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GREEN ROAD VEGETATION CO_2 SEQUESTRATION POTENTIAL ON TRANSPORTATION CO_2 EMISSIONS (CASE STUDY: JALAN JAGIR WONOKROMO, SURABAYA)

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ABSTRACT

Green Road Vegetation CO_2 Sequestration Potential on Transportation Co_2 Emissions. Transportation is one of the anthropogenic activities that emit CO2. Its existence is essential for human mobilization, which causes the need for mitigation and solutions that can support the continuity of activities while minimizing the impact of emissions. In this case, the green belt of Jalan Jagir Wonokromo contains a mixture of road protection and CO2-absorbing vegetation that can reduce emissions. For this reason, a study was conducted to determine the CO2 absorption potential of green belt vegetation to provide information and a reference for optimizing green open space. The research was conducted using a quantitative descriptive method, which included measuring road ambient CO2 concentrations, calculating vehicle volume, measuring breast height diameter as a biomass component, and researching correcting CO2 absorption by vegetation. According to the research results, the average ambient concentration of CO2 on roads is 785 mg/m3. The transport CO2 concentration was calculated using a Tier II approach and yielded a value of 186.87 kg/hour, contributing 79% to the ambient CO2 concentration. Furthermore, a box model is used to analyze the concentration of CO2 that will be absorbed by vegetation, resulting in 103.47 tons per year. Meanwhile, the ability to absorb CO2 from vegetation is 152.74 tons/year after being corrected by a pilot-scale study that considers vegetation's age and physiological factors. All emissions on Jalan Jagir Wonokromo can still be absorbed by vegetation, but optimization needs to be done in the form of intensification, extensification, and mitigation.

INTRODUCTION

Jalan Jagir Wonokromo is a secondary arterial road with high traffic density, which directly influences motor vehicle CO2 emissions as the largest contributor to CO2 emissions compared to other sources. Increasing CO2 concentrations have an impact on changes in environmental conditions, such as climate instability and rising temperatures. On the other hand, transportation is an important part of human activity that supports mobilization from one place to another, so mitigation is needed that is able to support the sustainability of transportation activities while minimizing the impact of emissions.

The availability of green open space is the ideal solution and mitigation for this issue; its presence in urban areas serves as a balance between land activity and ecological conditions [1], with its diverse vegetation capable of absorbing carbon through photosynthesis [2]. Green lanes, which are green open spaces located on roadsides, road medians, and road islands, play a significant role in absorbing and reducing transportation CO2 emissions. However, its ability is influenced by the amount of CO2 emissions generated by motor vehicles and the composition of the vegetation that makes it up [3, 4].
The selection of green belt vegetation types in Surabaya has been adapted to the directional functions of adequate absorption of pollutant emissions, reduction of pollutants, and minimizing noise. [5]. However, previous research conducted on Jalan Ahmad Yani analyzed the adequacy of the green belt, revealing that the remaining CO2 emissions, amounting to 158,081.58 tons per year, had not been absorbed by vegetation. Meanwhile, another study on Jalan Ir. Soekarno, which divided the road into three segments, found residual CO2 emissions of 6.74 gr/second in one segment and successful absorption in the other two segments. [7]. As a result, it can be concluded that the green lane CO2 emission absorption capacity on roads in the city of Surabaya has not been optimized equally. For this reason, carrying out research on Jalan Jagir Wonokromo is needed as a review of the CO2 absorption capacity of the green lane and to select strategies for optimizing CO2 emission absorption on primary arterial roads.

MATERIALS AND RESEARCH METHODS

Time and Location of Research

The research was conducted for one month, from the end of March to the end of April 2023. The data collection location was Jl. Jagir Wonokromo, which is 300 m long and based on Surabaya City Regional Regulation No. 07 of 2003. It is a secondary arterial road with heavy traffic, so it meets the location qualifications for monitoring mobile source air quality according to Minister of Environment Regulation No. 12 of 2010.

Transportation Emissions Research

1. Vehicle Volume Calculation
   There are 2 sampling time periods in one day, namely morning 08.00 – 09.00 WIB and afternoon 16.00 – 17.00 WIB.
2. Ambient CO2 Concentration Measurement
   Ambient CO2 concentration is measured using an electrochemical sensor gas analyzer that has been calibrated and provides real-time data. Ambient concentration measurements were carried out based on SNI 19-7119.9-2005.
3. Monitoring Meteorological Conditions
   Monitoring of meteorological conditions is carried out based on SNI 19-7119.9-2005.

Vegetation CO2 Uptake Research

1. Vegetation Identification
   Identification of vegetation in plots is based on the Biodiversity Report by the Environmental Service for 2021. Individual vegetation is observed for its morphology and its type is determined using PlantNet software and related vegetation literature.
2. Breast Height Diameter Measurement
   *Breast height diameter*measured for the level of poles, stakes, and trees at breast height using a phi band or tree meter that has been scaled in diameter[8].
3. Pilot Scale Leaf CO2 Absorption Research
   A sample of one individual new vegetation that can represent the type of green belt vegetation on Jalan Jagir Wonokromo. The sample was put into a closed reactor measuring 50 cm x 50 cm x 80 cm and then injected with CO2[9].

4. Measurement of Leaf Thickness and Stomata Density
   The leaf samples were cleaned using a tissue and then cross-sections were made on the leaf samples using a cutter. The preparations were observed under a microscope with an objective and ocular micrometer with a calibration of 40 x 10, leaf thickness was measured by multiplying the measurement results by the micrometer magnification.(10).

Analysis

1. **Generation of Tier II CO2 Emissions**

   Q=Ni x Fei x Ki x L (1)

   Information :
   Q= Total CO emissions $_2$(gr/hour)
   Ni= Number of motorized vehicles (vehicles/hour)
   Fei= CO emission factor $_2$motorized vehicles (gr/liter)
   Ki= Vehicle fuel consumption (liters/km)
   L= Length of road (km)
2. **Box Models**

   $$C(t) = \frac{qL}{UH}\ (1 - e^{\frac{Ut}{L}}) \quad (2)$$

   Information :
   C(t) = Pollutant concentration (mg/m ^{3})
   q= Average pollutant emissions per area (mg/m^2)
   L= Length of box (m)
   H= Tree height (m)
   U= Average wind speed (m/sec)
   t= Travel time (seconds)

3. **Biomass**
   W = 0.11 x ρ x Dbh$^{2.62}$ (3)

   Information :
   P= Specific gravity of wood (gr/cm3)
   Dbh = Chest height diameter (cm).

4. **Stored Carbon**
   Cb=W x % organic C (4)

   Information :
   Cb= Stored carbon content (kg)
   W= Total biomass (kg)
   % organic C = Percentage carbon content of 0.47.
5. **Carbon Uptake**

   CO2= Cb x 3.67 (5)
   Information :
   CO2 = Carbon uptake (kg)
   Cb= Stored carbon content (kg)
   3.67= Equivalence number for the element carbon (C) to CO $_2$
   [atomic mass C = 12 and O = 16, CO2 (1x12) + (2x16) = 44;

conversion(44:12) = 3.67].

6. **O2 potential**

   O2= Cb x 2.67 [6]

   Information :

   O2 = Net oxygen production (kg/year)

   Cb= Net carbon stocks (kg/year)

   2.67 = Equivalent number for the element carbon (C) to O_2

7. **CO2 Absorption Potential**

   The availability of green open space is calculated using the following equation[11]:

   Adequacy of green open space: CO2 absorption (tons/ha/year) – CO2 emissions (tons/year)

RESEARCH RESULTS AND DISCUSSION

Ambient CO2 Concentration

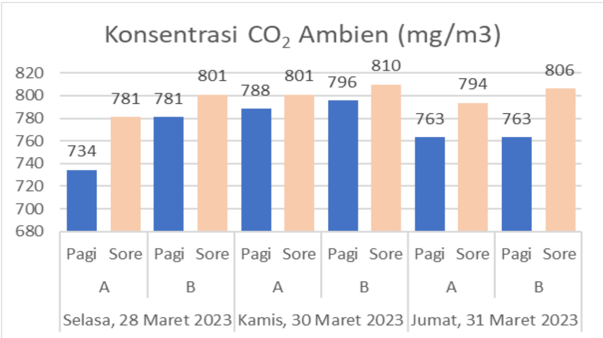

Figure 1. Ambient CO2 concentration on Jalan Jagir Wonokromo
(Source: Research Data)

The average CO2 concentration is 845 mg/m3, which indicates that the air quality on Jalan Jagir Wonokromo is still within normal limits for human activity. The highest CO2 concentration on Jalan Jagir Wonokromo was at Thursday afternoon sampling point 2, with a level of 872 mg/m3, and the lowest concentration was at Monday morning sampling point 1, with a level of 791 mg/m3. Ambient CO2 concentration levels are influenced by meteorological factors, vehicle density, and land use around the sampling point. This concentration is consistent with research on three routes, including roads in the city of Bandung, which states that roads have concentrations ranging from 400 to 900 ppm, or the equivalent of 755–1743 mg/m3 [12].

The difference in CO2 concentrations in the morning and evening is influenced by meteorological conditions, which change in both time periods. Furthermore, if it is related to the ability of the surrounding vegetation to absorb CO2, the ambient CO2 concentration can be absorbed more in the morning because the vegetation uses CO2 in the photosynthesis process, which is then supported by the presence of sunlight so that the process runs continuously. [13]. In the afternoon, CO2 absorption by vegetation gradually decreases in line with the minimum intensity of sunlight because the rate of photosynthesis is directly proportional to sunlight. [14].

Tier II CO2 concentration

Table 1. Tier II CO2 concentration

Transportation type	Amount	Road length (km)	Emission factor (gr/l)	Fuel consumption (liters)	CO2 concentration (g/hour)	CO2 concentration (mg/s)	Total concentration (kg/hour)
Motorcycle	3933	0.3	2390	0.03	73318.99	20366,385	
Gasoline car	1004	0.3	2390	0.12	84865.39	23573.72	
Solar car	156	0.3	2700	0.11	14309.19	3974.77	186.87
Bus	3	0.3	2700	0.17	430.92	119.7	
Truck	93	0.3	2700	0.19	13948.61	3874.61	

(Source: Research Data, 2023)

Vehicles on the Wonokromo Jagir Road generated an average of 186.87 kg/hour of total monthly carbon dioxide emissions. The order of vehicles with the highest monthly emissions contribution is gasoline cars, motorcycles, solar cars, trucks, and buses. It's influenced by each vehicle's fuel consumption. According to a study by Nurjanah (2014), cars contributed the most to the generation of CO2 emissions, with a volume of 141.50 kg/hour, surpassing that of motorcycles, which produced only 82.85 kg/h. However, when analyzed in quantity, motorcycles contributed more than cars.

Box Model

Table 1. CO2 Box Concentration Model

Type	Concentration Type
Ambien	130454,54
Tier II	103478,66

(Source: Research Data, 2023)

The contribution of the estimated carbon dioxide (CO2) moon with the Tier II method to the environmental concentration of CO2 is at an average level of 79% of the environment's CO2 moon, which means that the other 21% comes from other human activities such as offices and settlements that are also present at the sampling site. Meanwhile, if the reduction in the concentration of carbon dioxide (CO2) after the model box method reaches 37%, then the gas has reacted with the air component and formed other compounds. [7].

Meteorological Factors

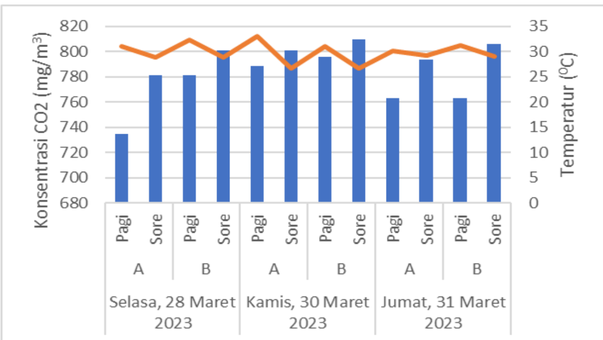

Figure 2. Air temperature fluctuations

(Source: Research Data)

Temperature differences have an inverse effect on the concentration of CO2 at the sampling site; an increase in temperature causes a decrease in CO2 concentration, while a decrease in temperature causes an increase in CO concentration. According to [16], the pattern of influence stems from a more rigid air density during high conditions and a more dense air density during low temperatures. In examinations with summer and winter time periods, the air temperature directly affects the photosynthesis process, so that CO2 levels are lo wer in summer than in winter. (17).

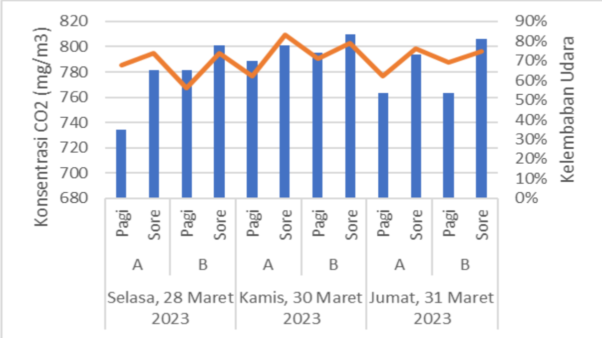

Figure 3. Air humidity fluctuations
(Source: Research Data)

The highest atmospheric humidity on Jagir Wonokromo Road occurred on Thursday afternoon at sampling site A with a magnitude of 83%. At that time, the concentration of carbon dioxide (CO2) was 801 mg/m3. Meanwhile, the lowest ambient air humidities on Jagir Wanokromo Street occurred in the morning on Tuesday at Sampling Site B with a magneticity 56%; the CO2 concentration at the time was 781 mg/mm3. This suggests that an increase in air humidity influences the concentration of carbon dioxide (CO2). (18). However, in this study, no such patterns occur because traffic density is more influential.

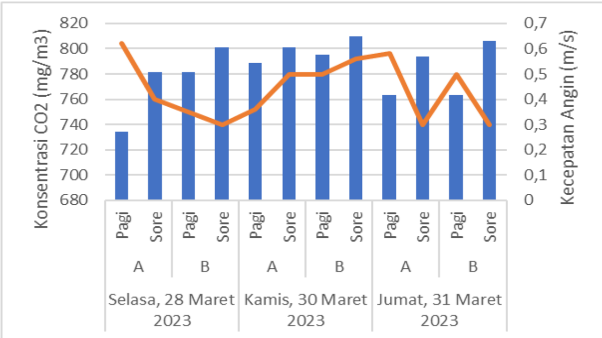

Figure 4. Wind speed fluctuations
(Source: Research Data)

The highest wind speed on Jalan Jagir Wonokromo occurred on Tuesday morning at sampling location A, with a magnitude of 0.62 m/s; the carbon dioxide (CO2) concentration at that time was 734 mg/m3. Meanwhile, the lowest wind speed on Jalan Jagir Wonokromo o ccurred on Tuesday afternoon at sampling location B and Friday afternoon at sampling locations A and B with a magnitude of 0.3 m/s; the carbon dioxide (CO2) concentration at that time was respectively 801 mg/m3, 794 mg/m3, and 806 mg/m3. This pattern shows that the faster the wind speed, the lower the carbon dioxide concentration, and vice versa. This is because high wind speeds can carry carbon dioxide in the air to other directions and locations (18).

Biomass, Stored Carbon, and Carbon Uptake

The green belt of Jalan Jagir Wonokromo is dominated by protective plants in the form of Trembesi (Samanea saman), Angsana (Pterocarpus indicus), Bintaro (Cerbera manghas), and

Lamtoro (Leucaena leucocephala). Trembesi (Samanea saman) has 46 individuals along the 300-meter green belt of Jalan Jagir Wonokromo. This is followed by Bintaro (Cerbera manghas), which has 40 individuals, Angsana (Pterocarpus indicus), which has 11, and Lamtoro (Leucaena leucocephala), which has 3. Plant classification is divided into sapling, pole, and tree levels.

Table1. Green Belt Vegetation Classification

Vegetation Type	Level	Diameter	Amount
Trembesi	Pole	10 - 20 cm	1
	Tree	> 20 cm	45
Angsana	Pole	10 - 20 cm	1
	Tree	> 20 cm	10
Bintaro	Pole	10 - 20 cm	33
	Tree	> 20 cm	7
Lamtoro	Tree	> 20 cm	3

(Source: Research Data)

Table2. Biomass, Stored Carbon and Carbon Uptake

Vegetation Type	Biomass (kg /year)	Stored Carbon (kg /year)	Carbon Uptake (kg /year)
Trembesi (Samanea Saman)	108857.5	54428.73	199753.44
Angsana (Pterocarpus Indicus)	15026.8	7513.4	27574.17
Bintaro (Cerbera Manghas)	2235.42	1117.71	4101.1
Lamtoro (Leucaena leucocephala)	6686.36	3343.18	12269.5
Total	132806.04	66403.02	243699.09

(Source: Research Data)

The plant Trembesi has the greatest contribution to carbon absorption, which is influenced by the dominant level of tree vegetation with a diameter of > 20 cm. On Jalan Jagir Wonokromo, the plant Bintaro has the lowest contribution to carbon absorption, which is influenced by the dominant level of tree vegetation on stakes and poles with a diameter of less than 20 cm.

Stems are said to account for 73% of plants' average biomass; therefore, biomass estimation is emphasized based on stem diameter, which is also influenced by age. [(19)]. HighThe size of the stem circumference positively correlates with high biomass yield, primarily because photosynthesis results in the storage of carbohydrates in the stem (2Some of the carbon becomes fuel in vegetation's life processes, while the other part is stored in plant structures and becomes part of, for example, cellulose, which is a sugar molecule and the substance that makes up the wood in the stem [(21)].

Potential Oxygen (O2)

Vegetation has the ability to produce oxygen as a result of the photosynthesis process, which utilizes carbon dioxide (CO_2). The amount of oxygen produced by protective plants in the Jalan Jagir Wonokromo green belt can be estimated based on the equivalence ratio with the amount of carbon stored.

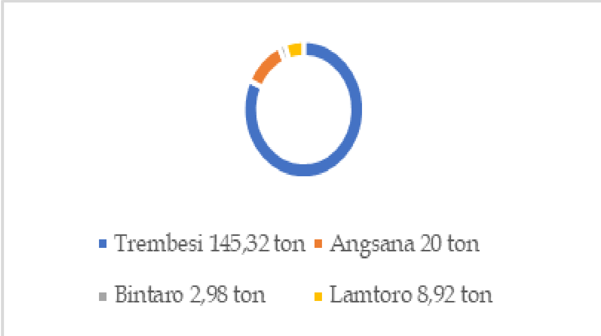

Figure 5. Oxygen Potential
(Source: Research Data)

CO2 absorption ability correction

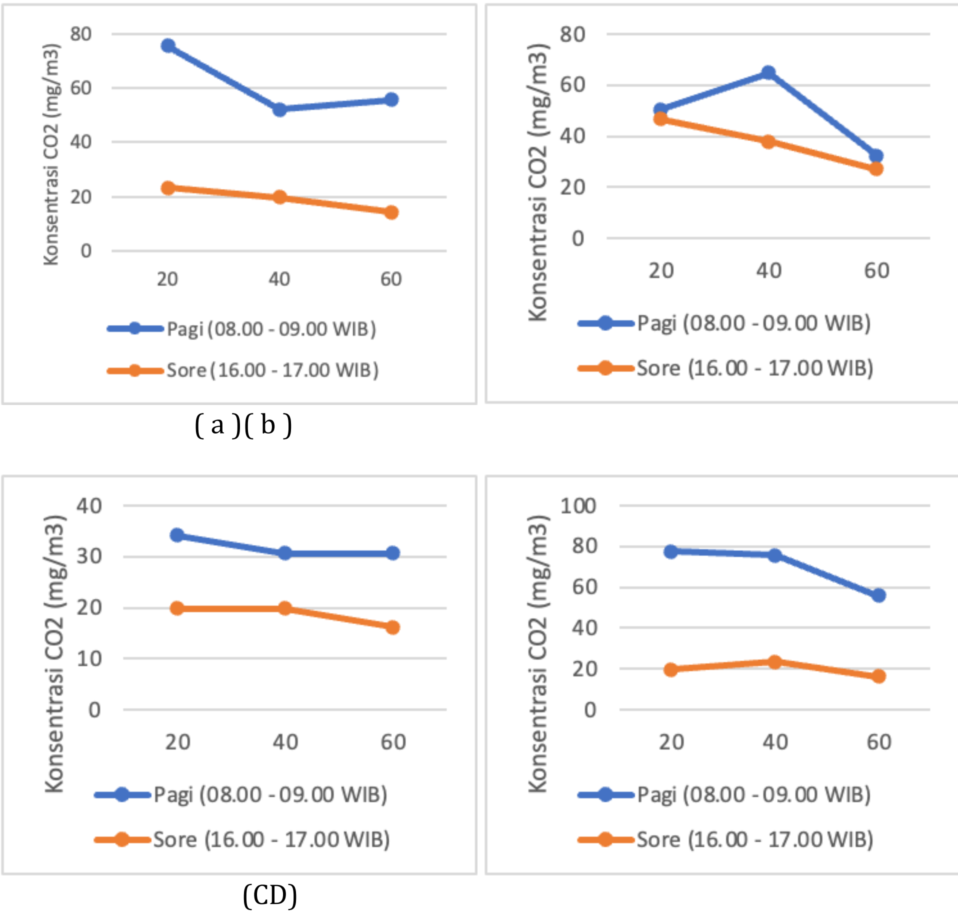

Figure 6. Vegetation CO2 Absorption Ability
(a) Trembesi; (b) Angsana; (c) Bintaro; (d) Lamtoro
(Source: Research Data)

Internal and external factors influence differences in vegetation's ability to absorb CO2. External factors in the form of microclimate, as evidenced by the absorption of CO2 by vegetation in the morning and evening, show differences in concentration. This result occurs as a result of the CO2 concentration reduction process, which is basically carried out by

vegetation through the process of photosynthesis, where CO2 and water, with the help of sunlight, carry out metabolic stages to produce output in the form of sugar, oxygen, and water (22). Meanwhile, internal factors include leaf area, leaf thickness, leaf color, and leaf stomata components (23). Types of vegetation with fast growth rates have more absorption capacity; however, not all vegetation with fast photosynthesis rates also have fast growth.
In the research, observations on leaf thickness and stomata density were made to see and prove their relationship with CO2 absorption.

Table3. Leaf Thickness and Stomata Density

Vegetation	Leaf thickness (mm)	Stomata density (per mm2)	
		DA	DB
Trembesi	1.16	220	200
Angsana	1.27	220	180
Bintaro	1.1	160	140
Lamtoro	1,175	320	320

(Source: Research Data)

The classification of stomata density for each vegetation also varies; lamtoro with a density of 320/mm2 falls into the medium density category, namely 300–500/mm2. Meanwhile, Angsana and Trebesi are between medium and low density because they are still in the range of > 200/mmm2, whereas Bintaro is in the low density category, namely < 200/mmm2. This classification pattern shows that the denser the stomata of a vegetation, the higher its CO2 absorption capacity [24]. Apart from the density of stomata, the opening of leaf stomata affects the photosynthetic capacity of vegetation. In the process of CO2 diffusion into leaf tissue, stomata that are slightly closed have lower diffusion than stomata that are clearly open. [25].

CO2 Uptake to Plant Age Ratio

In correcting the ability to absorb carbon dioxide (CO2), the age ratio is a factor that is taken into account. The relationship between the carbon dioxide (CO2) absorption capacity of vegetation and the age of the vegetation is the same as the relationship between the age of the vegetation and the size of the vegetation volume [26]. At a certain age, vegetation undergoes a phase of stopping growth and reaching a stable volume size. The physiological condition of each organ has a significant influence on the absorption process.

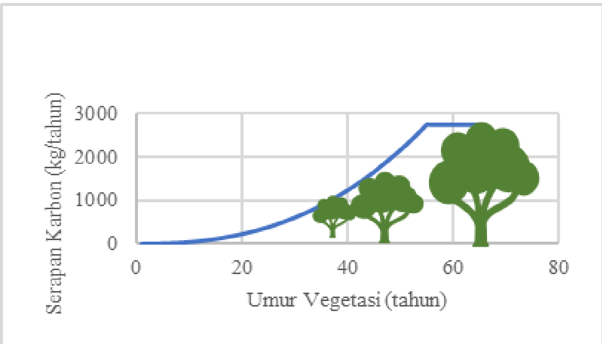

Figure 7. Plant Growth Rate

The curve is determined by analyzing vegetation growth with carbon absorption capabilities. We perform the analysis by determining the age of the plants based on a 0.5–0.8 cm annual increase in plant diameter [27], and then calculate the carbon absorption using the biomass approach. The percentage increase in carbon absorption every year is recorded and applied to the calculation of the correction of the carbon capability to reach the average age of existing vegetation. The vegetation correction year ranges from 51 to 55 years, based on a growth rate against carbon dioxide absorption that displays stable data for more than 50 years.

Table 5. CO2 absorption Correction

Vegetation Type	Correctional Carbon Absorption (kg/year)
Trembesi (Samanea Saman)	115806,63
Angsana (Pterocarpus Indicus)	25197,01
Bintaro (Cerbera Manghas)	4102,00
Lamtoro (Leucaena leucocephala)	7635,65
Total	152741,30

(Sumber: Data Penelitian)

Under the total carbon dioxide absorption correction, the estimated amount of carbon dioxide was absorbed 37% less than what it actually was. This was because the biomass estimate model didn't take the plant age into account.

Remaining Emissions

Based on the calculations carried out, both the emission concentration of vehicles and the environment are still able to be absorbed by the vegetation of the green lanes on the Wonokromo Jagir Road. Absorbable carbon dioxide leaves a space of 12.93 kg/hour for estimated CO2 absorption and 2.54 kg/h for correctional CO2 absorption. However, optimization recommendations are still in place to mitigate the traffic density, which is expected to increase every year as green line performance decreases and carbon dioxide absorption gradually stabilizes to decrease at an age of over 50.

Green Track Optimization Recommendations

1. **Intensification**
   Intensification is the process of developing and improving vegetation composition by considering its carbon dioxide absorption quality. This strategy can be implemented at the Jagir Road Wonokromo Green Line research site by cutting down dead trees and replanting with new vegetation. When this strategy is established, the amount of CO2 absorption in the green lane of Wonokromo Jagir Road will increase by 504.9 kg/year, or 0.3% of the initial CO absorptions.
2. **Extension**
   Extension is the development of green open space to increase carbon dioxide absorption capability. At the research site on Jagir Wonokromo Road, the expansion of the green open space area is no longer possible because the area is used for transportation, pedestrians, settlements, industry, and markets. To address this issue, we have implemented a vertical greening system as a strategy.
   We recommend implementing a vertical greening system on the green line of Jagir Road Wonokromo, which involves planting ivy leaves (Hedera helix) on a frame panel. Ivy leaves are capable of absorbing 2351 kg of carbon dioxide per year on an area of 1000 m2, which is equivalent to 2,351 kg of CO2/m2. When planning for 35 VGS units with a length of 20 m and a height of 2.5 m, each unit is given a distance of 5 m. If implemented, the strategy will increase CO2 absorption by 3% of the initial CO2.

3. **Mitigation**

Mitigation is meant for the maintenance of road green lanes and the planned vertical greening system. According to Minister of Public Works Regulation No. 5 of 2008 concerning Guidelines for Providing and Utilizing Green Open Space, maintenance that can be carried out includes fertilizing, watering, and pruning.

In addition to increasing CO2 absorption capacity, CO2 emission reduction strategies, particularly in the transportation sector, can also be implemented as a form of mitigation. When analyzed, the types of vehicles that contribute the most emissions are private vehicles, namely petrol cars and motorbikes. Providing adequate infrastructure in the form of widening pedestrian paths and minibus public transportation. This method can also be called low-carbon city planning (Large cities like Los Angeles have developed this kind of concept, transforming it into a transit-oriented direction where more budget is spent on building public transit facilities than on road repairs. irs. [30].

CONCLUSIONS AND RECOMMENDATIONS

The CO2 concentration on Jalan Jagir Wonokromo is caused by transportation emissions. CO2 levels with an average of 785 mg/m3 are still within normal limits, which do not interfere with human activities. Fluctuations in meteorological factors such as wind speed and temperature influence CO2 concentrations, whereas air humidity does not have a significant influence. The average wind speed at the Jalan Jagir Wonokromo location is 0.4 m/s, the average air temperature is 29.9 °C, and the average air humidity is 70%.

The green lanes on the right and left sides of the road, consisting of Trembesi, Angsana, Bintaro, and Lamtoro species, have the ability to absorb CO2 emissions on the road. However, optimization must still be carried out, taking into account the increasing amount of transportation from year to year and the ability of vegetation to absorb CO2, which will stagnate until it stops when it reaches >50 years of age. Optimization can take the form of intensification, extensification, and mitigation.

REFERENCES

1. Irundu D, Beddu MA, Najmawati N. Potensi Biomassa Dan Karbon Tersimpan Tegakan di Ruang Terbuka Hijau Kota Polewali, Sulawesi Barat. J Hutan dan Masy [Internet]. 30 Juli 2020;12(1):49. Tersedia pada: http://journal.unhas.ac.id/index.php/jhm/article/view/9675
2. Indrajaya Y, Mulyana S. Simpanan KArbon Dalam Biomassa Pohon Di Hutan Kota Kebun Binatang Bandung. In: Prosiding Seminar Nasional Geografi UMS. 2017. hal. 550–60.
3. Putra BP, Nawawi M. Vegetasi Sebagai Pereduksi Co 2 Udara Ambien Tepi Jalan Vegetatation for Reducing Co 2 Roadside Ambient Air. 2013;
4. Marisha S. Analisis Kemampuan Pohon dalam Menyerap CO2 dan Menyimpan Karbon pada Jalur Hijau Jalan di Subwilayah Kota Tegalega, Kota Bandung. IOP Conf Ser Earth Environ Sci [Internet]. 1 Juli 2020;528(1):012035. Tersedia pada: https://iopscience.iop.org/article/10.1088/1755-1315/528/1/012035
5. Dinas Lingkungan Hidup Kota Surabaya. Profil Keanekaragaman Hayati Kota Surabaya. 2021. hal. 209–15.
6. Trisandy AY. Analisis Perhitungan Ruang Terbuka Hijau Penyerap Gas CO2 di Koridor Ahmad Yani Surabaya. 2018.
7. Gracia AS. Kajian Kecukupan Ruang Terbuka Hijau Untuk Menyerap Gas Karbon Dioksida (CO2) Dari Kendaraan Bermotor Di Jalan Dr. Ir. H. Soekarno, Surabaya (Merr IIC). 2016.

8. Badan Standarisasi Nasional. SNI 7724:2011 Pengukuran dan Penghitungan Cadangan Karbon – Pengukuran Lapangan untuk Penaksiran Cadangan Karbon Hutan (Ground Based Forest Carbon Accounting). 2011. hal. 1–24.
9. Shishegaran A, Shishegaran A, Najari M, Ghotbi A, Boushehri AN. Effect of plants on an environment with high carbon dioxide concentration. Clean Eng Technol [Internet]. 2020;1(September):100002. Tersedia pada: https://doi.org/10.1016/j.clet.2020.100002
10. Dacosta YO, Daningsih E. Ketebalan Daun dan Laju Transpirasi Pada Tanaman Hias Dikotil. J Ilmu Pertan Indones [Internet]. 12 Januari 2022;27(1):40–7. Tersedia pada: https://journal.ipb.ac.id/index.php/JIPI/article/view/38470
11. Utomo IW, Widaningsih T, Napitupulu F. Representasi Feminisme di Bidang Olahraga Dalam Film The Queen ' s Gambit (Analisis Semiotika Roland Barthes) Jurnal Media Penyiaran. 2022;02:40–5.
12. Aziz MF, Abdurrachman A, Chandra I, Majid LI, Vaicdan F, Salam RA. Pemantauan Konsentrasi Gas (Co pada Struktur Horizontal di Kawasan Dayeuhkolot , Cekungan Udara Bandung Raya. 2020;18(1):1–12.
13. Efbertias S, Muhammad IM, David S, Asmuliani R, Erni M, Irwan S, et al. Pengantar Ilmu Lingkungan. Medan: Yayasan Kita Menulis; 2022.
14. Wardhani AK, Budianto B, Sugiarto Y. The Role of Vegetation in Reducing Anthropogenic CO2 in Bogor City. Agromet. 2018;32(1):42.
15. Nurjanah N. Emisi CO2 akibat Kendaraan Bermotor di Kota Denpasar. Puslitbang Perhub Darat dan Perkeretaapi. 2014;4(2014):9–15.
16. Ginting AL, Mirwan M. Analisis Kualitas Udara Berdasarkan Volume Lalu Lintas di Jalan Kedung Cowek Surabaya. INSOLOGI J Sains dan Teknol. 2022;1(5):603–13.
17. Savio N, Lone FA, Bhat JIA, Kirmani NA, Nazir N. Study on the effect of vehicular pollution on the ambient concentrations of particulate matter and carbon dioxide in Srinagar City. Environ Monit Assess [Internet]. 2022;194(6):1–19. Tersedia pada: https://doi.org/10.1007/s10661-022-09927-4
18. Sudiadnyana IW, Aryana IK, Sali IW. Hubungan faktor meteorologis dan kepadatan lalu lintas dengan kualitas udara di kota tabanan. 2022;12(2):93–8.
19. Lokbere M, Pollo HN, Tasirin JS. Estimasi Biomassa Pohon Mahoni di Areal UNSRAT. COCOS. 2017;9(6):321–9.
20. Sahuri. Potensi Peningkatan Penyerapan Karbon Melalui Sistem Tanaman Sela Berbasis Karet. Bumi Lestari J Environ. 2018;18(1):33.
21. Santoso N, Sutopo, Pambudi GP, Danarta VF, Wibisono RA, Astuti TP, et al. Pendugaan biomassa dan serapan karbon di beberapa areal Taman Hutan Kota Jakarta, Bekasi, dan Bogor. J Penelit Hutan Tanam. 2021;18(1):35–49.
22. Hidayati N, Mansur M, Juhaeti T. Variasi serapan karbondioksida (CO2) jenis-jenis pohon di "ecopark", cibinong dan kaitannya dengan potensi mitigasi gas rumah kaca. Bul Kebun Raya. 2013;16(1):38–50.
23. Iqbal M, Hermawan R, N Dahlan E. POTENSI SERAPAN KARBONDIOKSIDA BEBERAPA JENIS DAUN TANAMAN DI JALUR HIJAU JALAN RAYA PAJAJARAN, BOGOR. J Penelit Sos dan Ekon Kehutan [Internet]. 31 Maret 2015;12(1):67–76. Tersedia pada: http://ejournal.forda-mof.org/ejournal-litbang/index.php/JPSEK/article/view/709
24. Hidayanti SR. Analisis Karakteristik Stomata, Kadar Klorofil Dan Kandungan Logam Berat Pada Daun Pohon Pelindung Jalan Kawasan Lumpur Porong Sidoarjo [Internet]. Fakultas Sinstek Dan Teknologi Universitas Islam Negeri Malang Malang. 2009. Tersedia pada: http://etheses.uin-malang.ac.id/995/1/02520020 Skripsi.pdf
25. Taluta HE, Rampe HL, Rumondor MJ. Pengukuran Panjang dan Lebar Pori Stomata Daun Beberapa Varietas Tanaman Kacang Tanah (Arachis hypogaea L.). J MIPA. 2017;6(2):1.
26. de Villiers C, Chen S, jin C, Zhu Y. Carbon sequestered in the trees on a university campus:

A case study. Sustain Accounting, Manag Policy J. 2014;5(2):149–71.
27. Lukaszkiewicz J, Kosmala M. Determining the age of streetside trees with diameter at breast height-based multifactorial model. Arboric Urban For. 2008;34(3):137–43.
28. Syafiq M. Perancangan Taman Vertikal pada Lingkungan Koridor Padat Kota dengan Pendekatan Konsep Sustainable Urban Landscape (Studi Kasus: Koridor Jalan Basuki Rahmat). Institut Teknologi Sepuluh Nopember. 2017.
29. Saputra DH. KEMAMPUAN RTH SEBAGAI PENYERAP EMISI GAS CO 2 KENDARAAN BERMOTOR PADA KAWASAN PERDAGANGAN DAN JASA KINGS (BLOK BALONGGEDE). FTSP Ser Semin Nas dan Disem Tugas Akhir 2022. 2022;278–86.
30. Sari MP. Walkable City untuk Kota Berkelanjutan dengan Emisi Nol Karbon [Internet]. Badan Pengembanagn Infrastruktur Wilayah. 2021. Tersedia pada: https://bpiw.pu.go.id/article/detail/walkable-city-untuk-kota-berkelanjutan-dengan-emisi-nol-karbon