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An Optimization Model for Utilizing Green Road Corridors and Urban Parks to Enhance Tree Absorption of Motor Vehicle CO_2 emissions in Pekanbaru City, Indonesia

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ABSTRACT

The surge in CO_2 emissions from vehicles has precipitated a rise in global temperatures, instigating the greenhouse effect. This study draws on case studies from prominent Indonesian cities, including Jakarta, Surabaya, and Manado, highlighting a notable dissonance between the capacity of plants to absorb carbon and the volume emitted. Green Road Corridors and Urban Forests assume multifaceted roles in urban ecosystems, functioning as barriers, filters, absorbers, and producers, contributing to air quality, noise reduction, and environmental preservation. Employing linear programming as a mathematical programming branch, this research integrates diverse factors into decision-making models. It strives to achieve optimal solutions pertaining to the selection and quantity of trees for maximizing CO_2 absorption resulting from motor vehicle activities in Pekanbaru City, specifically along Subrantas Street and Harapan Raya Street. Land cover classifications in Pekanbaru City encompass green spaces, buildings, open areas, undergrowth, water bodies, and non-private zones. The optimization model, targeting 10% utilization of the Jalan Subrantas urban park area, demonstrates a significant CO_2 absorption of 827,976 tons/ha and an O_2 surplus of 176,207.72 tons/ha. Conversely, full utilization of the Jalan Sudirman Urban Park area yields a CO_2 absorption of 206,982 tons/ha and an O_2 surplus of 9036.63 tons/ha. These optimized outcomes lay a foundation for potential carbon tax development within the urban transportation sector of Pekanbaru, with envisaged implementation by the year 2040.

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INTRODUCTION

Globally, urban air pollution is becoming an increasing and major concern and has a negative impact on human health. Respiratory health diseases and social disparities have increased due to air pollution (Sunyer et al., 2021; Wang & Huang, 2021). In light of this, afforestation has been pursued to reduce air pollution and improve the quality of life (Anguluri & Narayanan, 2017; Sunyer et al., 2021). It is believed that reducing exposure to air pollution through afforestation can improve the health of urban residents (Wang & Su, 2020). However, available evidence on the effect of afforestation on urban air pollution and health protection is still insufficient and unproven (Reames & Bravo, 2019; Wang et al., 2022). Air pollution is increasing due to rapid urbanisation, industrial manufacturing, and carbon emissions. This has led to the depletion of green natural environments and underestimated health impacts in underdeveloped countries (Balogun et al., 2020; Brauer et al., 2007; Tuśnio et al., 2020). Urban air pollution causes

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health problems, especially respiratory and cardiovascular diseases. According to a study conducted by Bikis and Pandey in Addis Ababa, 40% of urban residents are exposed to health risks from transport-related air pollution (Bikis, 2023). In addition, there are many causes of urban air pollution, namely manufacturing, combustion engines, motorised cars, food cooking, construction industry, and dust. These sources emit toxic gases into the atmosphere, such as particulate matter ($PM_{2.5}$), CO_2, CO, SO_2, NO_X, and PM_{10}.

The emission of harmful gases into the atmosphere due to accidents, human activities, natural disasters, or other reasons is a major threat to human populations, nature, and infrastructure (Balogun et al., 2020; Brauer et al., 2007; Tuśnio et al., 2020). Air pollution is one of the significant environmental problems that can cause adverse health impacts, such as asthma, allergies, infections, cancer, and the risk of low birth weight babies (Betancourt et al., 2021; McConnell et al., 2006; Morgenstern et al., 2008; Morley & Gulliver, 2018; Olvera-García et al., 2016; Relkar, 2022). These health-related problems are correlated with air pollution, especially in traffic (Betancourt et al., 2021). Therefore, air pollutant data acquisition, measurement, monitoring, evaluation model formulation, assessment, benchmarking, and forecasting are becoming increasingly important, especially in the current situation (Carmichael et al., 2008; Xing et al., 2022). Much effort has gone into developing appropriate air pollution-related methods and tools and their integration (Balogun et al., 2020; Brauer et al., 2007; Tuśnio et al., 2020).

The Ministry of Energy and Mineral Resources (ESDM) of the Republic of Indonesia published in 2019 that the transport sector was the largest energy consumer in 2018, amounting to 391 million TOE (Ton Oil Equivalent) or 42% of total final energy consumption. Almost all the energy used in transport comes from fossil fuels and vegetable oils, which account for 48% of the total energy mix. The transport sector emits 157,263 Giga CO_2, with an average annual growth of 7.17%. This increase in emissions is associated with a 7.56% annual increase in fuel use. In 2019, the transport category consumed 415 million barrels of oil equivalent (BOE), with liquid fuels accounting for almost all (99.97%). Fuel consumption continued to increase year-on-year, with an average annual growth rate of 8.32%.

The growth of urban transport modes has the potential to significantly increase the use of energy and natural resources, leading to an increase in the amount of waste and residue released into the environment, thus contributing to environmental degradation. This finding is supported by Hossain's research in 2012, which indicated that carbon dioxide (CO_2) is the most emitted greenhouse gas, with a significant amount of CO_2 emissions coming from the consumption of fossil fuels such as coal, oil, and gas (Hossain, 2012). CO_2 emissions have become an important issue globally as CO_2 is recognized as one of the main contributors to global warming, leading to higher temperatures and the greenhouse effect (Liu et al., 2020). Therefore, the presence of green open spaces (RTH) is very important for the ecological sustainability of a city. In addition, the presence of green spaces also has a considerable impact on natural air comfort (Fan et al., 2022). Temperature and humidity significantly influence the air comfort of green spaces, which is reflected in the Thermal Comfort Index (TCI). CO_2 emissions have become an important issue globally as CO_2 is recognized as one of the main contributors to global warming, leading to increased temperatures and the greenhouse effect (Cheng et al., 2021; Xie et al., 2020). Therefore, the presence of green open spaces (RTH) is essential for the ecological sustainability of a city. In addition, the presence of green spaces also has a considerable impact on natural air comfort. Temperature and humidity significantly affect the air comfort of green spaces, which is reflected in the Thermal Comfort Index (TCI).

Pekanbaru City is one of the provincial capitals in Riau Province and has the fastest-growing population. This increase will have an impact on consumer behaviour in terms of motor vehicle ownership. The number of motor vehicle ownership recorded in Pekanbaru City in 2018 was 720,737 units, whereas the number of motor vehicle ownership increased by 770,836 units in 2019. As reported by the Riau Province Regional Revenue Agency (Bapenda), there were around 1,285,313 units of private vehicles in Pekanbaru City in 2020, which indicates an increase of around 514,477 units from 2019.

Green Corridor Roads (GCRs) are an important component of urban green spaces, which serve three main purposes: reducing air pollution, muffling noise, and acting as barriers (Anguluri & Narayanan, 2017; Sunyer et al., 2021). In addition to these three functions, trees in green spaces also have important ecological functions as carbon sinks and contribute to reducing motor vehicle pollution (Wang & Su, 2020). Climate change mitigation efforts, such as reducing greenhouse gas emissions, can be achieved by utilising urban trees that act as carbon sinks (Balogun et al., 2020; Brauer et al., 2007; Tuśnio et al., 2020).

The application of urban green spaces such as GRCs is projected to reduce emissions generated by motorised vehicles by their function and designation (Carmichael et al., 2008; Xing et al., 2022). However, investigations on the ground show that urban GRCs do not function optimally. Investigations into cases in several Indonesian cities, such as Surabaya and Manado, show a significant gap between the amount of carbon plants can sequester and the amount of carbon emitted. In addition to the importance of Urban GRC, as explained above, the use of Urban Forests is also very important.

Urban Forest is one of the additional types of GRC authorised by the Central Government to be implemented in every city, province and district in Indonesia. As the identity of the city, retaining and filtering solid particles in the air, absorbing and absorbing lead particles dust, reducing noise, absorbing carbon monoxide (CO), absorbing CO_2 and producing O_2, windbreaks, climate improvement, waste management, and preserving groundwater, urban parks have an important role in urban life. Therefore, in response to the ever-increasing use of motorised vehicles, there is a need to increase the synergy between green spaces and urban parks to increase the absorption capacity of plants. This should be done using the spatial planning framework, specifically the 2018-2040 Regional Spatial Plan (RTRW) of Pekanbaru City.

Thus, this research aims to identify concrete solutions to address the problem of CO_2 emissions from motorised vehicles in Indonesian cities, focusing on Pekanbaru City. By utilising green road corridors and urban forests, this research aims to optimise the use of green open spaces in absorbing CO_2, generating oxygen and providing a basis for future carbon tax policies. Through a mathematical and scientific approach, this research seeks to make a tangible contribution to maintaining air quality, reducing climate change's impact, and improving urban communities' welfare. Thus, this research will guide policymakers and stakeholders in maintaining a sustainable environment.

MATERIAL AND METHODS

Research location

The research location is located along the stretch from Jl. Subrantas to the East Sumatra Highway in Pekanbaru City (bordering the Eastern Sumatra Corridor), which is administratively under Pekanbaru City's regulation. Supported by a land cover map stretching from Subrantas Road to the East Sumatra Highway, as shown in Figure 1

Green space, buildings, open space, undergrowth, water, and non-private areas are the land cover classifications in Pekanbaru City, along with their respective areas and weights. This will be presented in the form of a table, as shown in Table 1

Trees data in GRC

Below are the tree types and quantities observed on Subrantas Street: 1148 Trembesi trees and 118 Butterfly Trees were planted. 1343 Trembesi trees on Arifin Achmad Street. There are 684 Trembesi trees and 447 Glodokan Tiang trees on Sudirman Street. Finally, on Harapan Raya

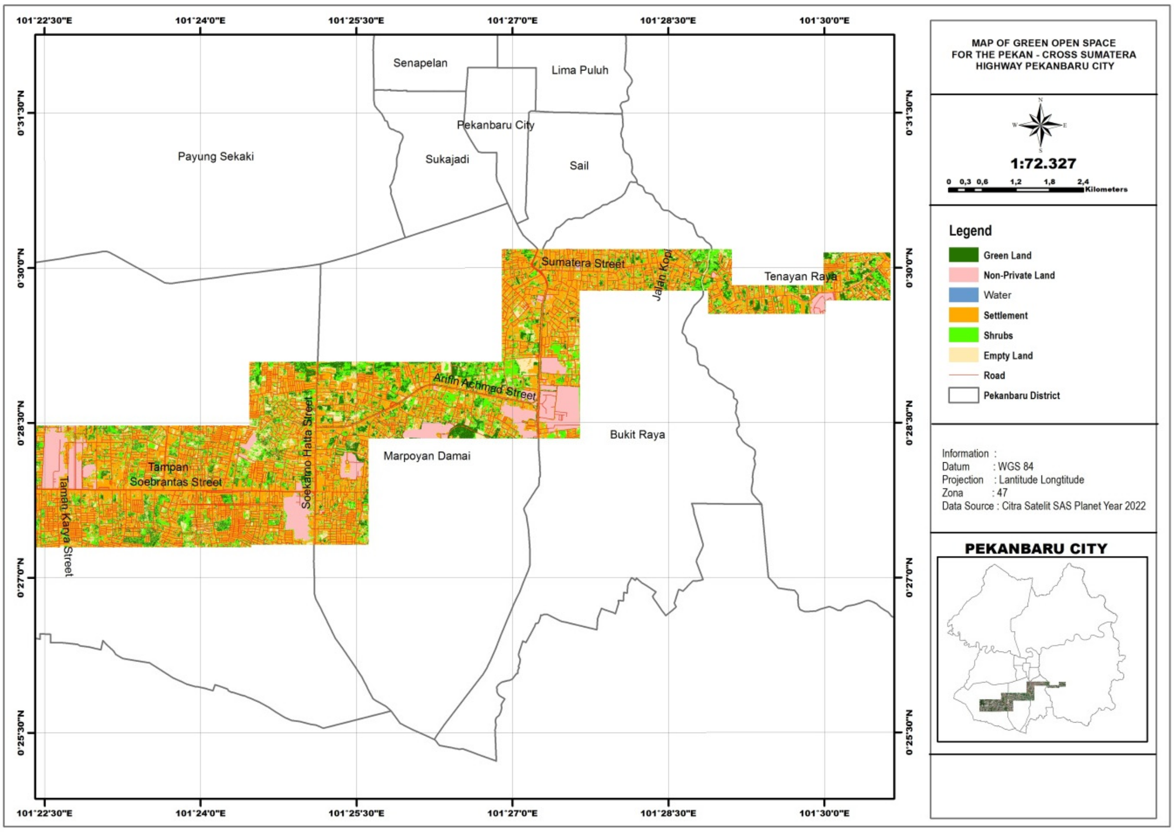

Fig 1. Map of land cover

Table 1. Classification of land cover, area, and weight in Pekanbaru City

Land cover	Area (km^2)	Area (ha)	Percentage (%)
Green space.	3415786	341,5786	11,543
Building	14004983	1400,4983	47,326
Open space	4454077	445,4077	15,051
Under growth	5336770	533,6770	18,034
Water	9934	0,9934	0,034
Non privat area	2371306	237,1306	8,013
Total	29592856	2959,2857	100,000

Source : Analysis results

Street, there are 516 Trembesi trees. Figure shows a description of the composition, amount, and types of existing trees data in GRC on Subrantas Street, Arifin Achmad Street, Sudirman Street, and Harapan Raya Street.

CO_2 Emissions in GRC Data

The analysis of the total carbon emission balance in 2040 represents the carbon emission values for each type of motorized vehicle traveling along the roads Subrantas Road to Jalan Lintas Timur Sumatera in Pekanbaru city, respectively totaling 1042.714,42 (ton/ha), 611.957,76 (ton/ha), 360.583,44 (ton/ha), and 146.758,89 (ton/ha). The absorption rates of the four Green

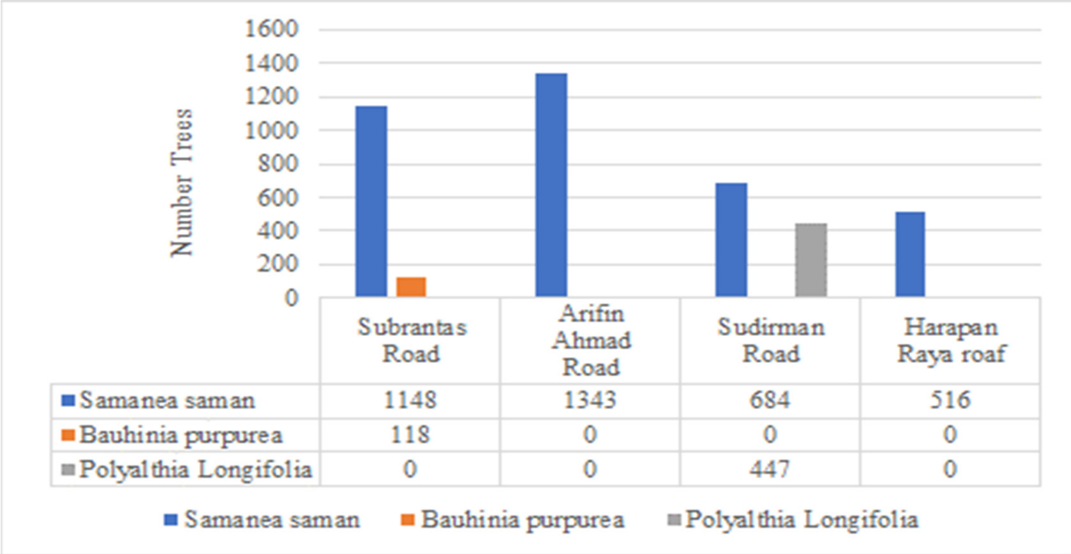

Fig. 2. GRC's composition, quantity, and various types of existing

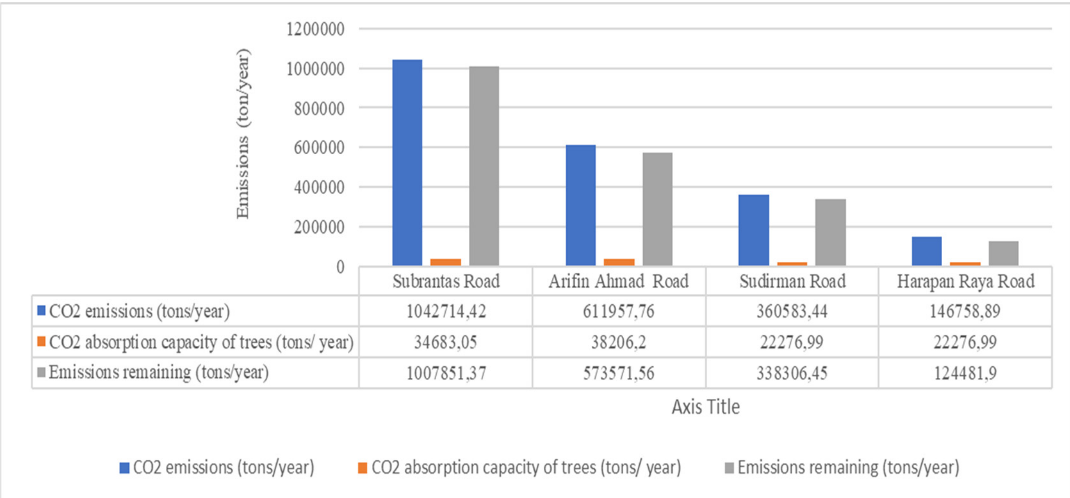

Fig. 3. Remaining CO_2 Emissions in the GRC in 2040

Open Spaces (Green Open Space or RTH) in absorbing CO_2 emissions generated by motorized vehicles on Subrantas Road, Arengka - Arifin Ahmad Road, Sudirman Road, and Harapan Raya Road are 34.034,99 (ton/ha), 38.206,20 (ton/ha), 22.276,99 (ton/ha), and 14.679,37 (ton/ha), respectively. The next step involves analyzing the remaining emissions that can be reduced by Green Open Spaces in the JHJ area along the roads from Subrantas Road to Jalan Lintas Timur Sumatera in Pekanbaru, and the detailed results are presented in Figure 3.

Referring to Figure 3 above, it can be concluded that the four Green Open Spaces (RTH) on Subrantas Road, Arifin Ahmad Road, Sudirman Road, and Harapan Raya Road have not been able to absorb CO_2 emissions generated by motor vehicles because there are remaining emissions of 1,007,851.37 tonnes/year, 573,571.56 tonnes/year, 338,306.45 tonnes/year, and 124,481.90 tonnes/year, respectively.

Model of linear programming

Linear programming is a branch of mathematical programming used to formulate a system

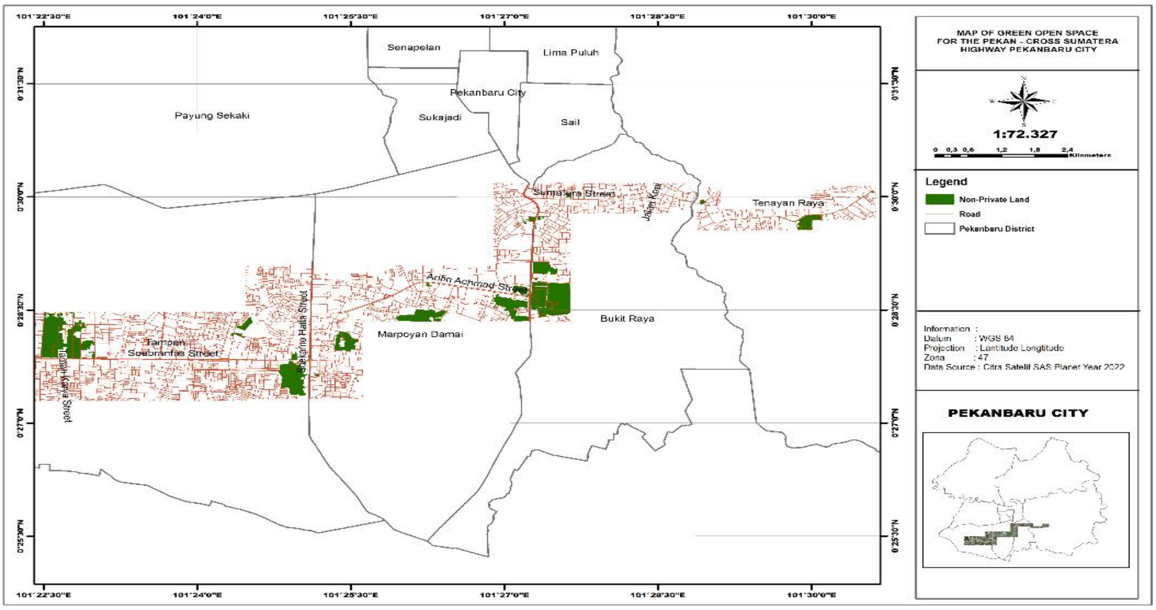

Fig. 4. GOS Map of Subrantas Road - Harapan Raya Road

model that aligns with real-world conditions, which can then be formulated into a mathematical model by separating essential elements to achieve a solution that meets the desired objectives or decision-making goals (Birim et al., 2022; van der Heijden, 2021). Fundamentally, linear programming consists of three key components (Birim et al., 2022; van der Heijden, 2021), namely: decision variables are the variables that are sought and assigned values that are most optimal for the intended objective; the objective function is a mathematical function that needs to be maximised or minimised, reflecting the goal to be achieved; and constraint functions are mathematical functions that impose constraints on the efforts to maximise or minimise the objective. The mathematical formulation that governs problem solving using linear programming is as follows:

Objective function for maximization:
$Zmax = C1X1 + C2X2 + \ldots\ldots + CnXn$
$Zmin = C1X1 + C2X2 + \ldots\ldots + CnXn$
Constraint function
$a11X1 + a12X_1 + \ldots\ldots + a1nXn \leq b1$
$a21X1 + a22X1 + \ldots\ldots + a2nXn \leq b2$
$am1X1 + am1X1 + \ldots\ldots + amnXn \leq bm$
Non negative
$X1 \geq 0; X2 \geq 0; \ldots\ldots ; Xn \geq 0$

Where Zmax is the objective function, Xn is the variable, Cn is the coefficient of the variable (cost), amn is the amount of resource m consumed by each activity unit n, bm is the amount of resource m available to allocate, m is the number of limited resources, and n is the number of activities that require limited resources.

RESULTS AND DISCUSSION

By analyzing vegetation along Subrantas Road, Arifin Ahmad Road, Sudirman Road, and

Table 2. Subrantas Road, Arifin Ahmad Road, Sudirman Road, and Harapan Road Vegetation Area

No	Road name	Road segment	Vegetation coverage (ha)
1	Subrantas Road	A1	11.352,4
2	Arifin Ahmad Road	A2	42,842
3	Sudirman Road	A3	66,062
4	Lintas Sumatera Road	A4	15

Source: Analysis results

Harapan Road using satellite imagery from the Sart Planet satellite, an optimization model for increasing tree absorption due to motor vehicle CO_2 emissions was developed. According to the classification methods, the interpretation accuracy is above 80 percent and meets the previously established conditions, with an overall accuracy of 88.89% and a Kappa coefficient of 0.86, as shown in Figure 4 and Table 2

Subrantas Road, Arifin Ahmad Road, Sudirman Road, and Harapan Road have vegetation covering of 11.352,4 ha, 42,842 ha, 66,062 ha, and 15 ha, respectively. This will be presented in the form of a table, as showed. Table 2.

Development of model

Linear Programming, as a branch of Mathematical Programming, is a tool capable of integrating various multifactor aspects in decision-making through model formulation to achieve optimal solutions related to the quantity and types of trees that can be optimized to determine the magnitude of tree absorption concerning CO_2 emissions from motor vehicle usage in Pekanbaru City, particularly along Subrantas Street, Arifin Achmad Street, and Harapan Raya Street.

Objective function of model (Subrantas and Sudirman Road)

In Marisha's (2018) study, several plant species were identified as capable of absorbing CO_2 (Nocito & Dibenedetto, 2020). Another research by Liang et al (2021) identified 31 vegetation varieties with the ability to absorb CO_2 (Liang et al., 2021). The research conducted in 2007-2008 highlighted the trembesi tree (Samanea saman) as the top performer in CO_2 absorption, capable of absorbing 28,488.39 kg of CO_2 annually. Apart from the trembesi tree, various other types of vegetation were also found to exhibit significant CO_2 absorption capacities.

Optimization model for CO_2 absorption by trees on Subrantas and Sudirman roads. The objective function is a mathematical function that must be maximized in order to achieve the goal of maximum CO_2 absorption through the composition of the total number and types of trees along the GRC and Urban Forest, with its administrative presence on Subrantas Road, as shown in equation 1.

$$Zmax = 28,4884\ X1 + 11,663\ X2 \ \text{(ton/year)} \tag{1}$$

With C1 is absorption coefficient variable for Trembesi trees (Samanea saman), which is a species capable of absorbing CO_2 at a rate of 28,488.39 kg/tree/year or 28.4884 tons/year, C2 is absorption coefficient variable for Glodokan Tiang trees (Bauhinia purpurea), which is a species capable of absorbing CO2 at a rate of 11,662.89 kg/tree/year or 11.663 tons/year, X1 is number of Trembesi trees (Samanea saman), X2 is number of Glodokan Tiang trees (Bauhinia purpurea).

Constraint function of model (Subrantas Road)

The constraint function is a mathematical function that imposes constraints on the absorption capacity based on the composition of the total number and types of trees along the GRC and

Urban Forest, with their administrative presence on Subrantas Road, in order to maximize the objective function of absorption based on the composition of the total number and types of trees in relation to CO_2 emissions. As a result, the mathematical equations representing the limitations to be met for problem-solving are given by equations 2, 3, 4, and 5.

$$X_1 + X_2 \leq 29712 \quad (2)$$

(10% of the Subrantas Road Urban Forest area, which covers an area of 11,352 ha, assuming that 1 ha is planted with 25 trees, equivalent to 28,375 selected Trembesi trees, as well as the existing number and types of trees along the GRD, which consists of 1,148 Trembesi trees and 189 Glodokan Tiang trees, for a total of 29712 trees)

$$X_1 \leq 29532 \quad (3)$$

$$X_2 \leq 189 \quad (4)$$

Non negativity :

$$X_1 \geq 0; X_2 \geq 0 \quad (5)$$

With : X1 is number of Trembesi trees (Samanea saman) X2 is number of Glodokan Tiang trees (Bauhinia purpurea).

Constraint function of model (Sudirman Road)

The mathematical equations that represent the constraints that require being satisfied in order to solve the problem are given by equations 6, 7, 8, and 9.

$$X1 + X2 \leq 7767 \quad (6)$$

The total area of the Urban Park on Jalan Sudirman is 66.06 hectares, assuming that every hectare is planted with 100 trees, totaling 6,606 assigned Trembesi trees. The current number and types of trees in the GRC are 684 Trembesi trees and 189 Glodokan Tiang trees, with a total of 7767 trees.

$$X1 \leq 7290 \quad (7)$$

$$X2 \leq 477 \quad (8)$$

Non negativity :

$$X1 \geq 0; X2 \geq 0 \quad (9)$$

Analysis of Linear Programming Model

Input of Linear Programming Model

The POM QM Windows software program is one of the applications that can be used to find solutions for quantitative, production, and operations management modeling by providing a menu of solutions by inputting a series of mathematical equations for the Linear Programming model's objective and constraint functions. Howard J Weiss developed it, and Pearson Education, including Pearson Prentice Hall, published it (Jay Heizer, 2014). The mathematical equations from equation 1 to equation 5 are entered into the POM QM Windows software program's

Table 3. POM QM Windows Input Model (Subrantas Model)

	X1	X2	Operation	RHS	Equation Form
Maximum	28,488	11,663			Max 28,488 X1+11,663 X2
Constraint 1	1	1	<=	29712	X1+ X2<= 29712
Constraint 2	1	0	<=	29532	X1<=29532
Constraint 3	0	1	<=	189	X2<=189

Sources : Input model POM QM Windows

Table 4. POM QM Windows Input Model (Sudirman Road Model)

	X1	X2	Operation	RHS	Equation Form
Maximum	28,488	11,663			Max 28,488 X1+11,663 X2
Constraint 1	1	1	<=	7767	X1+ X2<= 29.712
Constraint 2	1	0	<=	7290	X1<=29.532
Constraint 3	0	1	<=	477	X2<=189

Sources : Input model POM QM Windows

Table 5. Optimization results in Subrantas road

	X_1	X_2	Operation	RHS	Dual
Maximum	28,488	11,663			
Constraint 1	1	1	<=	29712	6
Constraint 2	1	0	<=	29532	22
Constraint 3	0	1	<=	189	0
Solution	29.532	189		827.976	

Sources : The POM QM Windows Model's output

Table 6. Optimization results in Sudirman road

	X_1	X_2	Operation	RHS	Dual
Maximum	28,488	11,663			
Constraint 1	1	1	<=	7767	6
Constraint 2	1	0	<=	7290	22
Constraint 3	0	1	<=	477	0
Solution	7290	477		206.982	

Sources : The POM QM Windows Model's output

Linear Programming menu, as shown in Table 2 and Table 3.

The linear programming model's output

The optimization results of the Linear Programming model utilizing a set of mathematical equations from equation 1 to equation 5 using the POM QM Windows software program are shown in Table 4 and Table 5 for Subrantas Road and Sudirman Road, respectively.

Referring to Table 5 above, the obtained results for the number of Trembesi trees (X1) is 29,532 trees, and the number of Glodokan Tiang trees (X2) is 189 trees, with the absorption of CO2 emissions along the GRC and Urban Forest along Subrantas Road totaling 827,976 tons/ha.

Referring to Table 6 above, and the results show that the number of Trembesi trees (X1) is 7290 trees and the number of Glodokan Tiang trees (X2) is 477 trees, with a carbon dioxide absorption rate of 206,982 tons/ha for the GRC and Urban Park along the Sudirman Road.

Table 7. The Magnitude of CO_2 Emission Predicting, Optimization Model Results, CO_2 Absorption Reason, and Contribution of Urban Forest Area.

No	Road segments	Magnitude of CO_2 emission Predicting (tons/year)	Optimization model results (ton/year)	CO_2 absorption reason (tons/ha)	Contribution of urban park area. (ha)
		(1)	(2)	(2-1)	
1	Subrantas Road	651.768,28	827. 976	176.207,72 Surplus O_2	10% of the total Urban Park area
2	Sudirman Road	197.945,73	206.982	9036,63 Surplus O_2	100% of the total Urban Park area

Source : Analysis result

According to the data presented in Table 7, applying 10% of the forest area in the Subrantas road segment as input for a linear programming optimization model yields a CO_2 absorption of 827,976 tons/ha. This leads to an excess of 176,207.72 tons/ha of O_2, considering the anticipated CO_2 emissions from motor vehicles based on the Pekanbaru City Spatial Plan for the period 2018-2040, which is projected at 651,768.28 tons/ha. On the other hand, employing 100% of the forest area in the Sudirman road segment in the linear programming optimization model results in a CO_2 absorption of 206,982 tons/ha. This generates an O_2 surplus of 9,036.63 tons/ha based on the expected CO_2 emissions from motor vehicles in accordance with the Pekanbaru City Spatial Plan for the period 2018-2040, totaling 197,945.73 tons/ha.

CONCLUSION

By utilising green road corridors and urban forests, this study successfully optimised CO_2 absorption by trees in response to motor vehicle emissions in Pekanbaru City. It was found that the use of 10% of the urban park area on Jalan Subrantas resulted in significant CO_2 sequestration of 827,976 tonnes/ha, with an O_2 surplus of 176,207.72 tonnes/ha. Meanwhile, full utilisation of the urban park area on Jalan Sudirman resulted in CO_2 sequestration of 206,982 tonnes/ha, with an O_2 surplus of 9036.63 tonnes/ha. These results show that integrating green road corridors and urban forests can be a concrete solution to reduce the impact of motorised vehicle emissions on the environment and the health of urban communities. In conclusion, this study provides valuable guidance for policymakers and stakeholders in maintaining air quality, mitigating climate change impacts, and improving the well-being of urban communities.

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The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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