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The Effect of Tree Planting within Roadside Green Space on Dispersion of CO_2 from Transportation

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Abstract: Transportation has become one of the most significant contributors to CO_2 in the world because of its fuel usage. Trees are planted on the roadside to reduce levels of CO_2 in the air because trees have the ability to absorb CO_2 to be used in the photosynthesis process. This ability will be maximized if the dispersion of CO_2 is concentrated around the tree. However, there are some differing results from previous studies regarding this. Some research results have found trees can increase CO_2 concentration and vice versa. Accordingly, this study aims to evaluate the effect of tree planting on the roadside in dispersing CO_2 using a real 3D environment. The methods used in this research are CO_2 emission analysis to obtain the amount of CO_2. Then, Computational Fluid Dynamics (CFD) analysis is used to simulate the dispersion of CO_2 in the study area both without trees and with trees. However, due to the mixing of air and CO_2, this simulation uses a scalar mixing analysis. Some conditions are considered, such as the characteristics of buildings, the characteristics of trees, and environmental conditions. The result indicates that trees can decrease the velocity and increase the concentration of CO_2 on the roadside but decrease CO_2 concentration on the road. Tree planting can decrease the velocity by 4.3% in the value range 0.9-1 m/s. This condition increases CO_2 concentration on the roadside. Trees can increase CO_2 by 25% on the right of a roadside and increase CO_2 concentration by 10% on the left side.

1. INTRODUCTION

CO_2 is a greenhouse gas resulting in many negative global impacts. It has a direct effect on global climate change and increased global warming. If this is not resolved soon, it will lead to adverse impacts to people throughout the world. One of the highest contributors of CO_2 is transportation; the number of vehicles in the world is increasing every year, especially in countries without good public transportation systems. The existing transportation system in Indonesia is not functioning effectively; people prefer to use private transportation such that the number of vehicles increases rapidly every year. In a decade, the number of motor vehicles in Indonesia has increased by 40.5% (BPS, 2016).

Transportation has become one of the most significant contributors to CO_2 in the world because of its fuel usage. The Environmental Protection

Agency noted that transportation contributes 34% of the total CO_2 in the air every day from using gasoline and diesel as fuel (EPA, 2016). Jie (2011) and Sullivan et al. (2004) showed in their research that using gasoline produces more CO_2 but will emit less other types of emissions (such as PM and NO_X). Conversely, the use of diesel can reduce CO_2 but produce more PM and NO_X emissions. Despite these facts, over 90% of motorized vehicles in the world still use gasoline and diesel as fuel.

The best solution to this problem is to reduce the number of vehicles being used. The Indonesian government has made several efforts to suppress the growth rate of motor vehicles, including their impact on water pollution, through encompassing energy efficient and environmentally clean vehicles, clean fuels, traffic management, and a policy framework including regulatory, pricing, and taxation measures (Faiz, 1992). But this effort has not been able to stop people's desire to own a private vehicle. Therefore, the government has made efforts to reduce CO_2 by multiplying vegetation in urban areas, especially in roadside. Trees, shrub, and grass have the ability to absorb CO_2 in the air through the photosynthesis process (Mardin, Soetanto, & Santosa, 2006). Nevertheless, each type of vegetation has a different level of effectiveness in absorbing CO_2 and trees are more effective than other vegetation types. Trees in urban areas can reduce CO_2 by 88 t in a year (Selmi et al., 2016). This ability will be maximized if the dispersion of CO_2 is concentrated around the tree. Therefore, some researchers have conducted studies on the dispersion of CO_2 around trees. Nevertheless, there are some differing results from some studies. Šíp & Beneš (2016), Janhäll, (2015) and Gromke & Ruck (2010) found that trees can increase the concentration of CO_2, but Jeanjean et al. (2015) showed that trees can reduce ambient concentrations of road traffic emissions. Jeanjean et al. (2015) show that proximity to pollution sources will increase the concentration of a pollutant. Meanwhile, Gromke & Ruck (2010) conducted a study comparing the distribution of road traffic emissions in a street canyon both without trees and with trees. Street canyons with trees are better than street canyons without trees where there is increasing CO_2. Tree planting of high crown porosity can increase concentration by 23%. In addition, a street canyon with tree planting of low crown porosity can increase concentration by 22%. In general, the researchers who say trees can increase CO_2 concentration do simulations using an ideal building; they do not consider the real buildings around the trees. This model ignores the layout and height of actual buildings.

On the other hand, research from Jeanjean et al. (2015) has used real buildings and tree data from LIDAR to reconstruct a 3D representation at the city scale. This research showed that trees have a regionally beneficial impact on road traffic emissions. However, this research shows different results to other researchers. The result demonstrates that trees can reduce ambient concentrations of road traffic emissions by 7%.

Accordingly, these differences in results become interesting to examine more deeply. Therefore, this study aims to evaluate the effect of tree planting in the dispersion of CO_2 from transportation using a real 3D environment. This study will compare the results of simulations between study areas without trees and with trees. Conditions will be considered, such as the characteristics of the buildings, the characteristics of trees, and environmental conditions. Variables of building condition are the layout and height of a building. Variables of trees' characteristics are tree height and shape of the canopy. Variables of the environmental condition are vehicle emissions and wind conditions. Hence this research can contribute to providing more accurate results because it considers actual field conditions. This can then support other research results regarding dispersion of CO_2 in real 3D environments.

2. METHOD

2.1 Study Area

Surabaya city is the capital of East Java Province. Surabaya is geographically located at 07˚09`00 "- 07˚21`00" South Latitude and 112˚36`-112˚54` East Longitude. The area of Surabaya covers a land area of 350.54 km² and an ocean area of 190.39 km². This city has become the second most populous city in Indonesia with a population of more than 3 million people.

The size of the population affects transportation needs. The unevenness of public transportation services has also caused the increase of private vehicles in Surabaya City to rise rapidly. *Figure 1* shows the growth trend of vehicles in Surabaya from 2009 to 2015 (BPS, 2016)

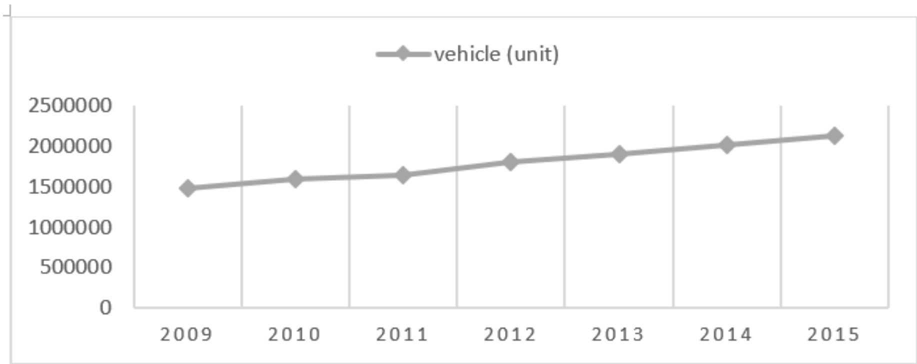

Figure 1. The trend of increasing number of vehicles in Surabaya

This condition causes traffic jams at points in Surabaya and results in heavy emissions to the air. This research therefore focuses on one of the streets in Surabaya city that has a high frequency of traffic jams. The street is Jalan Panglima Sudirman. In 2012, the number of vehicles passing this road reached 130,508 within 16 hours.

Besides that, Jalan Panglima Sudirman also has pedestrians and several planted trees. Trees planted in the pedestrian areas have a linear distribution with various forms of tree characteristics. The length of the path used as a research site is 100 m (*Figure 2*).

Figure 2. Orientation of research area (Jalan Panglima Sudirman) to Surabaya City

2.2 Research Framework

This research focuses on the dispersion of CO_2 along the roadside both without trees and with trees. The comparison of these two conditions aims to evaluate the effect of tree planting in distribution of CO_2 from transportation. Achieving this goal requires several stages of analysis and requires some data to support each analysis. The stages of the analysis process in this study are displayed in the following research framework *(Figure 3)*.

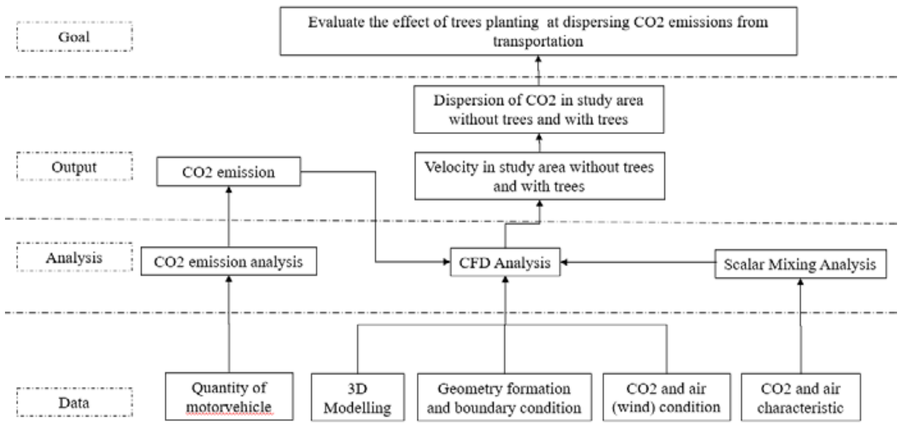

Figure 3. Research Framework

2.3 3D Modelling

An important factor that distinguishes this research from other research is the study area modelling. This study models according to the conditions of the study area. Buildings are modelled according to their size and height, matching the original (*Table 1*). Trees are modelled according to the number of trees, canopy shape, stem condition, tree height, and existing tree distance. There are many types of canopy, such as rounded, umbelliform, oval, columnar, conical, spread, square and vertical. However, all the canopy shapes in this research area are rounded. Other than that, trees differ in height, and diameter of the trunk and canopy (*Table 2*).

The modelling of trees has an assumption to facilitate simulation. This study assumes a canopy base height of 1/3 the canopy top height (*Figure 4*).

This assumption is based on literature that has modelled trees in the same wind tunnel (Gromke & Ruck, 2010; Šíp & Beneš, 2016; Jeanjean et al., 2015).

Table 1. Characteristics of buildings in the study area

Number of Building	Width (m)	Length (m)	Height (m)
1	24	18	12
2	14	30	20
3	20	35	18
4	26	40	16
5	18	40	12
6	40	12	5
7	8	20	10
8	5	5	4

Table 2. Tree characteristics in the study area

Trees on the Left Side				Tress on the Right Side			
Diameter of Trunk	Height	Diameter of Canopy	Shape of Canopy	Diameter of Trunk	Height	Diameter of Canopy	Shape of Canopy
50	12	7	Rounded				
50	12	7	Rounded				
20	5	3	Rounded				
20	5	3	Rounded				
20	5	3	Rounded				
30	14	4	Rounded				
40	14	5	Rounded				
50	14	7	Rounded				
50	14	7	Rounded				
				60	14	8	Rounded
				50	14	7	Rounded
				50	12	7	Rounded
				50	12	7	Rounded
				60	14	8	Rounded
				50	12	6	Rounded
				40	10	5	Rounded
				40	10	5	Rounded
				50	12	6	Rounded

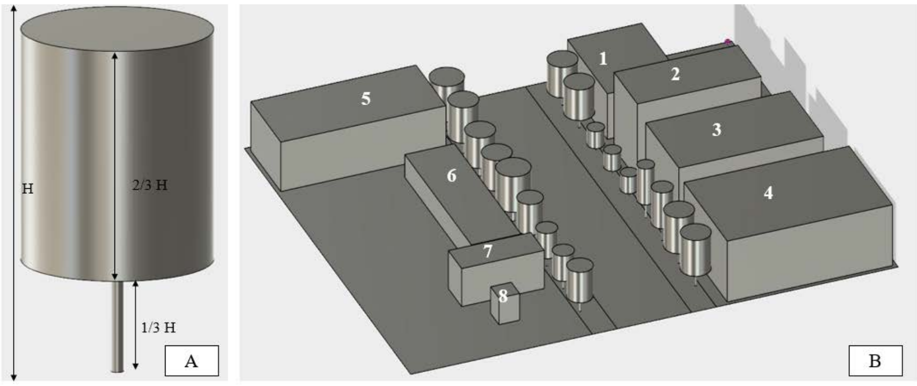

Figure 4. a) Tree modelling in the study area; b) 3D modelling of the research area

2.4 CO_2 Emission Analysis

The volume of CO_2 can be calculated from several sources, such as electricity, vehicle & equipment fuel use, natural gas & fuel oil, commercial flights, charter flights, and hotels & housing. In this study, CO_2 is calculated based on the use of fuel used by each type of motor vehicle. The volume produced by each vehicle is obtained through an average daily traffic survey during peak hour at the study site. There are morning, daytime and afternoon observations conducted over two days, consisting of a weekday and weekend day. After this, the total volume of CO_2 is calculated based on the volume of the motor vehicle. The calculation that can be used to determine the amount of CO_2 produced by vehicles is as follows (AEA, 2012; Hidayat, 2013):

$$CO_2 \text{ emission} = \text{vol} \left({}^{\text{unit}}/_{\text{hour}}\right) \mathbf{x} \text{ street (km) x emission factors}\left({}^{gCO_2}/_{km}\right) \quad \text{Eq. 1}$$

Based on *Equation 1,* there are vehicle emission factors that should be entered into this calculation. Vehicle classification standards used in this research are displayed in *Table 3* (AEA, 2012)

This classification is based on fuel use for each type of motor vehicle. Nowadays, almost all motor vehicles in the world use gasoline or diesel as fuel. These fuels have proven to be the largest sources of CO_2 besides electricity usage. This classification is then used to get an amount of CO_2 in more detail based on fuel use.

Table 3. Vehicle emission factor

Transportation classification	Definition	Average emissions ($kgCO_2/km$)
A	Small petrol car, up to 1.4-liter engine	0.16442
B	Medium diesel car, from 1.7 to 2.0 litre	0.17573
C	Large diesel car, over 2.0 litre	0.23381
D	Small petrol motorbike (mopeds/scooters)	0.08499

There are four transportation classifications with different average emissions. The types of motor vehicles that are included in the first group (A) are private cars, public transport, jeeps, pick-ups, taxis, and vans. The types of motor vehicles that are included in group B are the medium buses, cargo cars, and medium-sized trucks. Group C consists of large trucks and large buses. The last type (D) consists of motorcycles, under the assumption that all motorcycles have a capacity of 0-125cc.

2.5 Computational Fluid Dynamics (CFD)

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to analyse and solve problems that involve fluid flows. Nowadays, there are some CFD software programs that can be used to analyse fluid flows. In this research, CFD analysis is used to simulate the dispersion of CO_2. Two conditions are simulated at this stage. First is the simulation of CO_2 deployment along roadsides without trees. while the second is the simulation of CO_2 distribution along roadsides with trees. The results will show the difference in CO_2 distribution between the two different situations. The spread of CO_2 is modelled through CFD applications. CFD models can resolve three-dimensional distributions of CO_2 dispersion, where the structure of the research area can be more diverse with buildings, streets, and trees. In this study, the software used is CFD Autodesk. This is used because this software allows considering some conditions in the study area environment, whether they be physical or nonphysical conditions.

There are some equations utilised in this simulation (Chung, 2002; Andersson et al., 2012). The CFD model used in this study is the Reynolds-averaged Navier-Stokes (RANS) equations. The Navier-Stokes equations are used in fluid mechanics to describe the movements of fluids. There are two general forms of the Navier-Stokes equations (NSE) that can be used. The following are the conservation of mass (*Equation 2*) and conservation of momentum (*Equation 3)* based on the Navier-Stokes equations:

$$\frac{\partial u_i}{\partial x_i} = 0 \qquad \text{Eq. 2}$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial u_j u_i}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\partial u_i}{\partial t}\right) - \frac{1}{\rho}\frac{\partial p}{\partial x_i} \qquad \text{Eq. 3}$$

Where ρ is the fluid density $(kg\ \ m^{-3})$, u is the fluid velocity $(\ m\ \ s^{-1})$. *i* and *j* represent either x, y, or z (coordinate geometry in boundary).

The Navier–Stokes equations can describe the momentum transfer of flow. The Navier-Stokes equations can be solved numerically using different CFD models know as Direct Numerical Simulation (DNS), Large Eddy Simulation (LES) and Reynolds-averaged Navier-Stokes (RANS). This research uses Reynolds-averaged Navier-Stokes (RANS) to conduct mathematical operations on momentum. The Reynolds decomposition method used to derive the Navier-Stokes equations is a mathematical operation which decomposes the time-averaged and fluctuating components from the steady state component, such that:

$$u = \bar{u} + u' \qquad \text{Eq. 4}$$

$$p = \dot{p} + p' \qquad \text{Eq. 5}$$

Where the steady state components *u* and *p* are on the left-hand side of *Equations 4* and *5*. $\bar{u}$ and $\dot{p}$ are time-averaged, and *u'* and *p'* are the fluctuating components. Following this is the application of the Reynolds decomposition to Navier-Stokes for the conservation of momentum. Limitations with the time-averaged RANS equation are introduced in the Reynolds stress term which accounts for turbulent fluctuations (*Equation 6*):

$$\frac{\partial \overline{u_i}}{\partial t} + \overline{u_j}\frac{\partial \overline{u_i}}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} + \nu\frac{\partial}{\partial x_j}\left(\frac{\partial \overline{u_i}}{\partial x_j}\right) - \frac{\partial \overline{u_i' u_j'}}{\partial x_j} \qquad \text{Eq. 6}$$

The Navier–Stokes equations describe the momentum transfer of flow. But for describing turbulent flows, the Navier–Stokes equations have limitations. The limitation with the time-averaged RANS equation is the introduction of the Reynolds stress term which accounts for turbulent fluctuations. Moreover, after a few mathematical operations on the incompressible and momentum Navier-Stokes equations, the K-ϵ model equation is used for turbulent kinetic energy (*Equation 7*):

$$\frac{\partial k}{\partial t} + \overline{u_j}\frac{\partial k}{\partial x_j} = -\frac{\partial}{\partial x_j}\left(\frac{1}{2}\overline{u_i' u_i' u_j'} + \frac{1}{\rho}\overline{u_j' p'} - \nu\frac{\partial k}{\partial x_j}\right) - \overline{u_j' u_i'}\frac{\partial \overline{u_i}}{\partial x_j} - \epsilon \qquad \text{Eq. 7}$$

These equations are automatically set in simulations using the Autodesk CFD software. In the simulation process, there are three main stages. The first step is pre-processing. In this step, 3D mapping must be input to define the geometry of the area being analysed. The grid formation is then made to determine the character of CO_2 and air, meteorology, and to determine the appropriate boundary condition. The 3rd step is solving. Based on this process, the size of the boundary is also important to consider. This research uses domain size determined by Franke et al. (2007).

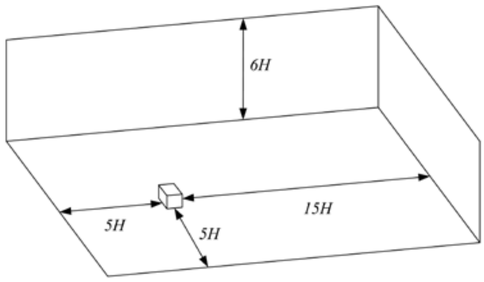

Figure 5. A reproduction of the domain

This research also has several assumptions, such as that air moves in a steady condition, airflow is considered uniform (uniform), air is not compressed (incompressible), or *p* is constant, and wind direction in the environment is deemed to be unidirectional during simulation.

2.6 Scalar Mixing Analysis

This research mixes two fluids to show dispersion, CO_2 and air. These fluids have different characteristics, so the dispersion cannot provide analysis directly without using scalar boundary and property variation; scalar mixing analysis is used to simulate the mixing of two fluids. Scalar boundary has a function to track the relative concentration of two fluids. Accordingly, this is needed to distinguish the distribution of two fluids. The scalar boundary condition of 0 is used to represent air as the 1st fluid, and a scalar boundary condition of 1 to represent CO_2 as the 2nd fluid. A diffusion coefficient is a required input to simulate the mixing. The diffusion coefficient for mixing air and CO_2 is 0.16 cm^2/s. This value is used to control the mass diffusivity of scalar quantities into other fluids. A value of 0 will prevent the diffusion of scalar quantities. This amount is D_{AB} in Fick's Law:

$$J_A = -\rho D_{AB} \nabla m_A \quad \text{Eq. 8}$$

Where j_A is the mass flux of the fluid. This is how much fluid is transferred (per time and per unit area normal to the transfer direction). It is proportional to the mixture mass density, and to the gradient of the species mass fraction, m_A. The units of the diffusivity coefficient are length squared per time.

3. RESULT

3.1 Identification Climate Condition in the Study Area

Surabaya city is a tropical city that has only two seasons, dry and rainy seasons. The dry season occurs when monthly rainfall is below 60 mm and vice versa. Generally, the dry season occurs from April-September, while the rainy season occurs from October-March. In fact, these conditions change every year. In 2017, the rainy season was longer than the dry season. This season lasted from November-June, whereas the dry season lasted from July-October. *(Figure 6)*. This condition caused the average temperature in the city to be around 28.7° C *(Figure 7).* 36 ° C is the highest the temperature in Surabaya reaches, and the lowest temperature is 24° C. The highest temperature occurs during the dry season in the daytime, and the lowest temperature occurs during the rainy season in the night and morning. On the other hand, the humidity in the city is also quite high. The 5-year average for humidity ranges from 70.7-77.9%.

Other aspects of the climate condition that will be used in this research simulation are wind direction and wind speed. Wind in the study area comes from five directions: North, North-East, East, West, and West-North. However, most winds come from the East and North. This simulation uses the northern direction because it is parallel to the road, meaning the simulation results will be clear. Therefore, the wind speed that will be used as the air velocity in this research is 1.6 knots.

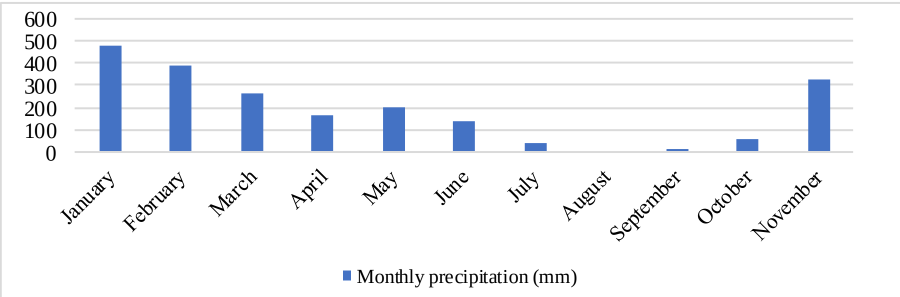

Figure 6. Monthly precipitation recorded by the local weather station in 2017

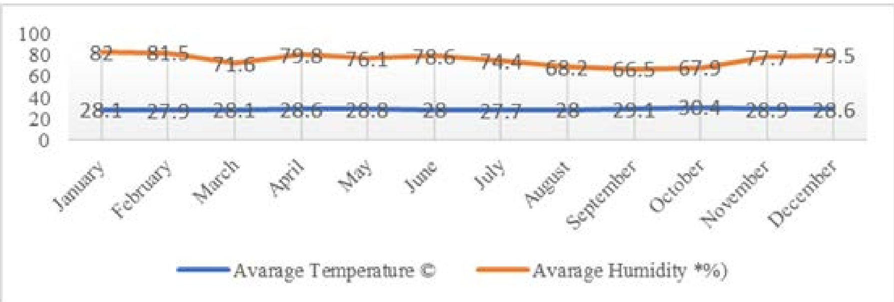

Figure 7. Average temperature and humidity recorded by the local weather station in 2017

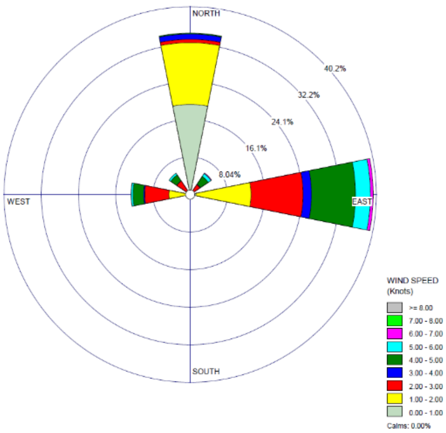

Figure 8. Wind speed and wind direction recorded by the local weather station in 2017

3.2 CO_2 Emissions from Transportation

The amount of CO_2 that comes from transportation depends on the number of vehicles passing by. Before calculating the value of CO_2 originating from motor vehicles, it is necessary to know in advance the number of vehicles crossing the road every hour. The number of vehicles was obtained through a direct survey at the study location during peak hour. Peak hours in the research area occur in the morning, daytime and afternoon, resulting in a calculation of the number of vehicles passing by within one hour at each peak hour. In the morning, observation is conducted from 7-8 am. In the daytime, it is conducted from 12 am until 1 pm, and in the afternoon it is conducted from 6-7 pm. The survey is conducted for two days, on a weekday and a weekend day. *Table 4* displays the number of vehicles for two days at each peak hour.

Table 4. The Number of Vehicles in the Research Area

No	Transportation Type	Total		
		Morning	Daytime	Afternoon
1	Motorcycle	7029	4768	8644
2	Private cars	2207	1104	2836
3	Public transport/Taxi	172	59	103
4	Pick-up / Box	1	2	0
5	Medium/Minibus	227	211	264
6	Medium truck	64	296	139
7	Large buses	2	5	2
8	Large trucks	2	4	0

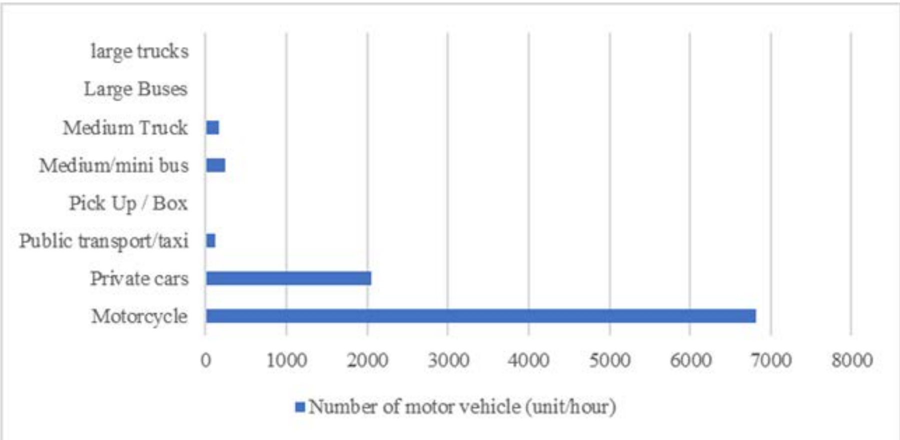

Figure 9. Number of motor vehicles by type (unit/hour)

The motorcycle type has the most significant number of vehicles passing through the study site (*Figure 9*). Motorcycles are vehicles that are widely used by the public. People prefer to use motorcycles because they simplify and accelerate mobility. The number of motor vehicles based on the type is necessary to obtain to calculate the amount of CO_2 because the emission factor of each classification is different. *Table 5* below shows the average number of vehicles that pass every hour at the study site.

Table 5. Average daily traffic

Classification	Type of Motor Vehicle	Amount (unit/hour)	Amount per Type (unit/hour)
Type A	Private car	2050	2161
Type A	Public transportation	111	
Type B	Mini bus	233	
Type B	Pick-up / Box	1	400
Type B	Mini trucks	166	
Type C	Big bus	3	
Type C	Truck 2 axis	1	5
Type C	Truck 3 axis	1	
Type D	Motorcycle	6814	6814
TOTAL		9380	9380

Each type of vehicle produces different emissions. *Table 6* shows the amount of CO_2 generated by each vehicle type.

Table 6. CO2 Emission in the research area

Transportation Type	Average Daily Traffic (unit/hour)	Length of the Street (km)	Emission Factor	CO_2 Emission (kg/hour)
Type A	2161	0.1	0.16442	35.5
Type B	400	0.1	0.17573	7.0
Type C	5	0.1	0.23381	0.1
Type D	6814	0.1	0.08499	57.9
TOTAL				100.6

Based on the result, transportation type D (motorcycle) contributes the highest amount of CO_2 at the study location. The CO_2 value of motorcycles reaches 57.9 kg/hour and the total of CO_2 in one hour is 100.6 kg/hour. In one day, the transportation therefore produces 2,414.4 kg.

This value of CO_2 will be used in simulation to display its dispersion as the mass flow rate. Two fluids will be mixed in this research, the 1st fluid is air (wind) and the 2nd fluid is CO_2. These fluids have different characteristics and velocity.

3.3 Velocity in Study Area without Trees and with Trees

Velocity needs to be known because it will affect the distribution of CO_2 at the study site. The velocity of air at the study location is known by conducting simulations using CFD analysis. The software used to process this analysis is CFD Autodesk 2018 free version for students. There are several formulas that must be used to find out this velocity. The CFD model used in this study is the Reynolds-averaged Navier-Stokes (RANS) equation. The Navier-Stokes equations are used in fluid mechanics to describe the momentum transfer of flow. But for turbulent flows, this simulation uses the K-ϵ model equation.

There is another essential factor to consider in this simulation, which is the two different fluids. This simulation has air and CO_2 that will mix in this process. Therefore, the fluid density $(kg\ m^{-3})$, and the fluid velocity $(\ m\ s^{-1})$ from CO_2 and air must be considered. The density of air used in the CFD analysis is 1.20473 kg/m^{3,} and the density of CO_2 is 1.82973 kg/m^3. The fluid velocity of air is the average wind speed in the study area. Based on *Figure 8*, the wind speed used in this simulation is 1.6 knots. Meanwhile, the velocity from CO_2 uses a mass flow rate that has been calculated in the previous analysis (*Table 6*).

This simulation was carried out in two different modellings. There is modelling both without trees and with trees, so the impact of trees on velocity will be known. The result of velocity in the study area is shown in *Figure 10 (A and B).*

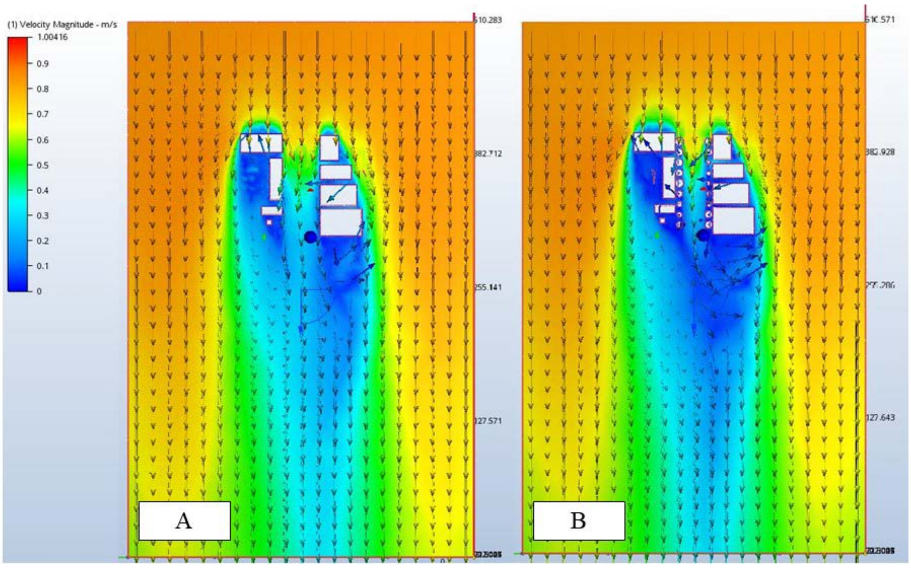

Figure 10. a) Velocity in the study area without trees, b) Velocity in the study area with trees

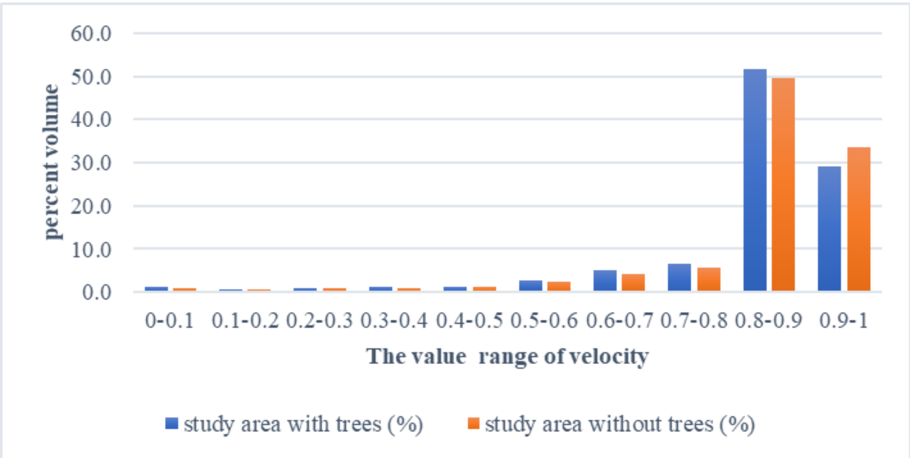

Figure 11. The velocity comparison in the study area with trees and without trees

Figure 11 displays that the study area with tree plantings has a velocity of magnitude lower than the study area without trees, especially around buildings and other trees. This can be seen from a blue colour (low velocity) that is spread more in area B than in area A. Based on the comparison, this result indicates that trees can decrease the velocity. Figure 10 displays the percentage of velocity in the two different models using the value range. The velocity in the study area without trees is higher than in the study area with trees. Tree plantings can decrease 4.3% velocity in the value range 0.9-1 m/s. Therefore, this shows that tree plantings could block the speed of the wind passing through it so that the air does not move as fast as usual.

3.4 Dispersion of CO_2 in Study Area without Trees and with Trees

Several studies have shown that trees can influence the distribution of CO_2 but there are differences in their results. Some researchers have said that trees could increase the concentration of emissions, while on the other hand, other researchers have shown that trees can decrease the concentration of emissions. However, the weakness of these studies is that they are not using models that are close to reality. Many variables are ignored in the studies, such as building layout, building height, canopy shape, canopy diameter, the distance between trees and stems, the real value of emissions, and wind condition. Meanwhile, this research considers these variables in 3D modelling and simulation.

This simulation uses CFD analysis and scalar mixing analysis to determine the distribution of CO_2, and uses a scalar mixing analysis to analyse the distribution of two fluids. 0 scalar is used to display the value of air and 1 scalar to display the value of CO_2. At this last stage of analysis it will be known the effect of tree planting on increasing CO_2 by knowing how much influence this has. The value of the flow that must be entered in the simulation has a different value for either CO_2 or air; CO_2 uses mass flow rate and air uses wind speed as the flow rate. The value of mass flow rate and wind speed are obtained from the previous analysis. The value of mass flow rate for CO_2 is 100.6 kg/h. This amount is obtained from CO_2 emission analysis. The wind speed in this simulation is 1.6 knots. This value is obtained from the identification of climate conditions in the study area.

The simulation in this study shows the dispersion of CO_2 and air using scalar 0-1. Scalar 0 shows the dispersion of air and scalar 1 display the dispersion of CO_2. The range of values approaching scalar 0 shows more air concentration than CO_2. Simulation results show that CO_2 from transportation is spread around the road and side of the road (*Figure 12*). The range of values approaching scalar 1 shows high CO_2 concentration. The results of this study found that trees could break down CO_2 concentrations on the road. Study areas without trees have higher concentrations on the road than study areas with trees (*Figure 13*). The highest concentration in the study area without trees is 0.8 scalar. Meanwhile, in the study area with trees, the highest concentration is 0.7 scalar. This means that the study area with trees decreases the concentration of CO_2 in the road space.

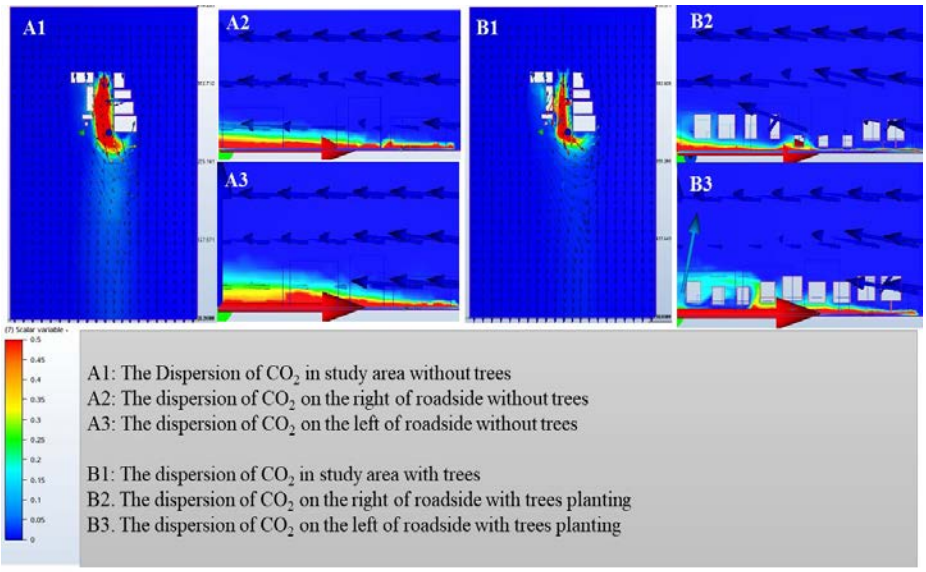

Figure 12. The dispersion of CO_2 in study area without trees and with trees

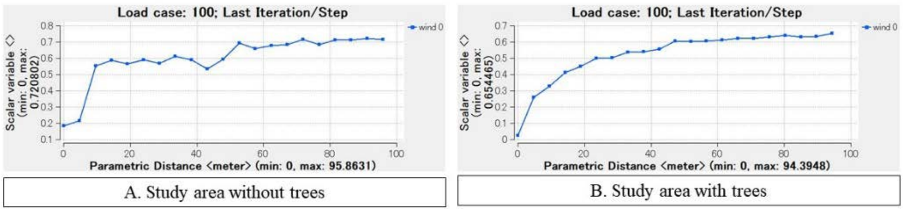

Figure 13. CO_2 concentration around the road

Another result displays the dispersion of CO_2 on the roadside or near trees (*Figure 14*). The difference of CO_2 concentration on the left and right roadsides are caused by the different layout of buildings and trees on the right and left of the roadside.

This study area has two sides of the road, the left and right roadsides. On the right roadside without trees, the highest concentration of CO_2 just reaches 0.25 scalar. This means air is dominant on this side. In addition, on the right side with trees, the concentration of CO_2 reaches 0.5 scalar, meaning that trees can increase CO_2 by 25% on the right of the roadside. The same result occurs on the left of the roadside. The highest concentration on the left of the roadside without trees is 0.5 scalar. Otherwise, the scalar value on the left side with trees reaches 0.6, meaning that trees can increase CO_2 concentration by 10% on the left side.

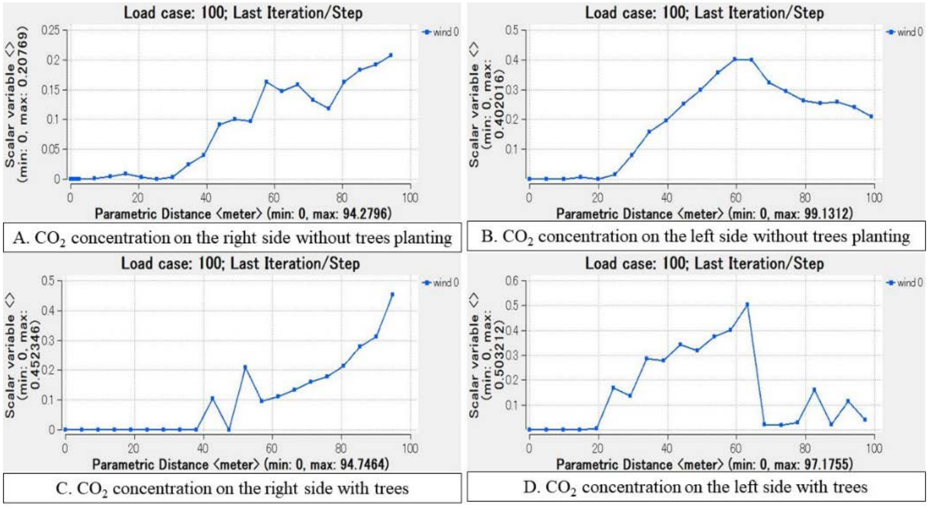

Figure 14. CO_2 concentration on the roadside (around trees)

4. CONCLUSION

This research focuses on simulating the dispersion of CO_2 from transportation using a real 3D environment. Simulation in this study considers several variables such as the building layout and height, canopy shape and diameter, tree height and wind condition to simulate the dispersion of CO_2 similar to reality. This study found that these variables influence the distribution of CO_2. This can be seen from the different concentration levels on the right and left of the roadside in accordance with the condition of the variable. However, this study does not focus on this matter, so this research is unable to explain the magnitude of the influence of these variables on the distribution of CO_2.

This research focuses on the effect of tree plantings on the CO_2 concentration. The result of this research found that trees have an impact on velocity. Tree plantings can decrease velocity by 4.3% in the value range 0.9-1 m/s, meaning tree plantings can block the speed of the wind so that air does not move as fast as usual. This condition has an impact on increasing CO_2 concentration on the roadside (around the trees) and decreases CO_2 concentration on the road.

Trees can increase CO_2 by 25% on the right of the roadside and increase CO_2 concentration by 10% on the left side. The difference of CO_2 concentration on the left and right of the roadside are caused by the different layout of building and tree characteristics on the right and left of the roadside. On the other hand, trees can break down CO_2 concentrations on the road, so trees can decrease CO_2 concentration in this area. The highest concentration on the road without trees is 0.8 scalar, while on the road with trees it is 0.7 scalar.

Based on this result, further research is needed to analyse variables that have an impact on increasing CO_2 concentration.

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