Species | Quantity |
|---|---|---|
| 1 | *Acacia mangium* | 150 |
| 2 | *Pterocarpus indicus* | 28 |
| 3 | *Dracaena* | 446 |
| 4 | *Cerbera odollam* | 646 |
| 5 | *Casuarina equisetifolia* | 33 |

| No. | Species | Quantity |
|---|---|---|
| 6 | *Erythrina crista-galli* | 263 |
| 7 | *Tectona grandis* | 67 |
| 8 | *Leucosyke capitellata* | 17 |
| 9 | *Plumeria* | 75 |
| 10 | *Caesalpinia pulcherrima* | 129 |
| 11 | *Hibiscus rosa-sinensis* | 33 |
| 12 | *Terminalia mantaly* | 3,130 |
| 13 | *Bauhinia purpurea* | 558 |
| 14 | *Leucaena leucocephala* | 37 |
| 15 | *Swettiana mahagoni* | 374 |
| 16 | *Pometia pinnata* | 50 |
| 17 | *Caesalpinia pulcherrima* | 400 |
| 18 | *Maniltoa grandiflora* | 58 |
| 19 | *Duranta erecta* | 17 |
| 20 | *Spathodea campanulata* | 116 |
| 21 | *Brugmansia (yellow)* | 643 |
| 22 | *Brugmansia (rosea)* | 1,377 |
| 23 | *Cordyline fruticosa* | 300 |
| 24 | *Samanea saman* | 643 |

The research takes a place in Segment 3 – Segment 6. The observed segments reportedly generated 235,000 trips per day in June 2024. Detailed information on the daily traffic within the research area can be seen on Table 2 below:

**Table 2.**

*Daily traffic within the research area in June 2024*

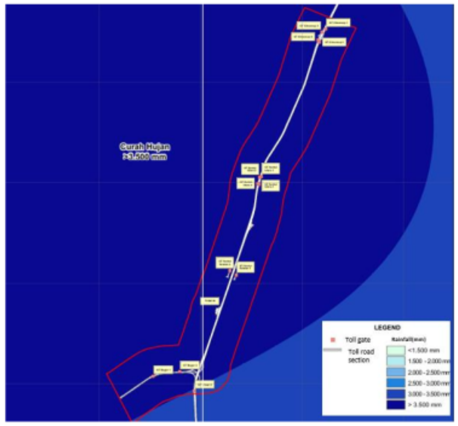
| No. | Segment | Distance (Km) | Daily Average Traffic |
|---|---|---|---|
| 1 | Segment 3: G.Putri-Citeureup (Km. 23+800 s.d Km. 27+100) | 3,300 | 22,456 |
| 2 | Segment 4: Citeureup -Sentul (Km. 27+100 s.d 32+800) | 5,700 | 27,119 |
| 3 | Segment 5: Sentul-Sentul Selatan (Km. 32+800 s.d Km. 36+700) | 3,900 | 56,614 |
| 4 | Segment 5: Sentul Selatan-Ciawi Gadog/Bogor (Km. 36+700 s.d Km. 44+500) | 7,800 | 129,139 |
| Total | | 20,700 | 235,329 |

### 3.2.2 SECONDARY DATA

The study uses secondary data on rainfall conditions (Fig. 2), types of soils (Figure.3), topography conditions (Figure 4), and other aspects. The secondary data is purposeful to explain current land physical characteristics, on which the quality and the land use of the land observed are assessed.

**Figure 2.**

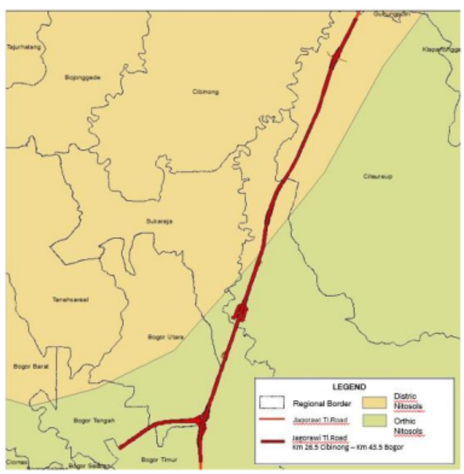
*Rainfall conditions*




The rainfall occurs in the research area at an average 3,500 mm per year. Therefore, the most suitable plants for this environment are those that can withstand high humidity and are resilient to diseases associated with excessive moisture.

**Figure 3.**

*Soil conditions*

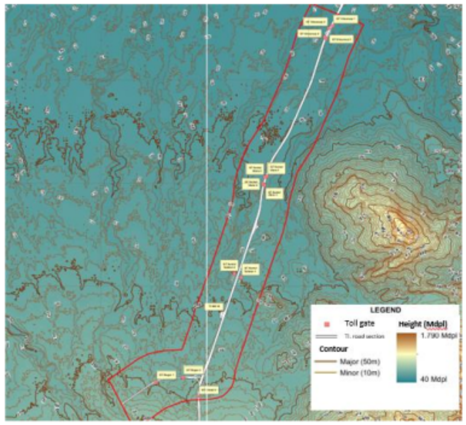



From the soil map, it was observed that the Jagorawi Toll Road from the KM 26,500 Cibinong – Km 43,500 Bogor is developed on two types of soils: Acrisols and Nitosol. During dry season, these types of soils often accumulate, resulting in both less fertile and fertile soils. These soils are often referred to as Red-Yellow Podzolic

Soils. The Red-Yellow Podzolic Soils have a crucial role in agricultural and plantation businesses as well as the purpose of greening such as the development of the green belts in the toll road area.

**Figure 4.**

*Topography conditions*




As observed from the topography and the soil conditions in Jagorawi KM 26,500 – KM 43,500, lowlands still exist within the observed area. In such conditions and lands, a sizable number of vegetation can grow with an exception of swamp-coastal vegetation such as Mangrove.

3.3 RESEARCH STAGES

This research consists of two main stages: 1.) The GOS Planning on the Jagorawi toll road that can fulfill ecological, socio-cultural, economic, and aesthetic functions, specifically the $CO_2$ emission absorption (planning stage), and 2.) Assessment on the GOS' capability in absorbing carbon. Each stage fits the objectives of this research (assessment stage).

The planning stage is done by assessing the suitability of various plants with their respective criteria with the physical characteristics of the planning area. The planning stage is expected to result in a landscape design map along with a list of suitable vegetation and quantities of vegetation to be planted within the GOS.

The assessment is carried out by collecting primary and secondary data through data gathering. The assessment is carried out by calculating: (1) Trees' $CO_2$ absorption capacity, (2) $CO_2$ emitted by vehicles driving through the 26,500-43,500 km section of the Jagorawi Toll Road.

### 3.4.1 PLANNING STAGE

In this stage, researchers select suitable types of vegetation to be planted on the Jagorawi Toll Road green belts. The criteria are as follows:

1) Possesses medium and high absorption;
2) Suits soil physical characteristics including topography, climate, types of soils, and other characteristics;
3) Functions as the corridor builder and improves road aesthetic aspects;
4) The vegetation can be planted on roadsides and other green areas based on the diameter of the canopy (big, medium, and small).

### 3.4.2 CALCULATION STAGE

In this stage, researchers will assess the absorption capabilities of vegetation. The stage is conducted as follows:

**Stage I: Calculation Stage ($CO_2$ Absorption)**

In this stage, researchers will calculate the $CO_2$ absorption of the trees that will be planted within the research area.

**Stage II: Calculation Stage ($CO_2$ Emission)**

In this stage, researchers will calculate the quantities of $CO_2$ emitted by vehicles driving through the research area.

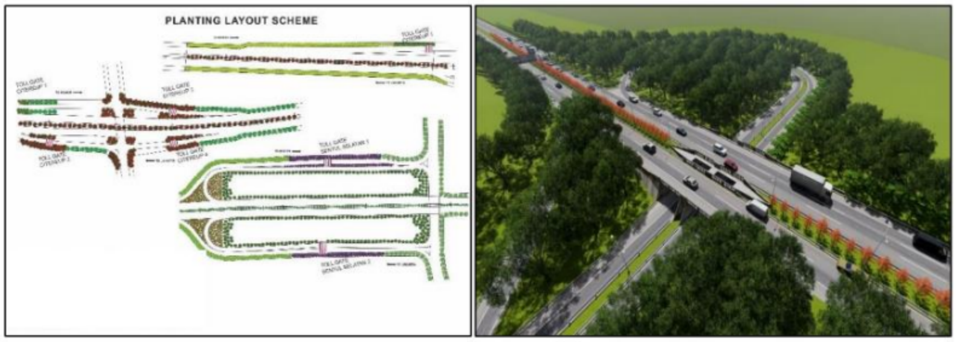
## 4 RESULTS AND DISCUSSIONS

### 4.1 PLANNED LAYOUT

Based on the criteria which describe that the vegetation that will planted within the research area is plants that possess medium-high absorption, suit soil physical characteristics including topography, climate, types of soils, and other characteristics, function as the corridor builder and improve road aesthetic aspects, and can be planted on roadsides and other green areas based on the diameter of the canopy (big, medium, and small), the quantities of planted trees are set at 10,197 trees. The planned plant layout can be seen in Figure 5 below.

**Figure 5.**

*Planned layout scheme.*




The 2D render

The 3D render

The plant plan also considers the aesthetic aspects and the formation of road corridor spaces. Small trees are placed in the green junction lane so as not to obstruct the driver's line of sight. On the other hand, large-sized trees are placed in the outermost roadside of the green belts and arranged in gradient. Lastly, medium-sized trees and small-sized plants are planted closer to the roadside shoulder.

The list of tree species, along with their $CO_2$ absorption capacity (annual and daily), can be seen in Table 3 below.

**Table 3.**

*Tree species with their $CO_2$ absorption capacity (annual and daily)*

| No. | Species | Annual $CO_2$ Absorption Capacity (kg/tree/year) | Daily $CO_2$ Absorption Capacity (kg/tree/year) |
|---|---|---|---|
| 1 | *Acacia mangium* | 15.19 [a] | 0.04 |
| 2 | *Pterocarpus indicus* | 11.12 [a] | 0.03 |
| 3 | *Dracaena* | 0.39 [b] | 0.001 |
| 4 | *Cerbera manghas* | 27.91 [c] | 2.32 |
| 5 | *Casuarina equisetifolia* | 45.00 [b] | 0.12 |
| 6 | *Erythrina crista-galli* | 4.55 [a] | 0.01 |
| 7 | *Tectona grandis* | 135.27 [a] | 0.37 |
| 8 | *Leucosyke capitellata* | 1.03 [d] | 0.003 |
| 9 | *Plumeria* | 44.00 [b] | 0.12 |
| 10 | *Caesalpinia pulcherrima* | 30.95 [a] | 0.08 |
| 11 | *Tiliparitiitiliaceum* | 1.61 [e] | 0.05 |

| No. | Species | Annual $CO_2$ Absorption Capacity (kg/tree/year) | Daily $CO_2$ Absorption Capacity (kg/tree/year) |
|---|---|---|---|
| 12 | *Terminalia mantaly* | 23.48[b] | 0.06 |
| 13 | *Bauhinia purpurea* | 1,280.68 [e] | 3.56 |
| 14 | *Leucaena leucocephala* | 1,425.60 [g] | 3.96 |
| 15 | *Swettiana mahagoni* | 295.73 [a] | 0.82 |
| 16 | *Pometia pinnata* | 329.76 [a] | 0.91 |
| 17 | *Caesalpinia pulcherrima* | 30.95 [a] | 0.08 |
| 18 | *Maniltoa grandiflora* | 8.26 [a] | 0.02 |
| 19 | *Duranta erecta* | 0.25[b]) | 0.001 |
| 20 | *Spathodea campanulat* | 211.64 [f] | 0.59 |
| 21 | *Tabebuia rosea* | 209.09 [g] | 0.58 |
| 22 | *Tabebuia rosea* | 209.09 [g] | 0.58 |
| 23 | *Cordyline fruticosa* | 0.25 [b] | 0.001 |
| 24 | *Samanea saman* | 28,448.39 [a] | 79.02 |
| 25 | *Cassia fistula* | 5,295.47 [a] | 14.71 |
| 26 | *Oleana syzyygium* | 123.87 [b]) | 0.34 |
| 27 | *Adenanthera pavoniana* | 221.18 [a] | 0.61 |
| 28 | *Schima wallichii* | 63.31 [a] | 0.17 |
| 29 | *Filicium decipiens* | 404.83 [a] | 1.12 |
| 30 | *Michelia champaca* | 8,280.00 [h] | 23.00 |
| 31 | *Manilkara kauki* | 36.19 [a] | 0.10 |
| 32 | *Canarium SP* | 8,280.00 [h] | 23.00 |
| 33 | *Bougainvillea spectabills* | 0.25 [b] | 0.001 |
| 34 | *Mimusops elengi* | 34.29 [a] | 0.09 |
| 35 | *Polyalthia longifolia* | 6,304.92 [f] | 17.51 |
| 36 | *Ficus benjamina* | 1,255.40 [b] | 3.49 |

Source: Dahlan, 2007 [a], Febriansyah *et al.*, 2022 [b], Aindo *et al.*, 2023 [c], Wikansari & Nurjani, 2018 [d], Nursyahbandi *et al.*, 2020 [e], Marisha, 2018 [f], Roshintha & Mangkoedihardjo, 2016 [g]

The types of species and quantities of vegetation to be planted within the research area are seen in Table 4.

**Table 4.**

*Planned types and quantities of vegetation to be planted within the research area.*

| No. | Species | Quantity | Percentage |
|---|---|---|---|
| 1 | *Oleana syzygium* | 2,266 | 22% |
| 2 | *Caesalpinia pulcherrima* | 1,648 | 16% |
| 3 | *Samanea saman* | 1,241 | 12% |
| 4 | *Cassia fistula* | 1,210 | 12% |
| 5 | *Terminalia mantaly* | 1,033 | 10% |
| 6 | *Bauhinia purpurea* | 869 | 9% |
| 7 | *Schima wallichii* | 380 | 4% |
| 8 | *Cerbera manghas* | 324 | 3% |
| 9 | *Bougainvillea* | 320 | 3% |

| No. | Species | Quantity | Percentage |
|---|---|---|---|
| 10 | *Filicium decipiens* | 229 | 2% |
| 11 | *Pometia pinnata* | 201 | 2% |
| 12 | *Erythrina crista-galli* | 197 | 2% |
| 13 | *Canarium Sp.* | 172 | 2% |
| 14 | *Mimusops elengi* | 73 | 1% |
| 15 | *Polyalthia longifolia* | 34 | 0% |
| Total | | 10,197 | 100% |

Quantities of species that will be planted within the research area are 15 types or equal to 10,197 trees. There are 5 trees that possesses above 10% percentage: Oleana syzyygium (22%), Caesalpinia pulcherrima (16%), Samanea saman (12%), Cassia fistula (12%), and Terminalia mantaly (10%). These five trees possess adequately high $CO_2$ absorption. In addition to the capacity of absorbing $CO_2$, other factors that are topography, climate suitability, and types of soils are also considered. Selection of the vegetation is also based on criteria such as enhancing the road visual aesthetics, acting as a composition for the roadside tree strata, forming the road corridor spaces, acting as the road guidance, and etc. as seen in Table 5.

**Table 5.**

*Criteria for the selection of vegetation.*

| No. | Species | Function |
|---|---|---|
| 1 | *Caesalpinia pulcherrima, Bougainvillea sp.* | Flowering plant. Enhancing the road visual aesthetics |
| 2 | *Oleana syzygium, Schima wallichii* | Foilage plant. Enhancing the road visual aesthetics |
| 3 | *Erythrina crista-galli* | Flowering tree. Acting as a composition for the roadside tree strata. |
| 4 | *Cerbera manghas* | Acting as a composition for the roadside tree strata. |
| 5 | *Pometia pinnata, Cassia fistula* | Large-sized tree, Forming the road corridor spaces. |
| 6 | *Bauhinia purpurea* | Flowering tree. Acting as a composition for the roadside tree strata. |
| 7 | *Terminalia mantaly* | Pyramid-shaped tree. Acting as the road guidance. sebagai pengarah jalan |
| 8 | *Polyalthia longifolia* | Columnar-shaped tree. Forming the road corridor spaces. |
| 9 | *Canarium sp.* | Large-sized tree. Bogor's landmark. |
| 10 | *Filicium decipiens, Mimusops elengi* | Forming the road corridor spaces. |
| 11 | *Samanea saman* | Large-sized tree. Acting as a shade tree capable of creating a microclimate. |

### 4.2. ASSESSMENT STAGE

#### 4.2.1 CALCULATION OF TREES' ABSORPTION CAPACITY

The total $CO_2$ absorption capacity of the trees is obtained by calculating the results of multiplying the quantities of trees by the absorption capacity of each tree (Equation 1) (Febriansyah *et al.*, 2022)

$$\sum_{i}^{n} = V_i \, x CAC_i \tag{1}$$

where:
Vi= quantities of vegetation settled
CACi= carbon ($CO_2$) absorption capacity

Referring to the planned plant, the number of trees to be planted within the research area consists of 15 species, meaning 10.197 trees in total (Table 4). As such, the total $CO_2$ absorption capacity of the trees in the GOS within the research area reaches 125,769.839 kg/day. The $CO_2$ absorption capacity of each tree is seen in Table 6 as follows.

**Table 6**

*Trees' absorption capacity.*

| No. | Species | Quantity | Annual $CO_2$ Absorption kg/tree/day | Daily $CO_2$ Absorption kg/day | |
|---|---|---|---|---|---|
| | | | | Kg/day | % |
| 1 | *Caesalpinia pulcherrima* | 1,648 | 0.08 | 141.68 | 0.11 |
| 2 | *Oleana syzyygium* | 2,266 | 0.34 | 779.69 | 0.62 |
| 3 | *Schima wallichii* | 380 | 0.17 | 66.83 | 0.05 |
| 4 | *Bougainvillea* | 320 | 0.001 | 0.22 | 0.00 |
| 5 | *Erythrina crista-galli* | 197 | 0.013 | 2.49 | 0.00 |
| 6 | *Cerbera manghas* | 324 | 2.32 | 753.49 | 0.60 |
| 7 | *Pometia pinnata* | 201 | 0.91 | 184.11 | 0.15 |
| 8 | *Cassia fistula* | 1,210 | 14.71 | 17,798.7 | 14.15 |
| 9 | *Bauhinia purpurea* | 869 | 3.56 | 3,091.42 | 2.46 |
| 10 | *Terminalia mantaly* | 1,033 | 0.06 | 67.37 | 0.05 |
| 11 | *Polyalthia longifolia* | 34 | 17.51 | 595.46 | 0.47 |
| 12 | *Canarium Sp.* | 172 | 23.00 | 3.95 | 3.15 |
| 13 | *Filicium decipiens* | 229 | 1.12 | 257.52 | 0.20 |
| 14 | *Mimusops elengi* | 73 | 0.09 | 6.95 | 0.01 |
| 15 | *Samanea saman* | 1,24 | 79.02 | 98,067.93 | 77.97 |
| Total | | 10,197 | | 125,769.84 | 100% |

Table 6 shows that the total $CO_2$ absorbed by the green belts within the research area is amounted at 125,769.84 kg/day. From the table, the Samanea saman possesses the highest absorption percentage of 77.97%.

### 4.2.2 CALCULATION OF $CO_2$ EMITTED BY VEHICLES

Mobile sources such as vehicles are known to emit direct greenhouse gas emissions such as carbon dioxide ($CO_2$), methane ($CH_4$), and nitrogen oxide (N2O). These gas emissions result the combustion of various fuels and other pollutants such as carbon monoxide (CO), Non-methane Volatile Organic Compounds (NMVOC), sulfur dioxide ($SO_2$), particulates (PM) and nitric oxide (NOx), all contributing to local/regional air pollution.

This research is focused on the calculation of one greenhouse gas emission of carbon dioxide ($CO_2$) which can be assumed by fuel consumption or the distance covered by vehicles. The amount of $CO_2$ emitted by vehicles driving through the research area is obtained by multiplying the fuel sold with the emission factor as shown in equation 2 as suggested by Miwa (2006) as follows:

$$\boxed{Emission = \sum_a [Fuel_a \bullet EF_a]} \tag{2}$$

where:

Emission= Emission of $CO_2$ (kg)

$Fuel_a$= Fuel sold (TJ)

$Ef_a$= Emission factor (kg/TJ)

a= Type of fuel

Based on the calculation using the equation 2, the amount of $CO_2$ emitted by vehicles crossing the study area can be seen in Table 7.

**Table 7.**

*Trees' absorption capacity.*

| Segment | Vehicle Quantity (Unit) | Road Length (Km) | Fuel Consumed (L) | Energy Conversion (TJ) | $CO_2$ Emission Factor (Kg/TJ) | Total $CO_2$ Emitted (Kg) |
|---|---|---|---|---|---|---|
| Segment 3 G.PUTRI - | 22,456 | 3.30 | 9,263.25 | 0.30 | 69,300 | 21,184 |

| Segment | Vehicle Quantity (Unit) | Road Length (Km) | Fuel Consumed (L) | Energy Conversion (TJ) | $CO_2$ Emission Factor (Kg/TJ) | Total $CO_2$ Emitted (Kg) |
|---|---|---|---|---|---|---|
| CITEUREUP | | | | | | |
| Segment 4 CITEUREUP -SENTUL | 27,119 | 5.70 | 19,322.54 | 0.64 | 69,300 | 44,189 |
| Segment 5 SENTUL - SOUTH SENTUL | 56,614 | 3.90 | 27,599.14 | 0.91 | 69,300 | 63,116 |
| Segment 6 S. SENTUL - CIAWI GADOG/ BOGOR | 129,139 | 7.80 | 125,910.88 | 4.15 | 69,300 | 287,946 |
| TOTAL | 235,329 | 20.7 | 182,095.83 | 6.00 | | 416,435 |

The total $CO_2$ emissions produced by as high as 235,000 vehicles driving through the research area daily reach as high as 416,000 Kg/day. The highest emissions are produced by vehicles driving through the South Sentul area towards Gadog/Bogor. Assumptions used in the calculation of $CO_2$ emitted by vehicles driving through the research area are as follows:

1) The average vehicle driving through the research area is a minibus.
2) The average vehicle uses gasoline as fuel.
3) The fuel consumption for the minibus type is 8 Km/Liter (Suhardi & Febrina, 2013).

## 5 CONCLUSION

The carbon absorption-based GOS planning within the Jagorawi Toll Road corridors results in a plan to plant 10,197 trees settled in the GOS with the total trees' carbon absorption capacity reaching 125,769/83 kg/day. From the emission calculation, it appears that the vehicles driving through the Segment 3-6 of the Jagorawi Toll Road emit a total 416,436 kg/day of $CO_2$. Comparing both calculations, the GOS is capable of absorbing as high as 33% of the total $CO_2$ emissions emitted by the vehicles driving through segment 3-6 of the Jagorawi Toll Road. Based on the results, the planned GOS is expected to contribute to the Government program in the GHG emission reduction as stipulated in Law No.16/2016 concerning The Ratification of the Paris Agreement to the United Nations Framework Convention on Climate Change in

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which the Government has set a commitment to reduce GHG emissions to 29% in 2030.

In addition, the total $CO_2$ absorbed by the green belts within the research area happens to be larger than that of the existing trees. As seen in Table 1, the quantity of trees currently planted within the research area is 9,558. By using the same equation as the previous (Equation 1), the total $CO_2$ absorbed by the existing trees settled in the research area reaches 56,342.004 kg/day. Comparing with the total $CO_2$ emitted by the vehicles driving through the research area, the existing trees only absorb 13.53% of the total emissions. As such, the planting layout scheme proposed in this research is assumed to be capable of absorbing $CO_2$ emitted by the vehicles driving through the research area twice higher than that of the existing layout.

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