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Evaluation of the Shape of Tree Crowns to protect Air Quality on the Roadside from the CO_2 Dispersion produced by Transportation

Nurul Aini[1*], Zhenjiang Shen[2], Respati Wikantiyoso[1], Pindo Tutuko[1], and Ardiyanto Maksimilianus Gai[3]
1 Department of Architecture, University of Merdeka Malang
2 School of Environmental Design, Kanazawa University
3 Department of urban and regional planning, National Institute of Technology (ITN) Malang
** Corresponding Author, Email: nurul.aini@unmer.ac.id*

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Abstract: This research focuses on evaluating the shape of a tree's crown and its impact on CO_2 dispersion from transportation. CO_2 emissions from motor vehicles can quickly spread and cause poor air quality on the roadside. The design of tree planting is a way to control air quality by reducing CO_2 dispersion. Therefore, the tree's crown shape is an essential element to consider when planting trees, as different crown shapes can have different effects on CO_2 dispersion. Selecting the wrong shape for a tree's crown can have negative consequences for controlling CO_2 dispersion on the roadside.

To evaluate the impact of different tree crown shapes, this research examines five common shapes found in Surabaya city: round, umbrella, oval, conical, and columnar. The study area is created in 3D modelling using Sim Studio tools software. Computational fluid dynamics (CFD) analysis is then used to simulate the spread of CO_2 emissions on the roadside. The simulation involves four scenarios that consider CO_2 dispersion in 0°, 90°, 180°, and 270° wind direction. The last step of this research involves validating the data using correlation analysis.

The results demonstrate that the shape of a tree's crown has a significant impact on CO_2 dispersion. The oval, conical, and columnar shapes are the most suitable for planting along the roadside because they can effectively reduce the dispersion of CO_2 emissions. In contrast, the round and umbrella shapes have the highest CO_2 distribution and are unsuitable for planting along the roadside.

1. INTRODUCTION

Urban areas are currently experiencing worsening air quality problems due to increasing vehicle emissions. The Environmental Protection Agency (EPA, 2016) indicates that transportation can contribute 34% of CO_2 in the air every day. The good air quality in the outdoor area should have CO_2 concentrations between 0.025%–0.04% (250–400 ppm) in the air according to Wisconsin Department of health service (2019). However, CO_2 dispersion from transportation can cause poor air quality in urban areas, which can impact human health. These environmental problems can be overcome by applying the concept of a green city. Many cities in the world have adopted the green city concept, although only a few attributes have been successfully applied to solve environmental problems. One effectively used attributes in urban areas is green open space (Subadyo, Tutuko, et al., 2019).

Related to the problem of low air quality due to the spread of CO_2 from transportation, the roadside is the area most affected by CO_2 dispersion. Trees are an essential element in green open space to address this problem. Planting trees on the roadside can be a solution to decrease CO_2 concentration on the roadside. Gromke and Ruck (2010), Janhäll (2015), Li, Lu, et al. (2016), Šíp and Beneš (2016), Aini and Shen (2019) have shown that areas with trees have lower dispersion of traffic emissions than sites without trees. However, the existence of these trees must also be supported by a good design. The wrong tree planting design can cause high levels of vehicle emissions on the side of the road. Janhäll (2015) shows that the impact of tree planting on urban air quality depends on the vegetation design, so the element of vegetation design on the roadside should be considered. Some elements can impact the dispersion of traffic emissions. Morakinyo and Lam (2016) and Aini and Shen (2020b) have shown that the position of the tree row influences the dispersion of that emission. The avenue-tree layout, such as the position and volume of the crown (Gromke and Blocken, 2015; Gromke and Ruck, 2007; Pretzsch, Biber, et al., 2015), column and row spacing (Nursery, 1999) also affects the distribution of vehicle emissions. Moreover, research from Aini and Shen (2020a) shows that some tree planting patterns on the same roadside can distribute different amounts of emissions on the roadside.

Hence, this research builds upon previous studies to find the appropriate tree planting design by the roadside based on a design element that has not been studied much, which is the crown shape. This study uses the crown shape of trees commonly planted on the roadside in tropical countries as our case study. In previous research, Hofman, Bartholomeus, et al. (2020) have proven that the morphology of a single tree canopy affects the local dispersion of atmospheric particles. Desyana, Sulistyantara, et al. (2017) also proved that rounded and columnar headers affect transport emissions. However, there are only two types of crowns studied in previous research, even though there are many tree crown shapes. As a study area for this research, Indonesia has eight crown shapes: rounded, umbrella, oval, conical, spread, square, columnar, and vertical (Indonesian Ministry Of Public Works, 2012). Moreover, these previous studies have not found which crown shape of the tree is suitable for planting on the roadside to maintain air quality from the CO_2 produced by transportation.

Therefore, selecting the tree's crown shape is crucial to maintaining near-road air quality exposed to CO_2 vehicle emissions. This research aims to provide alternative tree crown shapes for planting trees on the roadside that can reduce CO_2 dispersion. This research uses CFD to simulate the dispersion of CO_2 in some alternative crown shapes on the roadside. This method was not used in previous research to analyze the shape of the tree. This research can contribute to urban planners and architects in selecting trees when designing tree patterns on the roadside or pedestrian ways to maintain environmental air quality.

2. MATERIAL & METHOD

2.1 3D modelling of crown shape

Indonesia has eight types of crown shapes for trees planted in urban areas, but not all of them are suitable for roadside planting (Indonesian Ministry Of Public Works, 2012). This study focuses on five crown shapes that are commonly planted along urban roadsides (*Figure 1*): rounded, umbrella, oval, conical, and columnar. Rounded tree crowns are frequently planted on the side of the road for their aesthetic value. In Indonesia, Kiara Payung (*Filicim decipiens*) and Beautiful Violin (*Ficus pandurata*) are common species with rounded crowns planted on the roadside, while in other countries, American hornbeam, hedge maple, American yellowwood, bur oak, black maple, flowering dogwood, hackberry, and redbud are commonly planted. Besides the rounded shape, the umbrella shape is also commonly found on urban roadsides in Indonesia. The umbrella shape has a wide base that tapers towards the top. Bungur (*Lagerstroemia loudonii*) and Dadap (*Erythrina sp*) are commonly planted trees with this shape.

This study also analyses the oval crown shape, which has a characteristic canopy that spreads from the bottom to the top. Birch, Southern magnolia, White ash (*Fraxinus Americana*), Purpleblow (*Acer Truncatum*), Tanjung (*Mimusops Elengi*), and Johar (*Cassia Siamea*) are examples of tree species with this shape. The conical crown shape has a pyramid shape, with a wider base and a conical top. Trees with this shape include Cemara (*Casuarina Equisetifolia*), Glodokan (*Polyalthea Longifolia*), Kayu Manis (*Glycyrrhiza glabra*), and Kenari (*Cannarium Communeae*). The last crown shape analysed in this study is the columnar shape, which has a crown resembling a column or a cylinder. Trees commonly found in this shape include Bambu (*Bambusa sp*), GlodokanTiang (*Polyalthea sp*), cherry, sugar maple, European hornbeam, red maple, Lombardy poplar, quaking aspen, and tuliptree.

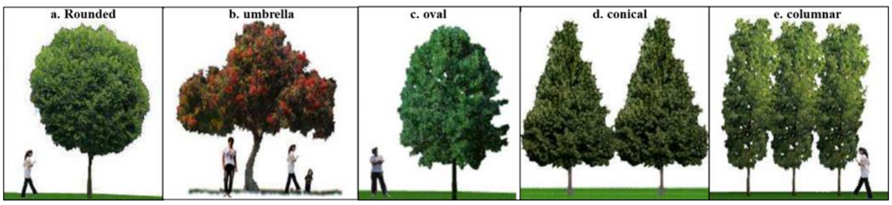

Figure 1. The basic shape of the tree crown (Indonesian Ministry Of Public Works, 2012)

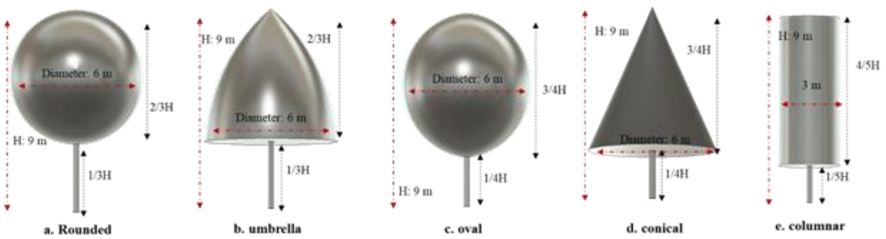

Figure 2. The shape of tree crown in 3D modelling

The five types of tree crowns have distinct characteristics in terms of tree height and canopy diameter. Trees with rounded, umbrella, oval, and conical crowns are medium-sized, with maximum heights of 10-15 meters and canopy diameters of 10-15 meters. In contrast, trees with columnar crowns can grow taller than other types but have smaller diameters. This study assumes a specific tree crown shape, as shown in *Figure 2*, and models it based on a tree height of 9 meters. The canopy diameter used for rounded, umbrella, oval, and conical crowns is 6 meters, while for columnar crowns, the diameter is 3 meters.

2.2 CO_2 Emission Calculation

The fluid simulated in this research is the CO_2 emissions emitted from transportation. The amount of this emission can be calculated using the following formula (AEA, 2012; Hidayat, 2013).

$$CO_2 emission = vol\ (unit/hour) \times street\ (km) \times emission\ factor\ (gCO_2/km) \tag{1}$$

According to this equation, the results of emission calculations for Panglima Sudirman Street (Jalan Panglima Sudirman) in Surabaya City, Indonesia, are presented in *Table 1*. The analysis is based on vehicle count data, road length, and an emission factor. The vehicle count data was obtained from the average daily traffic during peak hours on weekdays and weekends. The emission factor used in this research is based on (AEA, 2012). This data is used for the emission calculation in the CFD analysis.

Table 1. Data for vehicle emission calculation

Classification	**Definition**	**Type of motor vehicle**	**Average Daily Traffic (unit/hour)**	**Emission Factor ($kgCO_2/km$)**
Small car	Small petrol car, up to 1.4-litre engine	Private car Public Transportation	2050 111	0.16442
Medium car	Medium diesel car, from 1.7 to 2.0 litre	Minibus Pick Up / Box Mini Trucks	233 1 166	0.17573
Large car	Large diesel car, over 2.0 litre	Big bus Truck 2 axis Truck 3 axis	3 1 1	0.23381
Motorcycle	Small petrol motorbike (mopeds/scooters)	Motorcycle	6814	0.08499

2.3 CFD Simulation

2.3.1 The geometry of physical environmental conditions

Creating the geometry of 3D models is an important step before conducting simulations in CFD. The SimStudio tool from Autodesk is used to develop 3D models. The study area chosen for this research is Jalan Panglima Sudirman in Surabaya City, Indonesia. This road is suitable as a research sample because it has a roadside on the right and left, various building layouts, and building heights around it. Moreover, it also has a high density of motor vehicles during peak hours.

Based on the literature review of crown shapes *(Figure 3)*, this research will analyze five shapes of tree crowns. Therefore, five different models with varying tree crown shapes will be simulated using CFD. This research builds the physical environmental situation according to the actual location in the study area. The 3D models are based on the actual conditions, such as building height, building layout, the spacing between trees, and the average tree height.

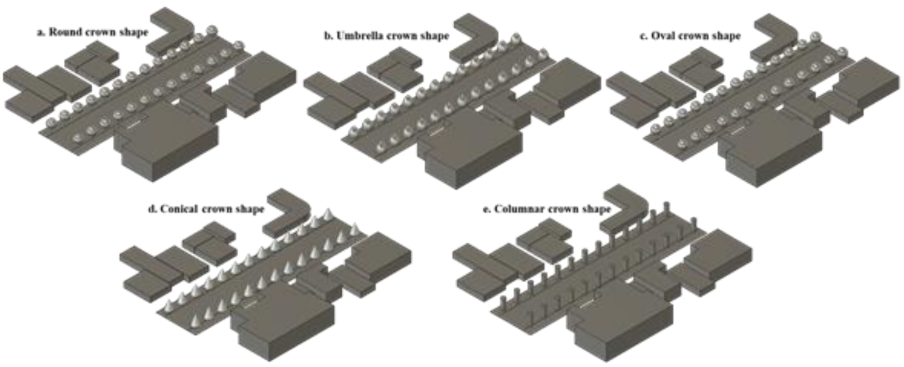

Figure 3. Five study area with different of tree's crown shape

2.3.2 Computational domain (Domain size and the boundary condition)

The next step is to determine the computational domain. The computational domain refers to a simplified representation of the physical domain in terms of geometry and size, as well as the boundary conditions for that domain. This computational domain must retain all the essential physical features of the problem while ignoring small details (D. Li, 2008).

For this research, the domain size was determined based on previous studies by Franke et al. (2004, 2007). which is commonly used for urban research, especially in street canyons or pedestrian ways. Based on this, the inlet and lateral in the urban area simulation should be positioned 5 Hmax away from the building. The outflow boundary should be a minimum of 15 Hmax away from the building. The top boundary should be at least 5 Hmax away from the building. Hmax represents the size of the tallest building in the model *(Figure 4.)*.

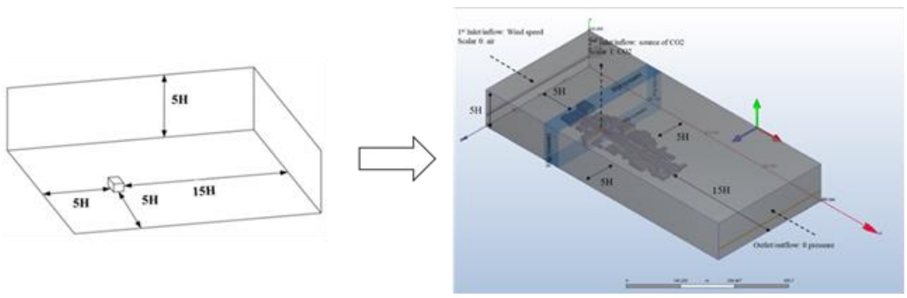

Figure 4. Domain size and the boundary condition

After determining the domain size for the simulation, the next step is to assign the boundary conditions. In this step, we need to assign some surfaces, including the inlet, outlet, lateral, and top boundaries. For the top and lateral conditions, a slip/symmetry boundary is assigned on this surface. The slip condition causes the fluid to flow along a wall instead of stopping at the wall. It typically occurs along a wall. The outflow/outlet condition is a static pressure with a value of 0. The inlet comes from two sources, which are the wind and CO_2 sources. This part will be explained in the next section.

2.3.3 Scalar mixing analysis

After determining these fluid conditions, there is one important thing that has to be considered in this simulation: mixing two different fluid characteristics. Air and CO_2 have different densities. Therefore, scalar mixing analysis is needed to mix two fluids, where A is scalar 0 (air), and B is scalar 1 (CO2) (Autodesk, 2019).

$$J_A = -\rho D_{AB} \nabla m_A \quad (2)$$

J_A is the mass flux of air. This is how much air is transferred (per time and unit area normal to the transfer direction). It is proportional to the mixture mass density (ρ_{AB}). The density of air (ρ_A) is 1.2047 e-6 g/mm^3, and the density of carbon dioxide (ρ_B) is 1.773e-6 g/mm^3. D_{AB} is the diffusion of scalar quantities based on Fick's Law. The diffusion coefficient to mixing air and CO_2 is 0.16 cm^2/s. The units of the Diffusivity coefficient are length squared per time. This simulation uses 3D modelling, so J_A is proportional to the gradient (∇) of the species mass fraction (m_A).

2.3.4 Mesh Sizing

The last step before proceeding to the solving section in the simulation is mesh sizing. This part is crucial for computational calculation in CFD. The geometry of the 3D modeling will be divided into elements and nodes. An element in mesh sizing is defined as a piece of geometry, while a node is a corner of each element. This research uses tetrahedral mesh sizing with four-sided triangular-faced elements *(Figure 5)*. Tetrahedral mesh sizing is commonly used for 3D modeling.

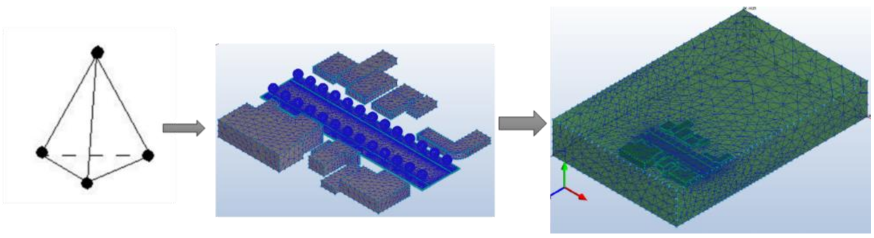

Figure 5. Process Mesh Sizing in CFD Autodesk

2.3.5 Solving in CFD analysis

In this stage, the simulation will be run. Hence, some equations should be chosen to analyse the distribution of CO_2. The Navier-Stokes equations (NSE) are used in the simulation to describe the movement of fluids, which are the moving air and CO_2. The NSE and continuity equations serve as the basis for modelling fluid motion. The law of motion that occurs in solids is authentic for all things consisting of liquids and gases. Fluids and solids differ in movement, which fluid can distort without limit. For example, if shear stress is given to a fluid, then particles of the fluid will transfer relative to each other. If the application of the shear force is stopped, it will not return to its original location. So, the analysis of fluids needs to take into account distortions (Sayma, 2009).

Therefore, there are some assumptions in this research simulation. Air moves under steady conditions and is considered incompressible or of constant density (ρ). The wind direction comes from one direction, and it is considered unidirectional during the simulation. This research uses turbulent airflow, not laminar, because it considers different characteristic tree planting patterns.

Therefore, to analyse a concentration gradient in the fluids, this research needs the species continuity equations involving the mass transport of chemicals. Accordingly, this energy formula would have an additional term to account for energy transport due to species diffusion. Based on the above restrictions in mind, the governing equations for the movement of air are steady-state, turbulent, three-dimensional modelling, and incompressible (conservation). So, the following equation for the conservation of mass (Equation 3.) (B.Andersson, R. Andersson, et al., 2012; Chung, 2002; Sayma, 2009):

$$\frac{\partial_\rho}{\partial_t} + \nabla.(\rho.\mathcal{U}) = 0 \quad (3)$$

$$\frac{\partial(\rho.\mathcal{U})}{\partial t} + \nabla.(\rho.\mathcal{U}.\mathcal{U}) = -\nabla P + \nabla_\tau + \rho \quad (4)$$

Where:

$\frac{\partial_\rho}{\partial_t}$ is the partial derivative of ρ with respect to t

ρ is density; and

t is time.

Tensor gradient (∇) is the stress variable. The stress variable is based on Galilean invariant.

u is velocity; and

∇u is flow velocity

Meanwhile, thisthe following equation is used to calculate the conservation of momentum based on Navier-Stokes EquationsNSE in 3D modelling (B.Andersson, R. Andersson, et al., 2012; Chung, 2002; Sayma, 2009)

$$x - component: \frac{\partial(\rho.u)}{\partial t} + \nabla.(\rho.u.u) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}\rho.g_x \quad (5)$$

$$y - component: \frac{\partial(\rho.v)}{\partial t} + \nabla.(\rho.v.u) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z}\rho.g_x \quad (6)$$

$$z - component: \frac{\partial(\rho.w)}{\partial t} + \nabla.(\rho.w.u) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\rho.g_z \quad (7)$$

Where:

ρ is the density

$\mathcal{U}$ is the flow velocity

∇ is divergence

p is the pressure

t is time

τ is the deviatoric stress tensor; and

g represents body accelerations acting on a the continuum, for example, gravity, inertial accelerations, electrostatic accelerations, and so on.

Another consideration in this research simulation is the use of different tree-planting designs in each simulation. Therefore, turbulent air flows are employed. However, the NSE have limitations in analysing turbulent flows. To address this, the time-averaged Reynolds-Averaged Navier-Stokes (RANS) equation will be solved, which introduces the Reynolds stress term to account for turbulent fluctuations. Therefore, the K-ε model equation is used to calculate the turbulent kinetic energy for the CFD simulation. The K-ε model consists of two equations: turbulent kinetic energy (k) and the dissipation rate of turbulent kinetic energy (ε) (B. Andersson, R. Andersson, et al., 2012; Chung, 2002; Sayma, 2009).

The formula for turbulent kinetic energy k:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right]+2\mu_t E_{ij}E_{ij}-\rho\varepsilon \tag{8}$$

Equation of dissipation ε

$$\frac{\partial(\rho \varepsilon)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_i}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t E_{ij}E_{ij}-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{9}$$

Where:

ρ is the fluid density $(kg\ m^{-3})$;
u is the fluid velocity $(\ m\ s^{-1})$;
i represents x, and *j* represents x, y, and z (coordinate geometry of the boundary);
u_i represents the velocity component in the corresponding direction;
E_{ij} represents the component of the rate of deformation; and
μ_t represents turbulent viscosity, which is $\mu_t\ =\rho C_\mu\ \frac{k^2}{\varepsilon}$. .

Based on that, the equation has some standard constants that should be divided. These are σ_k, σ_ε, $C_{1\varepsilon}$, $C_{2\varepsilon}$ and C_μ . The values of the standard constants are follows:

$\sigma_k\ = 1.00$ $\sigma_\varepsilon\ = 1.30$ $C_{1\varepsilon}= 1.44$ $C_{2\varepsilon}= 1.92$ $C_\mu= 0.09$

3. RESULT AND DISCUSSION

3.1 The amount of CO_2 emission (1st fluid) from transportation in the study area

The crown shape available for planting on the roadside in this research can be analyzed through simulation of CO_2 dispersion in the different crown shapes of the study area. This simulation involves two fluids: CO_2 emissions from transportation and air as a second fluid in the study area. The CO_2 emissions are calculated based on *Equation 1* and the data in *Table 1*. Some data are calculated in this step, such as vehicle number, road length, and emission factor for every transportation type. The results of the CO_2 emission calculation are displayed in *Table 2*. The calculation results show that the highest vehicle emissions are generated by motorcycles at 231.6 kg/hour. The second-highest CO_2 emission value is produced by small cars, including private cars and public transport, at 142.1 kg/hour. The total CO_2 emissions in the study area are 402.4 kg/hour. This value becomes the basic data for running the simulation.

Table 2. Vehicle emission (1st fluid)

Transportation		**Average daily traffic(unit/hr)**	**Length of the street (km)**	**Emission factor ($kgCO_2$/km)**	**CO_2 emission (kg/hr)**	**Total CO_2 emission (kg/hr)**
Classification	**Type**					
Small car	Private cars	2050	0.4	0.16442	134.8	142.1
	Public transport	111	0.4	0.16442	7.3	
Medium car	Pick up / Box	1	0.4	0.17573	0.1	28.2
	Medium/mini bus	233	0.4	0.17573	16.4	
	Medium Truck	166	0.4	0.17573	11.7	
Large car	Large buses	3	0.4	0.23381	0.3	0.5
	Large trucks	2	0.4	0.23381	0.2	
Motorbike	Motorcycle	6814	0.4	0.08499	231.6	231.6
TOTAL					402.4	402.4

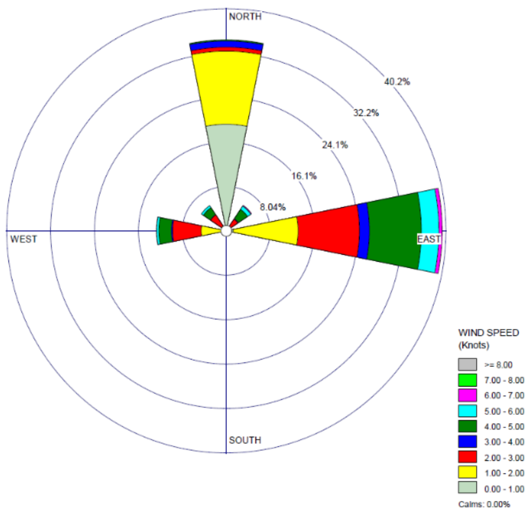

Figure 6. Wind speed and wind direction in 2017

3.2 The source of wind direction (2nd fluid) from transportation

The second fluid that serves as the basic data for running the simulation is air. Moving air, which is wind, in the study area will affect the distribution of CO_2. The value of air is obtained from the Local Weather Data in Surabaya City. The simulation in this research uses the highest wind speed, which is 10 knots or 5.14 m/s. Besides wind speed, wind direction also affects the distribution of CO_2 which this research also considers. Based on *Figure 6*, winds dominance comes from two directions which are 0° and 90° wind direction. Therefore, this research has two simulation scenarios. The first scenario is CO_2 dispersion.

3.3 CO_2 dispersion in the study area with different crown shapes

3.3.1 CO_2 dispersion at different altitude in 0° wind direction

The modelling simulated CO_2 dispersion in the five study areas from two wind directions. First, the wind comes from 0° wind direction. The results indicate that the tree's crown shape influences CO_2 dispersion, which is due to the differences in CO_2 dispersion in every tree's crown shape. *Figure 7* displays the CO_2 dispersion in five tree crown shapes at an altitude of 1.8 meters. According to this figure, the rounded tree's crown has the highest CO_2 dispersion of other crown shapes, which is 47.1%. Meanwhile, the oval tree crown has the lowest CO_2 dispersion among other tree crowns, which is 38.8% CO_2 dispersion. This result indicates that the oval tree's crown shape can decrease CO_2 dispersion more effectively than other scenarios.

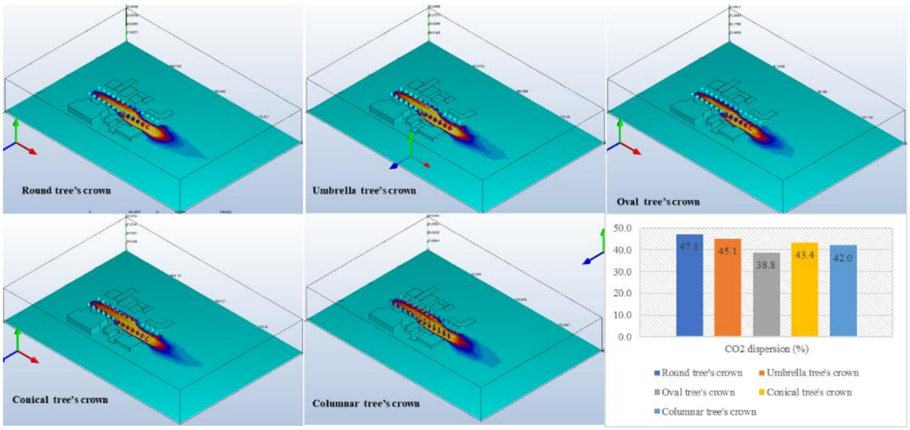

Figure 7. CO2 dispersion at an altitude of 1.8 meters based on 0° wind direction

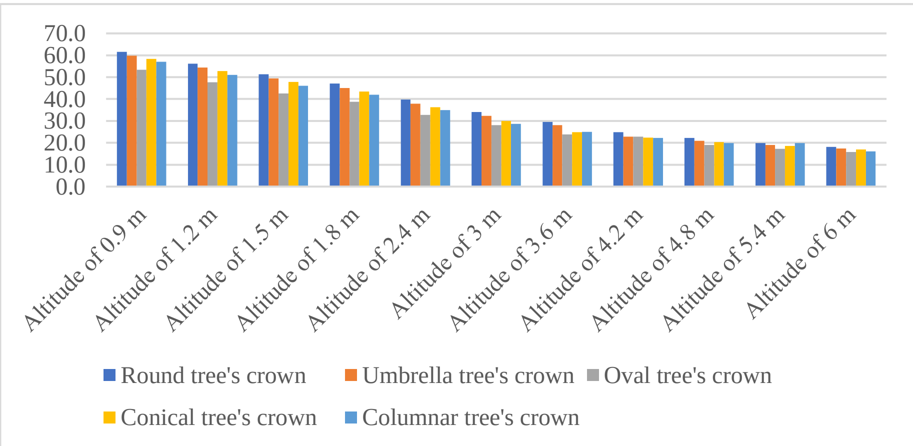

Figure 8. Comparison of the CO_2 dispersion in different altitude at 0° wind direction

Moreover, *Figure 8* shows the CO_2 dispersion in various altitudes to know another result of CO_2 dispersion in other conditions. This figure shows CO_2 dispersion in different heights, which is 11 different altitudes starting from 0.9

meters to 6 meters. CO_2 dispersion in different altitudes almost shows the same result but still has a different result in some altitudes. For example, the oval tree crowns have the lowest CO_2 dispersion than other crown shapes at almost every altitude. At an altitude of 4.2 m, CO_2 dispersion in the study area with an oval tree's crown shape becomes higher than the conical and columnar tree's crown shape. But, at an altitude of 4.8 meters, the oval tree's crown shape decreases CO_2 dispersion the least compared to others. The shape of the tree's crown, which is also quite good at reducing the distribution of CO_2 after the oval shape, is the columnar tree's crown. Columnar tree crowns can decrease CO_2 dispersion lower than round, umbrella, and conical crown shapes.

Meanwhile, based on the results, the round tree's crown indicates the highest CO_2 dispersion compared to other crown shapes. At an altitude of 1.8 meters, CO_2 dispersion in the study area with a round tree's crown can disperse 47.1% of CO_2. It indicates that the study area with round trees has an 8.3% higher CO_2 distribution than for oval tree crowns. Moreover, various altitudes in *Figure 8* also show that the study area with round tree crowns has the highest CO_2 dispersion compared to other crown shapes. Based on the results of simulation in 0° wind direction, it can be concluded that the oval tree crown has the lowest CO_2 dispersion compared to other tree crown shapes. This is then followed by the columnar and conical tree crowns. Meanwhile, the round tree's crown has the highest CO_2 dispersion, followed by the umbrella tree's crown. This result needs validation analysis to justify this result, which is described in the next section.

3.3.2 CO_2 dispersion at different altitudes in 90° wind direction

The second scenario of CO_2 dispersion simulation is based on another wind direction, which is 90° wind direction. *Figure 9* shows the CO_2 dispersion at an altitude of 1.8 meters. The result indicates the different result with CO_2 dispersion based on 0° wind direction. At the height of 1.8 meters in this section, the conical tree's crown became modelled with the lowest CO_2 dispersion with 21% of CO_2 distribution in the study area. Then it is followed by oval trees crown and columnar trees crown. Oval trees crown in the previous simulation scenario has the lowest CO_2 dispersion, but in this scenario has CO_2 dispersion a little higher than conical but still lower than others crown shape. This result also happens in the various altitude, conical, oval, and columnar tree's crown with lower CO_2 dispersion than others' crown shape. Therefore, conical, oval and columnar trees crown shape are better to decrease CO_2 dispersion in the study area.

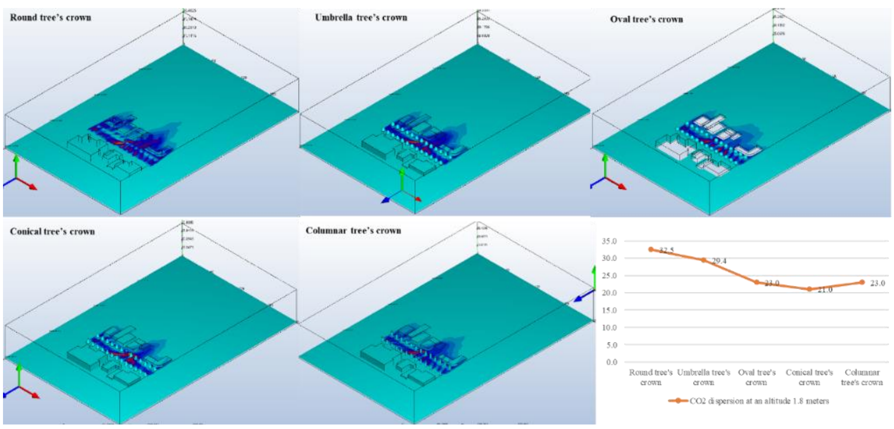

Figure 9. CO_2 dispersion at an altitude of 1.8 meters based on 90° wind direction

Moreover, the result with the highest CO_2 dispersion in the study area still displays the same result as the previous scenario. It is mean that round tree still has the highest CO_2 dispersion than other trees crown shape. Then it is followed by umbrella trees crown shape. *Figure 9* shows that the round tree's crown.

In addition to the distribution of CO_2 at a height of 1.8 meters, this study also shows the distribution of CO_2 at 11 different heights (*Figure 10*). CO_2 dispersion at an altitude of 0.9 to 4.8 m indicates that round tree and umbrella tree crowns have the highest CO_2 dispersion. Changes in CO_2 dispersion occur at the height of 4.8 m. Oval tree crowns have the highest CO_2 dispersion. But based on that result, the highest CO_2 dispersion commonly happened in the round tree's crown and umbrella tree's crown, while the lowest CO_2 dispersion occurred in oval, conical and columnar tree crowns. Accordingly, the validation analysis will be described in the next section to justify this result.

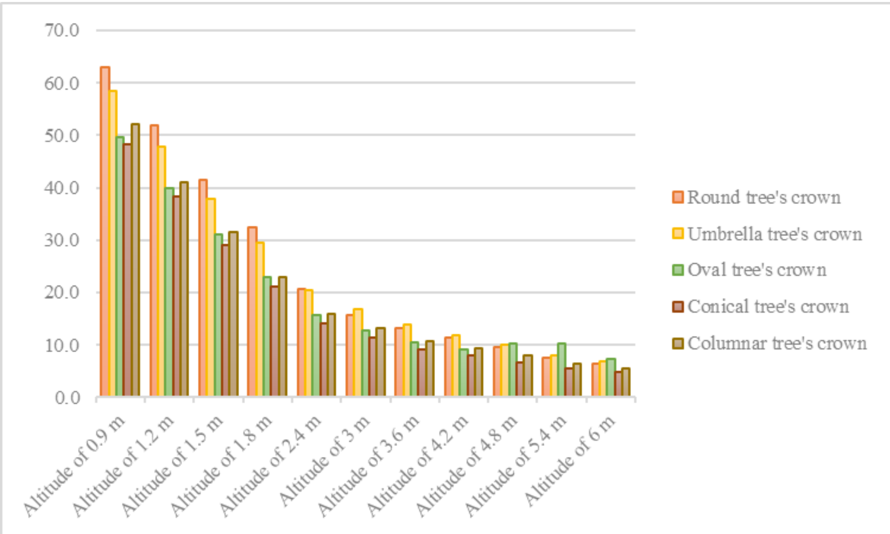

Figure 10. Comparison of the CO_2 dispersion in different altitude at 90° wind direction

3.4 Validation Data

This stage aims to validate the results of the analysis in the previous stages. There are two data analysed in this stage: the CO_2 dispersion at 0° wind direction and 90° wind direction. This stage uses coefficient correlation analysis based on the person's product-moment. SPSS is used to calculate the coefficient correlation analysis. The number of samples (N) used in this validation process is 11, which is CO_2 dispersion at 11 altitudes. The value of the correlation coefficient has a range between -1 and +1. A value close to 0 indicates a weak correlation, while a value closer to -1 or +1 indicates a strong correlation *(Figure 11).*

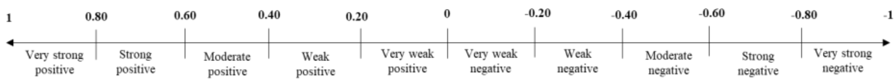

Figure 11. Index of the correlation coefficient

Table 3 and *Table 4* show strong coefficients of correlation among the scenarios. This means that CO2 dispersion has similarities in all five scenarios and has a strong correlation. Therefore, it can be concluded that round and umbrella trees can increase CO2 dispersion, while oval, conical, and columnar tree crowns can effectively decrease CO2 dispersion.

Table 3. Coefficient correlation analysis of CO_2 dispersion at 0° wind

		CO2 dispersion in 1st scenario	**CO2 dispersion in 2nd scenario**	**CO2 dispersion in 3rd scenario**	**CO2 dispersion in 4th scenario**	**CO2 dispersion in 5th scenario**
CO2 dispersion in 1st scenario	Pearson Correlation	1	1.000**	.996**	.998**	.997**
	Sig. (2-tailed)		.000	.000	.000	.000
	N	11	11	11	11	11
CO2 dispersion in 2nd scenario	Pearson Correlation	1.000**	1	.996**	.999**	.997**
	Sig. (2-tailed)	.000		.000	.000	.000
	N	11	11	11	11	11
CO2 dispersion in 3rd scenario	Pearson Correlation	.996**	.996**	1	.997**	.996**
	Sig. (2-tailed)	.000	.000		.000	.000
	N	11	11	11	11	11
CO2 dispersion in 4th scenario	Pearson Correlation	.998**	.999**	.997**	1	.999**
	Sig. (2-tailed)	.000	.000	.000		.000
	N	11	11	11	11	11
CO2 dispersion in 5th scenario	Pearson Correlation	.997**	.997**	.996**	.999**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	11	11	11	11	11

Note: **. Correlation is significant at the 0.01 level (2-tailed).

Table 4. Coefficient correlation analysis of CO_2 dispersion at 90° wind

		CO2 dispersion in 1st scenario	**CO2 dispersion in 2nd scenario**	**CO2 dispersion in 3rd scenario**	**CO2 dispersion in 4th scenario**	**CO2 dispersion in 5th scenario**
CO2 dispersion in 1st scenario	Pearson Correlation	1	.999**	.993**	.997**	.997**
	Sig. (2-tailed)		.000	.000	.000	.000
	N	11	11	11	11	11
CO2 dispersion in 2nd scenario	Pearson Correlation	.999**	1	.993**	.998**	.998**
	Sig. (2-tailed)	.000		.000	.000	.000
	N	11	11	11	11	11
CO2 dispersion in 3rd scenario	Pearson Correlation	.993**	.993**	1	.998**	.997**
	Sig. (2-tailed)	.000	.000		.000	.000
	N	11	11	11	11	11
CO2 dispersion in 4th scenario	Pearson Correlation	.997**	.998**	.998**	1	1.000**
	Sig. (2-tailed)	.000	.000	.000		.000
	N	11	11	11	11	11
CO2 dispersion in 5th scenario	Pearson Correlation	.997**	.998**	.997**	1.000**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	11	11	11	11	11

Note: **. Correlation is significant at the 0.01 level (2-tailed).

4. CONCLUSION

This research focuses on selecting the crown shape of trees for roadside planting. The study involved two stages of CO_2 dispersion simulation, one for wind direction at 0o and another at 90o. The results showed that the crown shape of trees has a significant impact on CO_2 dispersion, emphasizing the importance of selecting trees with optimal crown shapes. The study found that round and umbrella trees are not suitable for roadside planting as they disperse a high percentage of CO_2. Simulation results based on 0o wind direction showed that round trees disperse 47.1% of CO_2, while umbrella trees disperse 45.1%. Similarly, simulation based on 90o wind direction showed that round trees disperse 32.5% of CO_2 and umbrella trees disperse 29.4%. In contrast, oval, columnar, and conical tree crowns are better options as they decrease CO_2 dispersion. Simulation results showed that oval trees dispersed 38.8% of CO_2, conical trees dispersed 43.4%, and columnar trees dispersed 42% based on 0o wind direction simulation. These results were consistent with simulation based on 90o wind direction where oval trees dispersed 23% of CO_2, conical trees dispersed 21%, and columnar trees dispersed 23%. This indicates that oval, conical, and columnar crown shapes are more effective in reducing CO_2 dispersion compared to round and umbrella crown shapes.

Therefore, it can be concluded that selecting oval, conical, and columnar crown shapes can effectively reduce CO_2 dispersion from transportation on the roadside. In contrast, round and umbrella crown shapes are not appropriate for roadside planting as they increase CO_2 dispersion. The study's results are validated through coefficient analysis, showing a strong correlation for CO_2 dispersion among these five scenarios, which justifies implementing the simulation results for roadside planting.

However, the study has limitations, as it only focused on five crown forms commonly grown in tropical countries. Future research can analyse the shape of trees widely planted in four-season countries. Moreover, the study only focused on the dispersion of CO_2 from transportation. Future research can analyse other pollutants. Also, the study assumes the same characteristics in the 3D modelling of each tree in the study location. Future research can include other variables in selecting trees to be planted on the roadside, such as differences in tree height, tree canopy volume, etc.

AUTHOR CONTRIBUTIONS

Conceptualization, N.A. and Z.S. methodology, N.A., Z.S. and P.T.; software, N.A.; investigation, R.W. and A.M.G.; resources, N.A. and A.M.G; data curation, N.A.; writing—original draft preparation, N.A., P.T. and A.M.G.; writing—review and editing, N.A., P.T. and RW.; supervision, N.A. and Z.S. All authors have read and agreed to the published version of the manuscript.

ETHICS DECLARATION

The authors declare that they have no conflicts of interest regarding the publication of the paper.

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