How the position of trees planting can improve the near-road air quality exposed to CO_2 emission from transportation

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Abstract: This research focuses on evaluating the row position of trees planting to the near-road air quality exposed to CO_2 emitted from transportation. Since emission spread quickly to the roadside, it caused highly concentrated CO_2 in ambient air that may harm human health, meanwhile the roadside is public space for pedestrians. The design of trees planting is necessarily critical in controlling air quality. This research provides four positions of trees planting simulated in Surabaya City, Indonesia, and created the physical condition according to the actual condition in a real 3D environment. CO_2 emission was also calculated based on real data, simulated it using computational fluid dynamics (CFD) analysis. The result displayed that the position of trees planting impact on the air quality was caused by CO_2 dispersion. Planting the trees as a barrier between roadside and road in double-row position is an effective way of decreasing CO_2 dispersion.

Keywords: computational fluid dynamics; CFD; CO_2 dispersion; near-road air quality; design guideline; tree's row position.

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1 Introduction

This research focuses on evaluating the impact of the row position of trees planting on the CO_2 dispersion. It is an essential element in the design of the urban roadside because it influences the near-road air quality. As an emerging country, Indonesia is inevitably challenged with the annual increase of new vehicles. Report by the Statistics Bureau of Indonesia (2019) documented that motor vehicles exponentially increased by 300% during 2008–2018. The soaring number of motor vehicles in Indonesia occurs because citizens are most likely to drive private vehicles instead of taking public transportation. Therefore, chronic congestions on some roads in the urban area are unavoidable.

It is common knowledge that the rapid growth of vehicles accounts for the worsening of urban air quality. The highly significant concentration of CO_2 in the air caused by gasoline and diesel as fuel usage for the motor vehicle also contributes to the poor quality of air. This condition causes a high CO_2 dispersion on the road, and its emission can spread quickly to the area surrounding the area. While it may reduce the air quality in the area – the poor quality of air indicated by high CO_2 concentrations negatively affects human health. The high CO_2 concentration of 0.2%–0.5% (2,000–5,000 ppm) would cause several health issues to humans, such as headaches, sleepiness, stuffy air, stale, poor concentration, loss of attention and increased heart rate. The excellent air quality in the outdoor, contrarily, should be between 025%–0.04% (250–400 ppm) of CO_2 concentration.

Accordingly, the existence of the tree on the roadside can be an alternative to solve the problem. Previous studies showed that trees planting has been empirically proven to affect the distribution of vehicle emission and demonstrates a different impact on increasing and decreasing CO_2 concentration. Jeanjean et al. (2015) and Aini and Shen (2019) showed that trees could decrease CO_2 dispersion in the study area. Another research proved that trees could increase the emission concentration (Gromke and Ruck, 2010; Šíp and Beneš, 2016). These studies, similarly, compared the distribution of vehicle emissions between areas with and without trees. However, the differences in physical condition in 3D modelling influence the result. Some studies create physical health according to the real situation, such as the building height, building layout and characteristics of trees. In contrast, the physical condition in other research did not represent the real condition of the study area.

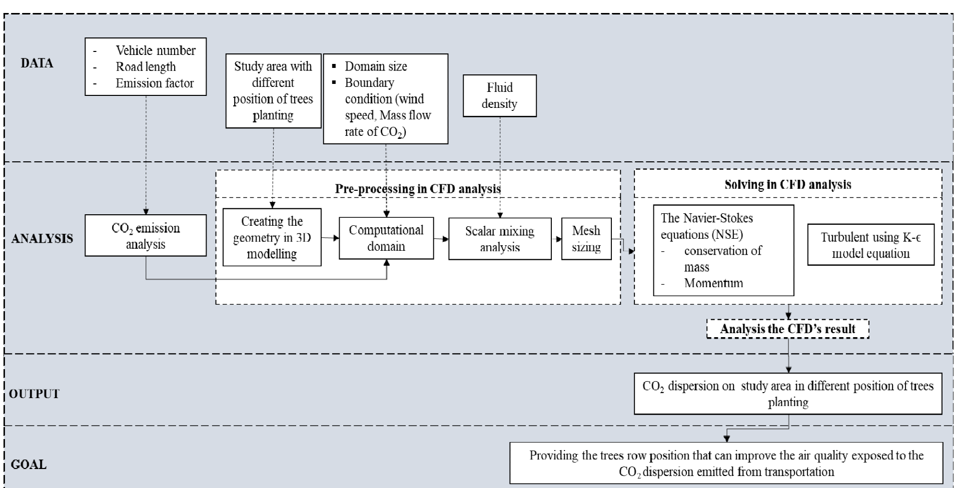
The design of trees planting in the roadside also impacts the CO_2 dispersion. One of the outstanding element designs in trees planting that influences the emission dispersion is trees row position (Morakinyo and Lam, 2016). Commonly, trees are planted in double-row positions and one-row position. In the road, there are many positions of trees planting that can be found based on the trees row position. This position can improve air quality around the road or worsen air quality. Thus, it is critical to plant trees in the right position.

Since the position of the tree's row becomes a consideration in this research to get the best position of trees planting in increasing air quality, this research employs physical conditions based on real situations in the study area to simulate the CO_2 dispersion in a real 3D environment. The result provides an alternative to the position of tree planting that can reduce the spread of CO_2 so that air quality can be maintained.

2 Method

This research utilised computational fluid dynamics (CFD) analysis to simulate the CO_2 dispersion in the different trees planting position. Figure 1 shows the research framework. This framework shows that there are three stages in CFD simulation. The first is pre-processing, followed by solving, and the last is result analysis. Nevertheless, before doing the simulation, some data must be prepared, which are CO_2 emission and modelling.

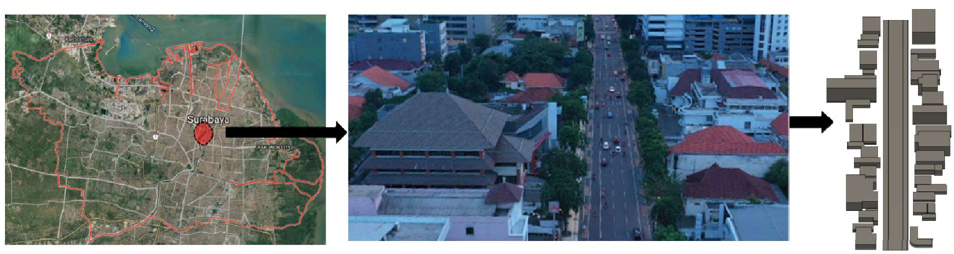
Figure 1 Research framework



2.1 Study area with different position of trees planting

The focus area for this study is Surabaya City, Indonesia, in which, as a metropolitan city, suffers from chronic congestion on its roads. This study chose the road, namely Panglima Sudirman (Figure 2), as a road with highly congested traffic jams. In this road, the researcher conducted the observation to calculate the number of the motor vehicle. This value is used as primary data to calculate the amount of CO_2 emissions that simulated in this study. This research also created the physical environment according to the real condition of this research area, which is the road, roadside and the building. This study selected 400 km of road as a studied area with various building height and building layout. The road is about 18 metre wide, and the roadside is 6 metre wide.

Figure 2 Location of research area (see online version for colours)



This study considers some trees planting positions that can found in some roads of Surabaya City. Figure 3 shows the familiar location of the trees planting that simulate in this research. The first scenario presented one-row of trees planting, and its row is planted in the middle of the road or road median. The second scenario showed that trees were planted on both of roadside. Row trees planted in the model plays as a barrier between roadside and the building area. While in the third position, trees were planted in the middle of the roadside. Eventually, in the last scenario, the tree's row is planted as a barrier between roadside and road. These simulated scenarios were performed to analyse the impact on the dispersion of CO_2.

2.2 CO_2 emission calculation

The following equation calculates CO_2 emission. Data were prepared before calculating CO_2 emission. The first data is the volume of the vehicle. Data were obtained from a survey that has completely done in the study area. The observation was done three times a day in the weekday and weekend. It showed the peak hours in the study area, which was in the morning, noon and afternoon. The following data is the length of the road that were analysed. Then, the last information is the emission factor. The emission factor has a different value according to the classification of transportation. Table 1 shows the emission factor used in this research (AEA, 2012)

$$CO_2\ emission = vol \left({}^{\text{unit}}\!/\!_{\text{hour}} \right) \times street\ (\text{km}) \times emission\ \ factors \left({}^{\text{gCO}_2}\!/\!_{\text{km}} \right) \tag{1}$$

Figure 3 The position of trees planting in Surabaya City (see online version for colours)

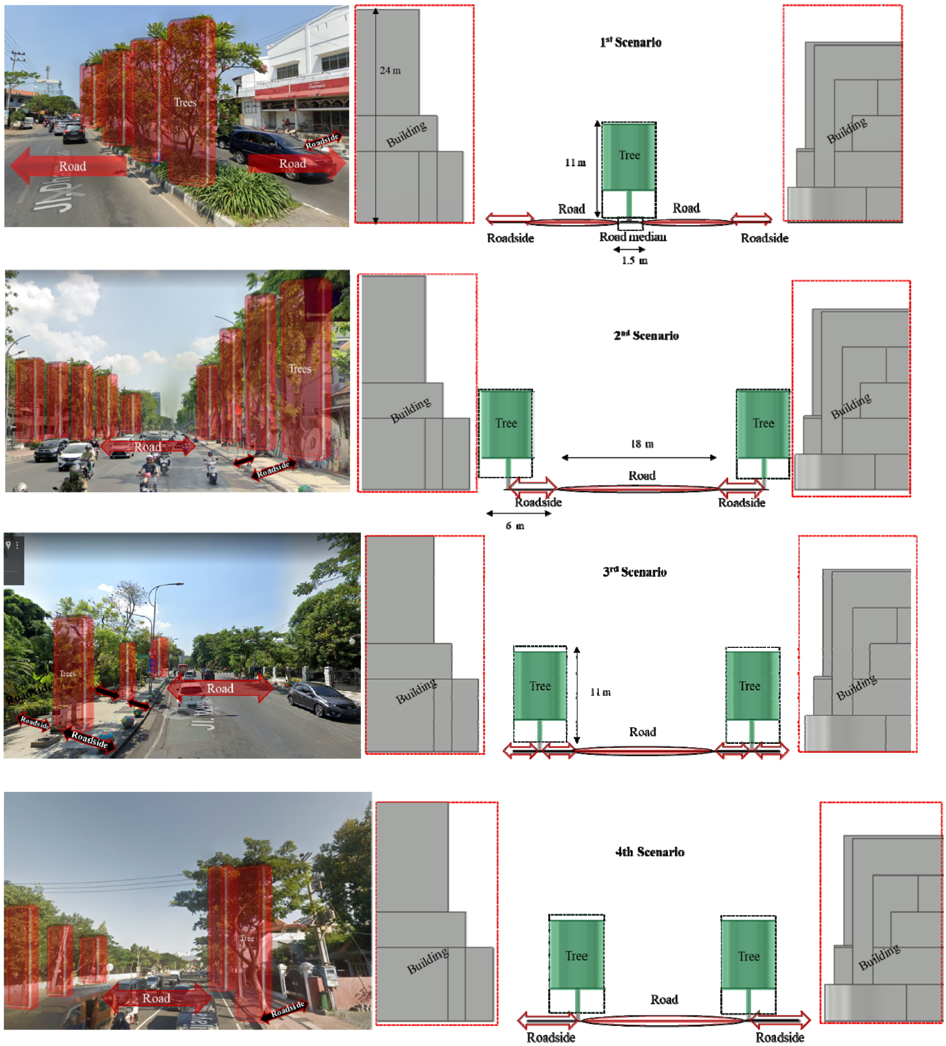


Table 1 Vehicle emission factor

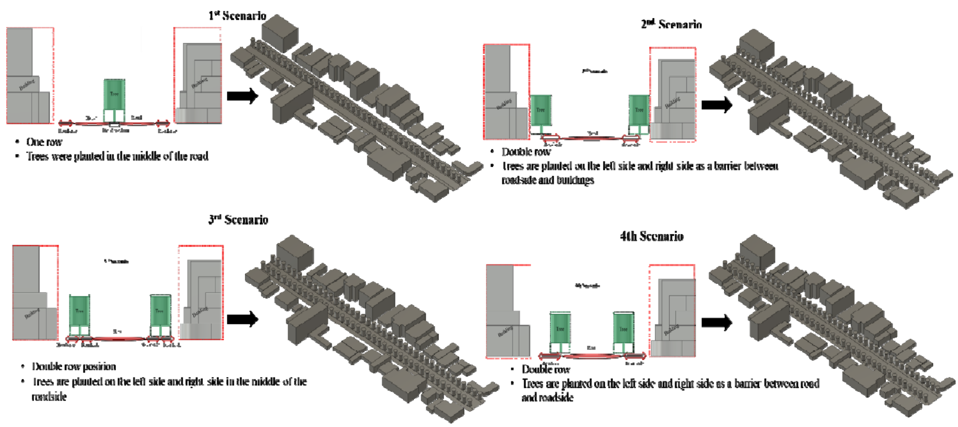
Transportation classification	*Definition*	*Average emissions (kgCO₂/km)*
Small car	Small petrol car, up to the 1.4 litre engine	0.16442
Medium car	Medium diesel car, from 1.7 to 2.0 litre	0.17573
Large car	Large diesel car, over 2.0 litre	0.23381
Motorcycle	Small petrol motorbike (mopeds/scooters)	0.08499

2.3 Pre-processing of CFD analysis

2.3.1 The geometry of 3D modelling

There were four positions of tree planting simulated in this research. These models were built using Sim Studio Tools from Autodesk. The first scenario has a one-row position, and trees were planted in the middle of the road. The second scenario is the double-row position. The trees were planted in both of roadside as a barrier between roadside and building. The third scenario also has a double-row position. Trees were planted in the middle of the roadside. Then, the last modelling has a double-row position that trees were planted as a barrier between the road and roadside Figure 4.

Figure 4 The geometry of 3D modelling (see online version for colours)



2.3.1.1 Computational domain

The physical domain simply made the computational domain both in the form of geometrical representation in domain size and boundary conditions for that domain. Hence, this part maintained all of the essential physical features of the problem but can ignore small details (Li, 2008).

The first step in the computational domain determined the domain size. This research used domain size according to the previous study by Franke et al. (2004, 2007). This domain was appropriate to use in urban studies, especially in the street canyon. Based on that domain size, the inlet and the lateral in urban area simulation must be positioned 5 H_{max} from the building. The outflow boundary and the top boundary should be a minimum of 15 H_{max} and 5 H_{max} away from the building, respectively. H_{max} was the size of the tallest building in the modelling. Figure 5 shows the domain size in this research.

The second step in the computational domain was to assign boundary conditions, which were the inlet, outlet, lateral and top boundary. For the top and lateral conditions, it was assigned as the slip/symmetry boundary. It caused the fluid to flow along a wall instead of stopping at the wall. It typically occurs along a wall. Then, outflow/outlet condition was a static pressure with a value of 0. Eventually, the last surface was the inlet which in this study originated from two sources: wind and CO_2 (Figure 5).

Figure 5 Computational domain (see online version for colours)

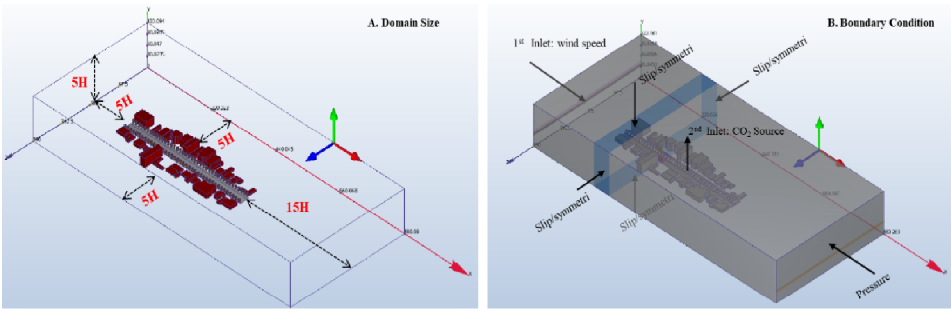
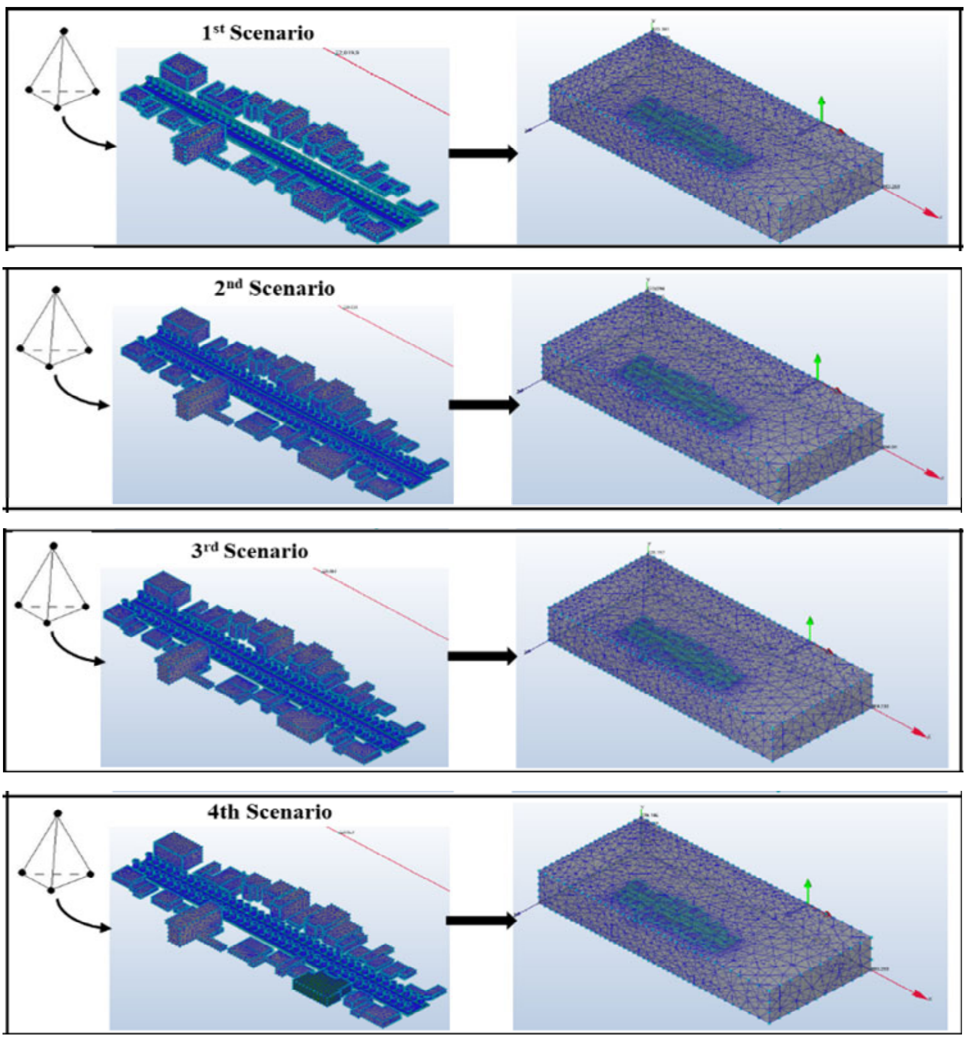


Figure 6 Mesh sizing (see online version for colours)



2.3.1.2 Fluid characteristic

This research simulates the different fluid, which is air (the first fluid) and CO_2 (the second fluid). These fluids have different density. The density of air (ρ_A) is 1.2047e–6 g/mm^3, and the density of carbon dioxide (ρ_B) is 1.773e–6 g/mm^3. So that, it needs the scalar mixing analysis to mix this fluid. The formula of scalar mixing analysis displays in the following equation:

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

where

J_A the mass flux of air (the amount of air transferred per time and unit area normal to the transfer direction)

ρ_{AB} mass density

D_{AB} the diffusion of scalar quantities based on Fick's law

∇m_A the gradient (∇) of the species mass fraction.

2.3.2 Mesh sizing

The last stage in the pre-processing part in CFD simulation was mesh sizing. This stage was critical for cutting geometry into small pieces in the form of nodes and elements. The combination of nodes and elements were called a mesh which was a tetrahedral – four side with a triangular-faced element. Mesh sizing facilitated the work of computers in analysing the distribution of fluids. Figure 6 shows the mesh sizing in four scenarios of trees planting position.

2.4 Solving in CFD analysis

This part is the main process in CFD simulation. The Navier-Stokes equations (NSE) were used in this research to describe the movements of fluids (air and CO_2). Air movement in this research was assumed in a steady condition, not compressed (incompressible), and density (ρ) was constant. Later, turbulent was used to analyse the airflow because this research considers the physical condition in 3D modelling. The following formulas are several mathematical equations in NSE to analyse the CO_2 dispersion conservation of mass

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

where

$\frac{\partial_\rho}{\partial_t}$ the partial derivative of ρ for t

ρ density

t time

∇ (tensor gradient) the stress variable based on Galilean invariant

u the flow velocity.

The formula of conservation of momentum for 3D modelling

$$x\text{-}component: \frac{\partial(p.u)}{\partial t} + \nabla.(\rho.u.u) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} \rho.g_x \tag{4}$$

$$y\text{-}component: \frac{\partial(p.v)}{\partial t} + \nabla.(\rho.v.u) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} \rho.g_y \tag{5}$$

$$z\text{-}component: \frac{\partial(p.w)}{\partial t} + \nabla.(\rho.w.u) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} \rho.g_z \tag{6}$$

where

ρ density

u the flow velocity

∇ divergence

p the pressure

t time

τ deviatoric stress tensor

g body accelerations are acting on the continuum, for example, gravity, inertial accelerations, electrostatic accelerations, etc.

On the other side, the NSE have limitations for describing turbulent flows. The limitations with the time-averaged RANS equation is the introduction of the Reynolds stress term, which accounts for turbulent fluctuations. Hence, the CFD model for turbulent kinetic energy using *K*-*ε* model equation. The *K*-*ε* model equation has two-equation to calculate the turbulent kinetic energy. Equation (7) is the calculation for turbulent kinetic energy (*k*), while equation (8) is a formula for calculating the dissipation of turbulent kinetic energy ε

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij} E_{ij} - \rho\varepsilon \tag{7}$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k} 2\mu_t E_{ij} E_{ij} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{8}$$

where

ρ the fluid density (kgm^{-3})

u the fluid velocity (ms^{-1})

i represent x

j represent x, y and z (coordinate geometry in boundary)

u_i represents the velocity component in the corresponding direction

E_{ij} represents the component of the rate of deformation

μ_t represents turbulent viscosity.

3 Result and discussion

3.1 Identification of CO_2 emission in the research area

This research calculated the CO_2 emission based on the type of transportation classification according to the fuel usage that can emit CO_2 emission. Equation (1) was used to count the CO_2 emission in the study area. Table 2 shows the average number of vehicles in the study area. This number was obtained by observation in the study area. Based on Table 2, the motorcycle has the highest number than other transportation classification. The total number reaches 6,814 units/hours. Indonesian's citizen prefers to use private motor vehicles on the road thank public transportation. The total unit of the motor vehicle in the study area was 9,380, as calculated and displayed in Table 3.

Table 2 The daily average of motor-vehicle number

Number	*Type of motor vehicle*	*Total (unit/hour)*	*Classification*	*Total (unit/hour)*
1	Private car	2,050	Small car	2,161
2	Public transportation	111		
3	Mini bus	233	Medium car	400
4	Pick up/box	1		
5	Mini trucks	166		
6	Big bus	3	Large car	5
7	Truck 2 axis	1		
8	Truck 3 axis	1		
9	Motorcycle	6,814	Motorcycle	6,814
Total	9,380		9,380	

Table 3 CO_2 emission

Number	*Type of motor vehicle*	*Total (unit/hour)*	*Road (km)*	*Emission factor*	*CO_2 emission*
1	Private car	2,050	0.4	0.16442	134.8
2	Public transportation	111	0.4	0.16442	7.3
3	Mini bus	1	0.4	0.17573	0.1
4	Pick up/box	233	0.4	0.17573	16.4
5	Mini trucks	166	0.4	0.17573	11.7
6	Big bus	3	0.4	0.23381	0.3
7	Truck	2	0.4	0.23381	0.2
8	Motorcycles	6,814	0.4	0.08499	231.6
Total of CO_2 emission					402.4

Based on Table 2, the CO_2 emission can be calculated using equation (1). Three data must be obtained, which were the total vehicle number (unit/hour), the length of the road that used in the simulation, and emission factor from each type of motor vehicle. According to Table 3, the highest CO_2 emission resulted from the motor vehicle, even though the emission factor is the lowest among the type of motor vehicle. The spreadable CO_2 emission from transportation is 402.4 kg/hour. This value will be input in the simulation to analyse the spread of CO_2 in some position trees planting as a source of CO_2 emission, which is the first fluid in simulation. The result of the simulation process is shown in the next section to examine the effect of tree planting position on CO_2 dispersion that impacts on air quality.

3.2 CO_2 dispersion at different altitude

This section shows the result of CO_2 distribution in different locations of trees planting designs. Four scenarios of tree planting position were analysed in this study (Figure 3). The first scenario was one-row trees planting, while the others were the double-row area of trees planting. In the first scenario, trees were planted in the middle of the road. In the second scenario, trees were planted on both of roadside as a barrier between roadside and building. It was also planted in the third scenario, but trees were planted in the middle of the roadside. In the last scenario, trees were still planted on the roadside, but the position shown as a barrier between road and roadside.

It is the same with the third scenario and fourth scenario that trees were planted on the roadside. Nevertheless, trees were planted in the middle on the roadside in the third scenario. At the same time, trees were planted as a barrier between road and roadside in the fourth scenario.

Figure 7 displays the CO_2 dispersion at an altitude of 1.8. It displays a comparison of CO_2 distribution at different altitudes. The colour of the scalar indicates CO_2 concentration. The red colour is an area that has 100% CO_2 dispersion emitted from transportation, and the blue one indicates the area not affected by CO_2 emitted from transportation (0% 0f CO_2). CO_2 dispersion in 3D modelling showed different dispersion in different tree positions. The first scenario and the second scenario have the highest CO_2 dispersion. 46.2% CO_2 disperse in the first scenario, and 47% CO_2 can disperse in the second scenario. Meanwhile, the third scenario and fourth scenario have lower CO_2 concentrations than other scenarios. The third scenario can disperse 41.7% of CO_2 concentration. This value showed a decrease of 6.2% in the second scenario. Then, the most effective in decreasing CO_2 dispersion is the fourth scenario. This scenario exhibits the lowest CO_2 dispersion, which is 33.1%. It indicates that this position can reduce 13.9% of CO_2 dispersion compare with the second scenario. Consideration of the validation data, so the result of CO_2 distribution, also showed at different altitudes in Figure 7.

Figure 8 displays the CO_2 dispersion at an altitude of 6 metres, which is parallel to the height of the tree crown on the roadside. In contrast to the previous elevation, the height is identical with the height of trees trunk. Based on Figure 8, there are similarities and a little different outcome with earlier results at an altitude of 1.8 metres. It showed the similarity of the result. The tree's position that can disperse better among other locations in the fourth scenario and the lousy position in dispersing CO_2 emission was the second scenario. In the fourth scenario, CO_2 disperse by 7.5%, then 17% of CO_2 emission disperse the second scenario. This result indicated in the fourth scenario can decrease of

CO_2 emission by 10.5%. This result is the same as the CO_2 dispersion at an altitude of 1.8 metres, which the fourth scenario as the best tree's position in CO_2 distribution, then the second scenario as the worst position in the CO_2 dispersion.

Figure 7 CO_2 dispersion at an altitude of 1.8 metre (see online version for colours)

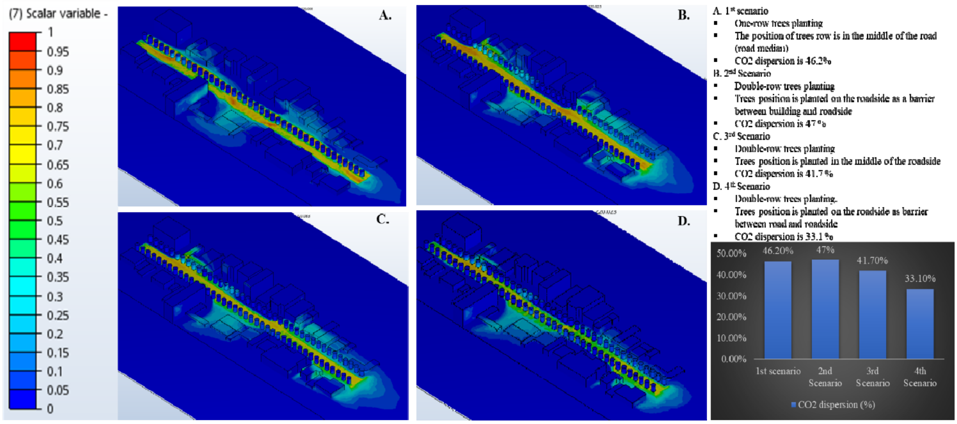
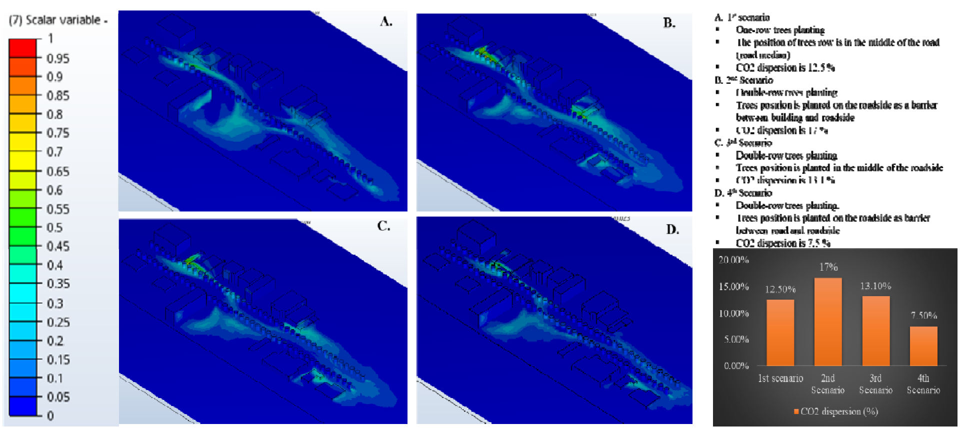


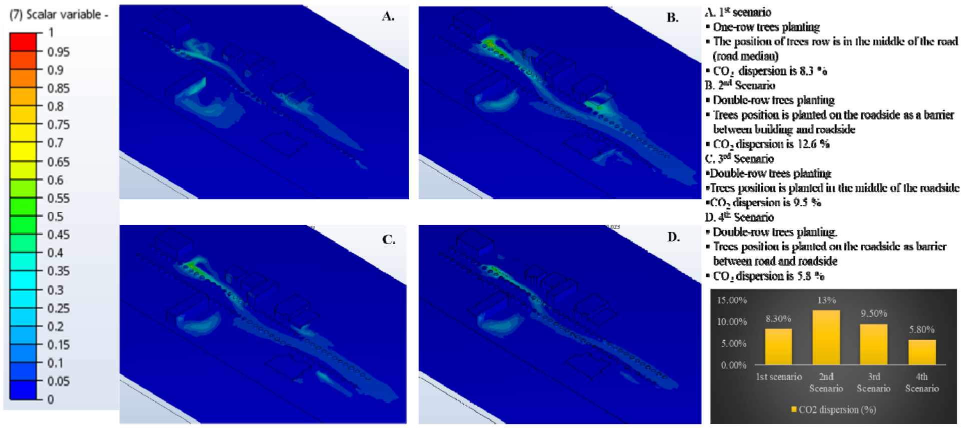
Figure 8 CO_2 dispersion at an altitude of 6 metre (see online version for colours)



Meanwhile, there is a difference in the second and third positions of trees planting. At an altitude of 6 m, the third scenario has CO_2 concentration higher than the second scenario. The second scenario has 13.1% of CO_2 dispersion, and the first scenario has 12.5% of CO_2 dispersion. So this section showed the CO_2 dispersion in another altitude in Figure 9.

Figure 9 displays the CO_2 dispersion at a higher altitude than the previous figure, which is 9.6 metres. In this elevation, the CO_2 distribution becomes lower than the previous altitude. Because the distance from the source of CO_2 emission is farther than the last altitude, according to this result, it can indicate that the fourth scenario still has the lowest CO_2 dispersion than other scenarios. Then, the second scenario is the position of trees planting that has the highest CO_2 concentration. This result is the same with CO_2 dispersion in previous altitude.

Figure 9 CO_2 dispersion at an altitude of 9.6 metre (see online version for colours)



While Table 4 and Figure 10 show the CO_2 dispersion at various altitudes. So it can be known which tree's position that appropriate to plant on the roadside.

Table 4 CO_2 dispersion in different position trees planting based on the different altitude of the modelling

Position of trees planting	*CO_2 dispersion at different altitude (%)*										
	1.8 m	*2.4 m*	*3 m*	*3.6 m*	*4.8 m*	*6 m*	*7.2 m*	*8.4 m*	*9.6 m*	*10.8 m*	*12 m*
Scenario 1	46.2	31.1	24.5	m19.2	14.5	12.5	10.3	9.1	8.3	7.5	6.9
Scenario 2	47.0	32.8	27.7	23.1	19.5	16.7	14.5	13.4	12.6	11.1	10.2
Scenario 3	41.7	25.4	21.6	18.2	15.5	13.1	11.2	10.2	9.5	8.5	8.0
Scenario 4	33.1	19.2	14.7	12.6	10.1	7.5	6.6	6.2	5.8	5.5	5.7

Figure 10 Comparison of the dispersion of CO_2 in every position of trees planting (see online version for colours)

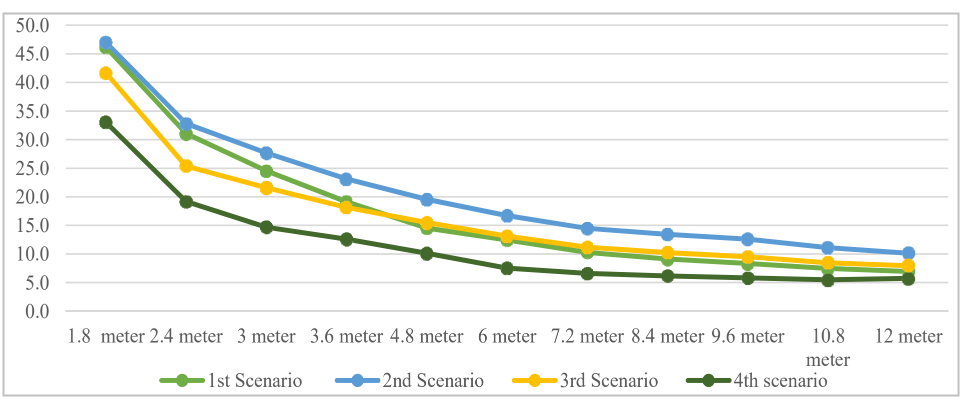


Table 4 and Figure 10 show that the second scenario has the highest CO_2 concentration at various altitudes which is 47% of CO_2 distribute in the modelling at an altitude of 1.8 metres. This value is the lowest of CO_2 dispersion than other scenarios. It also happens at another height. At an altitude 12 metres, CO_2 distribute by 10.2%, while other scenarios have CO_2 dispersion below that value. Hence, it can be concluded that the position of trees planting on the roadside as a barrier between roadside and building is not affecting in decreasing CO_2 dispersion. Since the CO_2 dispersion is high, it might harm the environment and human health.

On the other side, the next scenario that has high CO_2 dispersion is the first scenario and third scenario. Figure 10 displays that CO_2 dispersion in the first scenario is higher than the third scenario at an altitude of 1.8–4.8 metres. Then start from 4.8 metres until 12 metres; the third scenario has a higher CO_2 dispersion thank the first scenario. However, both modelling did not prove in reducing the distribution of CO_2 as well as the fourth scenario. CO_2 dispersion in the scenario is the lowest than others modelling. This scenario can disperse 33.1% of CO_2 emission at an altitude of 1.8 metres. It means that this position of trees planting can decrease CO_2 dispersion of 13.1%. Then in other altitudes, this scenario also has the lowest CO_2 dispersion. Trees were appropriately planted on the roadside as a barrier between road and roadside to reduce the dispersion of CO_2 dispersion.

3.3 The impact of the tree's row position on CO_2 dispersion

This section shows the influence of tree's row position on the CO_2 dispersion and CO_2 concentrations. The CO_2 distribution and CO_2 concentrations were displayed on the wall, which was a surface at 436 metres from the wind source (Figure 11). Therefore, the effect of the tree's planting position in CO_2 dispersion can be known (Figure 12). Figure 12 shows that the first, second and third scenarios, CO_2 dispersion, can spread to around the road. CO_2 can spread quickly to the roadside and road. Whereas in the fourth scenario, the position of the trees planting can withstand the distribution of CO_2. This value can be seen in Figure 13. The lowest CO_2 dispersion on the wall is in the fourth scenario, which is 0.16%. On the other side, the highest CO_2 dispersion is the second scenario, which is 0.44%. The third scenario also has high CO_2 dispersion by 0.43%.

Figure 11 The location of the wall (see online version for colours)

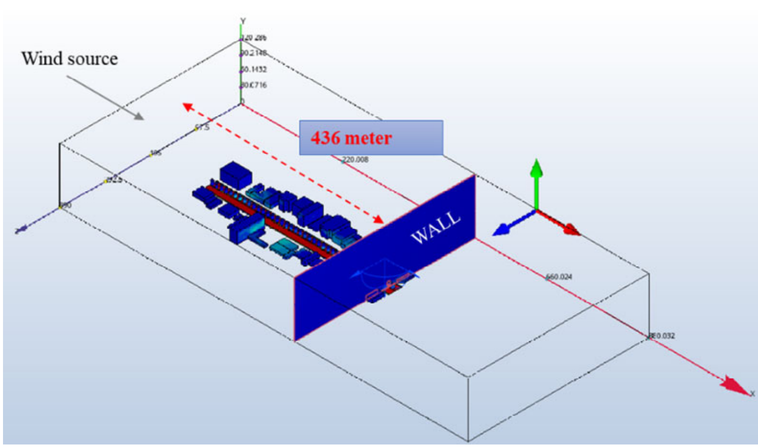


Figure 12 The effect of the tree's position to CO_2 dispersion (see online version for colours)

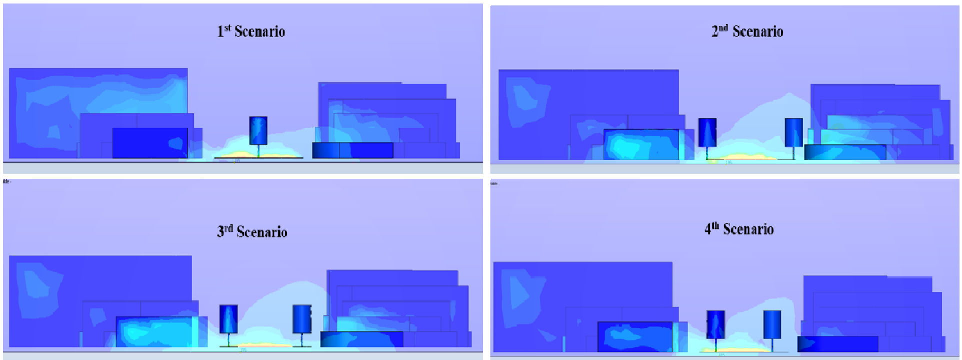
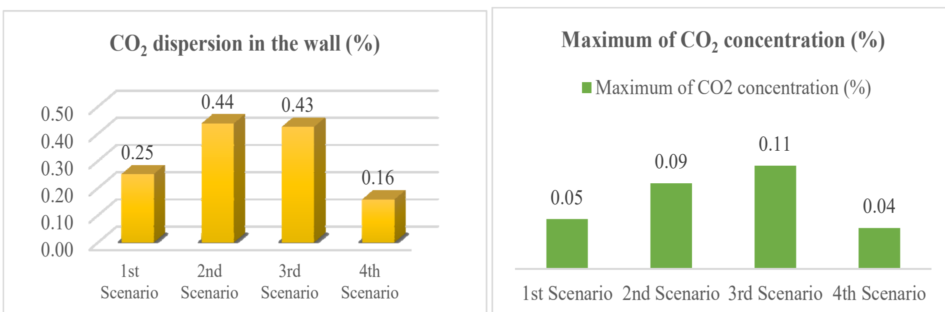


Figure 13 CO_2 dispersion and CO_2 concentration on the wall (see online version for colours)



Moreover, the CO_2 concentration on the fourth scenario is the lowest than other scenarios. It starts from 0%–0.04% (0–400 ppm). Meanwhile, CO_2 concentration in the second and third positions reach 0%–0.09% (0–900 ppm) and 0%–0.11% (0–1,100 ppm). Therefore, the tree's position as a barrier between road and roadside is appropriately decreasing the distribution of CO_2 emission. Accordingly, the next section explains the air quality among the four scenarios, so it can be known which scenario that can control the air quality.

3.4 The impact tree's row position on level air quality

This section shows the analyses of air quality in different tree's row position. Air quality is indicated by CO_2 concentration in the study area. This analysis followed the standard from the Wisconsin Department of Health Service (2019). Four-level air quality used in this study commonly occurred in an urban area (Table 5). First, there were two levels of good air quality based on this standard, which is the excellent air quality of indoor and outdoor. The air quality of the outdoor area should contain CO_2 concentration > 0.04% (400 ppm). It is different from the excellent air quality of the indoor space that should have CO_2 concentration by 0.04%–0.1% (400–1,000 ppm). Second, there were also two levels of poor air quality based on this standard – the first reduced air quality complaints of drowsiness. Then, poor air quality causes headaches, sleepiness and stagnant, stale, stuffy air, poor concentration, etc.

Table 5 Level of air quality

The standard of CO_2 concentration in the air		*CO_2 level (%)*			
Level of air quality	*CO_2 concentration*	*The first scenario*	*The second scenario*	*The third scenario*	*The fourth scenario*
Good air quality (normal background concentration in outdoor ambient air).	> 0.04% (400 ppm)	90.5	89.1	90.2	92.4
Good air quality (minimal CO_2 concentrations in indoor spaces) exchange.	0.04%–0.1% (400–1,000 ppm)	1.4	1.5	1.1	1.3
Poor air quality (complaints of drowsiness and poor air).	0.1%–0.2% (1,000–2,000 ppm)	3.2	2.5	2.7	1.6
Poor air quality (headaches, sleepiness, stagnant, stale, and stuffy air). Poor concentration, loss of attention, increased heart rate, and slight nausea may also be present.	0.2%–0.5% (2,000–5,000 ppm)	5.0	6.9	6.0	4.7

Figure 14 Comparison of level of air quality in every scenario (see online version for colours)

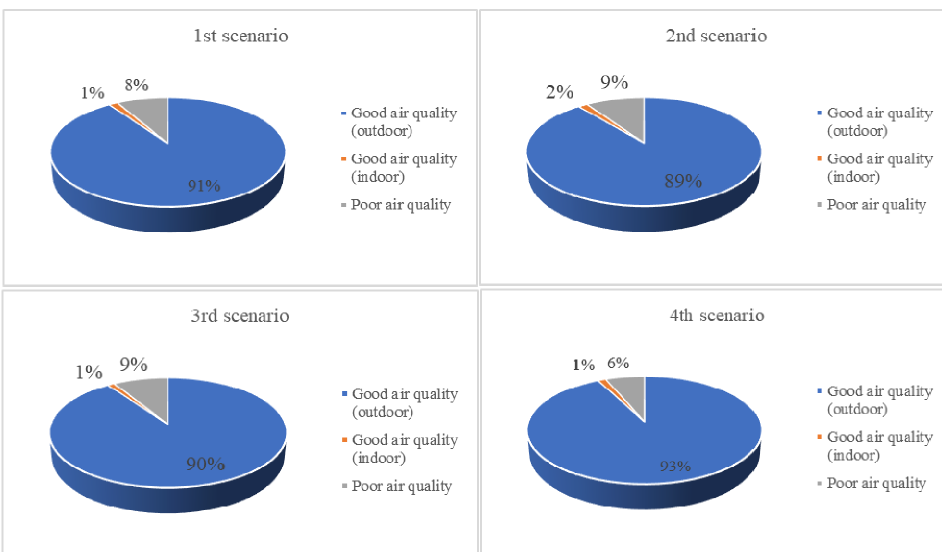


Table 5 and Figure 14 show the result of CO_2 concentration based on the level of air quality. According to the total area that has poor air quality, the second scenario has the highest poor air quality, which is 9.4%. There were 2.5% of poor air quality that might cause complaints of drowsiness and 6.9% of poor air quality that would negatively affect human health. The second scenario also presented the lowest percentage of good air quality in the outdoor area, which is 89.1%. Thus, the second scenario is the worst position of trees planting on the roadside to decreasing CO_2 dispersion. Trees were not appropriately planted on the roadside as a barrier between road and building, even though this position is commonly planted in urban areas.

Meanwhile, the first road and third road have good air quality better than other modelling, which is 90.5% and 90.2%. Then the poor air quality is lower than the second scenario, which is 8.2% and 8.7%. Therefore, the first road and the third are better than the second road in decreasing CO_2 dispersion emitted from transportation. 5% of poor air quality in the first scenario has an impact on human health, whereas 6% of poor air quality in the third scenario is an impact on human health. Accordingly, planting the trees in the road median and the middle of the roadside can be an alternative to decreasing CO_2 dispersion.

However, these results were not as good as the results shown in the fourth scenario. The fourth scenario has the highest good air quality and lowest poor air quality, among other scenarios. It displayed 92.4% of good air quality in the modelling – this value increases 3.3% than the second scenario. Then, the fourth scenario has 4.7% of poor air quality. It is mean this scenario can decrease by 2.2% than the second scenario. Therefore, trees are appropriate to plant on the roadside as a barrier between road and roadside.

4 Conclusions

This research aims to evaluate the row position of trees planting to the road-air quality exposed to CO_2 emission. The result provides shreds of evidence that the position of trees influenced the air quality by decreasing the CO_2 dispersion and CO_2 concentration emitted from transportation. Four positions of trees planting in the study area were observed in this study. The results showed that CO_2 dispersion at different altitudes, which were 1.8 metres to 12 metres. It could be concluded that planting the trees on the roadside as a barrier between road and roadside is better in increasing CO_2 dispersion than planting the trees in the 1st, 2nd, 3rd scenario, etc., as shown in the fourth scenario. The CO_2 dispersion in this trees planting position is the lowest than other scenarios.

Meanwhile, trees planted in the roadside as a barrier between roadside and building (the second scenario) is not appropriate to be implemented in the urban area because it showed the highest of CO_2 dispersion than other scenarios. Trees planting in the roadside as a barrier between road and roadside could disperse 33.1% of CO_2 emission at an altitude of 1.8 metres. It may decrease by 13.1% of CO_2 emission compared with CO_2 dispersion in the study area that planted the trees as a barrier between roadside and building.

Another result showed that trees planted on the roadside as a barrier between road and roadside could withstand the distribution of CO_2. However, in other positions, CO_2 emission could spread to the area around the road. It is shown in the wall, which was 436 metres from the wind source. CO_2 dispersion on the wall in the study area that planted the trees as a barrier between road and roadside is 0.16%, which is the lowest than other scenarios. Moreover, CO_2 concentration has a range of 0%–0.04% (0–400 ppm), which was the lowest CO_2 dispersion compared to other scenarios.

Based on the above explanation, the air quality of the study area could be examined. It is empirically concluded that planting trees as a barrier between road and roadside and its position are optimal in improving air quality in the study area. It showed 92.4% of good air quality in the mode, which significantly 3.3% higher than air quality in the study area where trees were planted as a barrier between roadside and building. Therefore, it is not suitable to apply this model in order to improve air quality. The most appropriate position to plant trees on the roadside is the fourth position where trees are planted on the roadside as a barrier between road and roadside.

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References

AEA (2012) *2012 Guidelines to Defra/DECC's GHG Conversion Factors for Company Reporting, Defra, and DECC*, DOI: v1.2.1 final.

Aini, N. and Shen, Z. (2019) 'The effect of tree planting within roadside green space on dispersion of CO_2 from transportation', *International Review for Spatial Planning and Sustainable Development*, Vol. 7, No. 4, pp.97–112.

Franke, J. et al. (2004) *Recommendations on the Use of CFD in Wind Engineering*, C16 ed., COST, Hamburg, Germany.

Franke, J. et al. (2007) *Best Practice Guideline for the CFD Simulation of Flows in the Urban Environment*, C73 ed., COST, Hamburg, Germany.

Gromke, C. and Ruck, B. (2010) 'Interaction of traffic pollutant dispersion with trees in urban street canyons', in *CLIMAQS Workshop' Local Air Quality and its Interactions with Vegetation'*, Antwerp, Belgium, 21–22 January, pp.93–97 [online] http://193.191.168.142/AQ-Vegetation-workshop/abstract/Gromke.pdf.

Jeanjean, A.P.R. et al. (2015) 'A CFD study on the effectiveness of trees to disperse road traffic emissions at a city scale', *Atmospheric Environment*, Vol. 120, pp.1–14, Elsevier Ltd., DOI: 10.1016/j.atmosenv.2015.08.003.

Li, D. (Ed.) (2008) 'Computational domain', in *Encyclopedia of Microfluidics and Nanofluidics*, p.275, Springer, Boston, MA, USA, DOI: 10.1007/978-0-387-48998-8_246.

Morakinyo, T.E. and Lam, Y.F. (2016) 'Study of traffic-related pollutant removal from street canyon with trees: dispersion and deposition perspective', *Environmental Science and Pollution Research*, Vol. 23, No. 21, pp.21652–21668, DOI: 10.1007/s11356-016-7322-9.

Šíp, V. and Beneš, L. (2016) 'Investigating the street canyon vegetation effects using the moment method', in *9th International Congress on Environmental Modelling and Software*, p.91, Toulouse, France [online] https://scholarsarchive.byu.edu/iemssconference/2016/Stream-A/91.

Statistics Bureau of Indonesia (2019) *The Number of Motorized Vehicles According to Their Type 2009–2015* [online] https://surabayakota.bps.go.id/subject/17/transportasi.html#subjekViewTab4 (accessed 20 February 2018).

Wisconsin Department of Health Service (2019) *Carbon Dioxide* [online] https://www.dhs.wisconsin.gov/chemical/carbondioxide.htm (accessed 17 February 2020).