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AN APPLICATION OF SYSTEM DYNAMICS IN AIR POLLUTION MITIGATION WITH SUSTAINABLE PERSPECTIVE IN THE CITY OF DEPOK

Yudith Vega Paramitadevi[1], Alimuddin Joop Vanadian[2], Irman Firmansyah[3]

[1] Sekolah Vokasi IPB University, Environmental Engineering and Management Program
[2] Islamic Ibn Khaldun University, Civil Engineering
[3] Postgraduate School of IPB University, Natural Resources Management Program

Corresponding author:
Corresponding author:
yudith.vega@apps.ipb.ac.id

ABSTRACT

Sustainable development in urban areas cannot be separated from environmental qualities, one of which is air quality and pollution. The target of reducing air pollutants can be pursued with policies that are following strategic studies. The system dynamics function as a tool for this study to analyze the relationship between the variable sources of pollutants and get the most likely scenario to be applied in Depok City until 2040. The system dynamic phases in this study include causal loop diagrams, stock and flow diagrams, and scenario simulations. There are 3 related net flows, air pollution level, private vehicle travel rate, and public transportation growth rate. The public transportation system development scenario can be applied in the city of Depok, since it can reduce the number of trips using private vehicles and can increase regional income. Although this policy can only be implemented in the next few years, the simulation results show the direction of stability. This means that in 2030-2040 the concentration of air pollutants can be removed if the population has consistent awareness.

KEYWORDS

air pollution, policy, net flow, system dynamics, public transportation

Introduction

Polluted air has become a global issue experienced by many countries. The pollution issues have spread to the fields of the environment, health, chemistry, and economy [3, 7]. Currently, many developed countries have implemented solutions to overcome the problem of air pollution. Countries in the European continent are intensively making mitigation efforts; one of their successes is implementing a smart transportation system that aims to reduce congestion while reducing air pollution [4]. The application of a smart transportation system requires socialization to the community within a sustainable development framework [5]. Based on research on air pollutants in big cities and experts' justifications, the main causes of air pollution are pollutants from industry, deforestation, population explosion, greenhouse gas emissions, urban heat islands, fuel consumption, traffic congestion, and transportation conditions [3, 4]. An important point to consider is the fact that air pollution is an environmental issue [3, 4, 5, 7].

The city of Depok became the subject of this study since most of the anthropogenic activities are found as a source of both moving and static emissions. Data retrieved from BPS of City of Depok shows that Depok is the middle city in Indonesia and has a population density of 11,635 person/ km2 in 2018 [1]. Another thing that acts as a source of emissions is the height of the inversion layer caused by industrial activities, transportation, and changes in land cover. In terms of transportation, the higher the need for fuel, the more it causes air pollution. In this case, the older vehicles are inefficient, so they emit more pollutants [3, 5]. The Air Quality Monitoring System (AQMS) in Indonesia is merely installed in big cities so that a medium-sized city like Depok cannot know the condition of air pollution in real-time. Research on air pollutants in the city of Depok has not been carried out thoroughly, covering chemical, economic, health or ecological aspects, and mitigation efforts. There needs to be a methodology that considers the variables and conditions of air pollution and the effectiveness of implementing air pollution policies in the city of Depok. System dynamics modeling is one of the socio-economic approaches that emphasize various variables but is easy to operate [5, 7]. System dynamics is a method with high reliability and can test policies in the system [6]. The simulation method is beneficial in estimating system dynamics, although this research is not a technical or chemical paper in predicting urban air pollution. This study aims to determine the system dynamics model of air pollution in the city of Depok and provide suggestions on applicable policies. This study consists of a methodology and an explanation of the relationship between research variables using a causal loop diagram and introducing the potential possible policy scenarios for the city of Depok.

Research Methodology

This study was carried out in two approaches, namely a literature approach and a field approach. The literature approach collects data or filters information through research journals and/or books related to research themes. Meanwhile, the field approach collects data by conducting direct surveys or ground checking of the research location. This survey can also be used to find as much information as possible from related parties. The data collected were population data, economic conditions obtained from the Central Bureau of Statistics (BPS), and the 2020 Strategic Environmental Assessment (KLHS) document for the city of Depok. The primary and secondary data analysis methods that have been obtained were analyzed using the POWERSIM software for Academic Purposes. Model development (Table 1) begins with the conceptualization of a waste management system as outlined in a causal loop diagram. Afterward, the model structure is arranged in the form of a stock-flow diagram. Finally, the model is evaluated and tested for validity by comparing the dynamic system simulation results with historical data.

Table 1. Method of Research Analysis

Instrument of Analysis	Purpose	Data Input	Data Output
Powersim for Academic Purposes	Designing a model for air management system in Depok City	Emission sources, cardinal directions, number of factories, number of vehicles	Dynamic models and scenarios for sustainable air management

System dynamics is closely related to Causal Loop Diagrams (CLD). CLD is arranged in a system dynamics composed of four fundamental building block elements. Figure 1 shows the relationship between variables that play a role in air pollution in the city of Depok. Parameters related to air pollution-CO_2 emission-inversion layer influence each other and thus affect air quality. The increasing public awareness-reducing the use of private cars-optimization of public transportation will further reduce the concentration of air pollutants. The system dynamics approach will be successful if it takes into account the source of air pollutants. Air quality is an environmental issue, so policies must also be related to sustainable development. Important points that need to be considered include the political and economic conditions in a city/ country at the time of policy selection, whether the city/ country has sufficient infrastructure to carry out the policy [5, 6]. This study discusses one of the policies chosen in the city of Depok by developing a public transportation system.

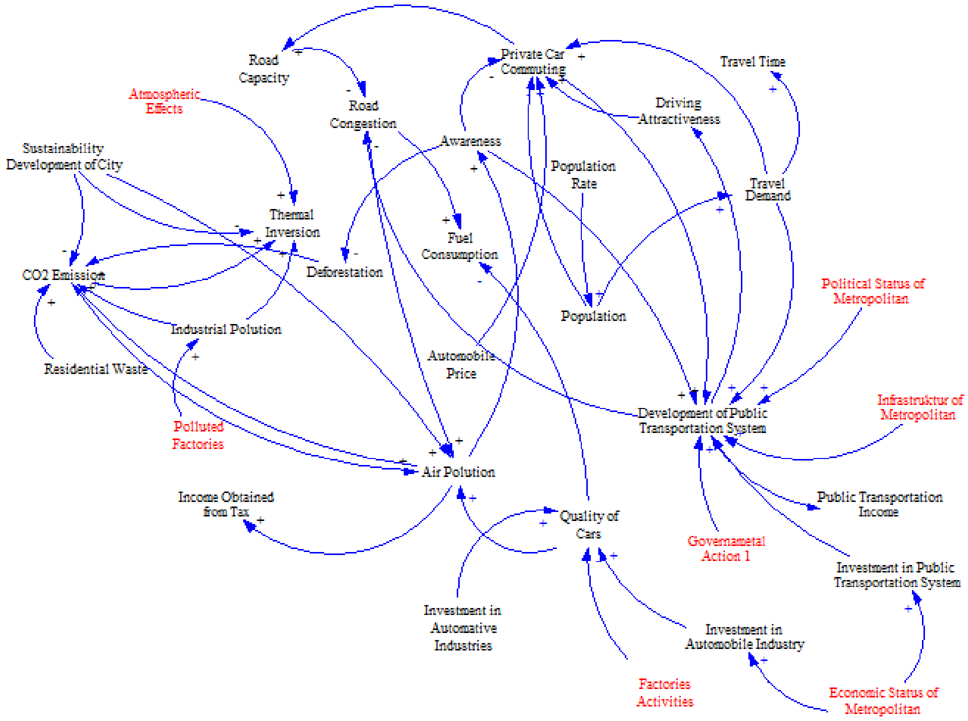


Figure 1. CLD of Air Pollution

CLD is the initial stage of a system dynamics that is used to show feedback and interrelation variables. CLD is sufficient in showing the impact of policies in handling air pollutants. The CLD which is equipped with a stock and flow model diagram, will be made easier. As previously mentioned, eight factors contribute to pollution problems in the city of Depok, including emissions from industrial sources, land conversion, population increase, inversion layer, fuel consumption, traffic density, and vehicle types. The higher one of the factors, the more the air pollutant increases (Figure 1). For example, the longer a vehicle operates, the more fuel it consumes. The inversion layer is formed due to greenhouse gas emissions and industrial pollutants and the relationship between variables in CLD. Apart from the variable sources of air pollution pollutants, there are other factors, namely the burning and handling of waste in residential areas.

Result and Discussion

The recovery of polluted air will work well if the rate of deforestation slows down. According to the KRP's direction in the 2020 KLHS document, deforestation is tackled by the growth of green open spaces in the city of Depok [2]. This is because green open spaces function as a means of natural purification, especially in the form of city parks. Thus, the air quality management planning system in the city of Depok also involves the number of open green parks, in addition to the regulations that have been implemented by the City Government of Depok.

Existing Condition of Air Quality Treatment Planning System

Air pollution or decreased air quality is the entry of living things, energy substances, and/or other components into the air or changes in the air system by human activities or natural processes. Thus, air quality drops to a certain level which causes the air to become less or unable to function anymore following its designation (Law No. 32/2009). The factor that causes a decrease in air quality is the increased physical development of cities and industrial centers. Air pollution is basically in the form of particles (dust, aerosol, lead, black) and gases (CO, NO_2, SO_2, H_2S, and hydrocarbons).

In general, data retrieved from 2017-2018 for SO_2 and NO_2 parameters showed that the air quality in the city of Depok met quality standards based on Government Regulation Number 41/1999 on Air Pollution Control (Table 2).

Table 2. Average Air Pollution in 2017-2018

No	Source	Duration	SO_2 (micro g/m^3) annual average 2017	SO_2 (micro g/m^3) annual average 2017	NO_2 (micro g/m^3) annual average 2018	NO_2 (micro g/m^3) annual average 2018
1	Transportation	15 days	9.95	30.731	45.8	29.55
2	Industry/factory	15 days	10.5	22.94	25.9	27.45
3	Residence	16 days	2.57	5.3	22.65	23.05
4	Commercial	17 days	5.315	13.7833	31.8	25
	Average		7.08	18.17	7.08	18.17

Source: Department of Environment and Cleanliness of the City of Depok (2018)

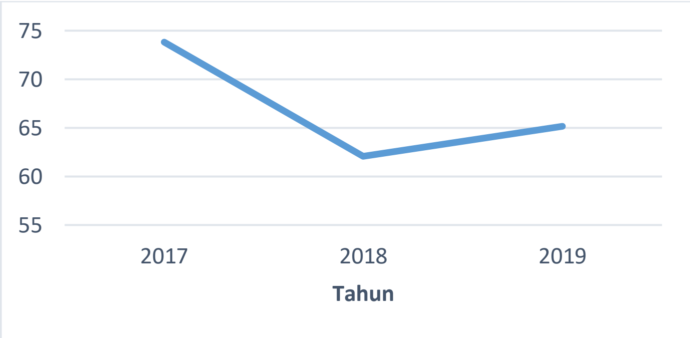


Figure 2. Air Quality Index of the City of Depok in 2017-2019
Source: Department of Environment and Cleanliness of the City of Depok (2019)

Table 2 shows that transportation, factory operations, and residential and commercial activities are the causes of the decline in air quality in the city of Depok. The number of private vehicle ownership in the city of Depok increases every year. Furthermore, the combustion process in a factory that produces large quantities of product will produce toxic fumes released into the air. Meanwhile, people living in residential and commercial areas commonly burn waste which becomes the cause of the SO_x parameter concentration to increase. However, the NO_x parameter decreased by 16.74% compared to the previous year. The industrial and housing sectors have contributed to the increase in the value of NO_x. However, all parameters were below the quality standard of Government Regulation Number 41/1999 on Air Pollution Control, i.e., 150 micro g/m^3.

The results of the Air Quality Index in the city of Depok from 2017 to 2019 (Figure 2) show a value of 73.82–62.07. Based on the Air Pollution Standard Index stipulated in the KEP-45/MENLH/1997 on Air Pollution Standard Index (51-100), it is in the medium category, meaning that the level of air quality does not affect humans or animal health but affects sensitive plants and aesthetic values. The conditions above indicate that the City Government of Depok has currently overcome air pollution, which was felt in the previous year, either through several actions, policies, or regulations. However, steps forward are still needed to maintain this condition.

Based on the Depok City Environment Agency (2019) active manual observations, there is a parameter with a value exceeding the quality standard, i.e., dustfall. The measurement results show that there are 3 (three) locations with values exceeding the quality standard of the Government Regulation No. 41/1999 (quality standard of 230 µg/Nm^3), i.e., DTC Pancoran Mas (256.1 µg/Nm^3), in front of Woody Garden, Cilodong District (355.40 µg/Nm^3), and in front of Margocity, Beji District (272.0 µg/Nm^3). Noise at all monitoring location points exceeds the quality standard based on Kep No. 46/MENLH/11/1996, with a value greater than 60 dB. If dustfall and noise are not managed properly, they will impact human health such as respiratory problems and physiological damage to the hearing organs. Therefore, it is necessary to prevent and sustainably tackle air pollution through government policies to maximize public transportation.

Existing Condition of Planning of Protection Function Supporting Capacity System in the City of Depok

Regional Spatial Planning (RTRW), Long Term Development Plan (RPJP), and National, Provincial and District/City Medium-Term Development Plans (RPJM) are the main documents in the preparation of spatial planning systems in a city. The RTRW of the City of Depok contains policy directives, plans and programs (KRP) to regulate city spaces. The spatial policy is described in spatial planning objectives, policies, and strategies. Meanwhile, the plans are described in the form of Spatial Structure Plans (service center system plans, network system development plans), Spatial Pattern Plans (protected area plans and cultivation area plans), strategic area plans (strategic areas for economic growth, strategic areas for environmental carrying capacity, and socio-cultural strategic). A program to control and realize spatial planning is described as a spatial use zoning program and plan. Both are attachments that are not legally separated in the RTRW document.

The green open space of the City of Depok consists of protected/natural areas, artificial green, and functional green. Green open space has a function for protecting ecosystems, protecting the environment from pollution, creating a microclimate, protecting water systems, enhancing the aesthetic image of the environment, creating cleanliness and health, recreational facilities, and production facilities. The allocation of green open space in Depok is divided into river borders, gas pipelines, nature reserves, city forests, city and environmental parks, cemeteries, green lines, agriculture, recreation, and tourism. Although the dominance of the largest built-in land use is in the city of Depok for settlements with an average annual area utilization rate of 125 Ha (Depok City Spatial Planning Agency, 2018), the city of Depok maintains 53 city parks with a distribution (Figure 3) in 10 of 11 wards.

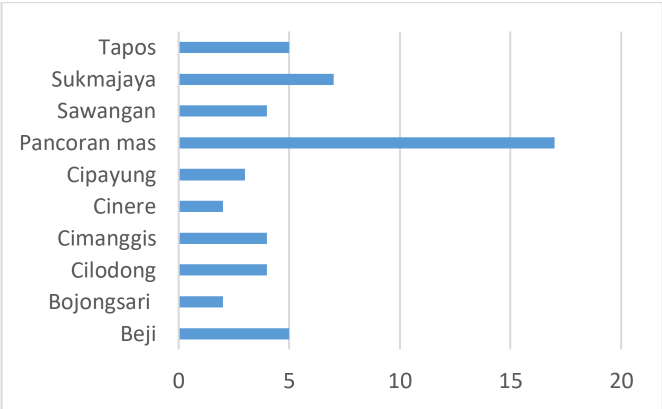


Figure 3. Number of City Parks in Depok in 2018
Source: Department of Environment and Cleanliness of the City of Depok (2019)

System Dynamics Model of Air Pollution in Depok City

The system dynamics model applied in this study is related to CO_2 emissions, inversion layers, and air pollutants in the city of Depok. Public awareness to switch to public transportation can reduce the impact of air pollution. The vehicle price element is included as a complementary variable in this study. The higher the car price, the more population is not interested in buying private vehicles. Travel needs and travel time were also included as variables indicating the mobility of the population from home to other locations. Road capacity reflects roads, toll roads, and roads that can accommodate vehicles during traffic congestion. Population rate indicates population growth. The price of the vehicle is a variable that directly affects the level of trips using private vehicles. The capital spent by the vehicle industry is shown as an investment in the vehicle industry. Investments in the public transport system are counted towards the development of public transportation. The income obtained from public transportation is considered as income; the more public transportation is used, the more income it will get. Stock and flow diagrams as part of system dynamic modeling are shown in Figure 4. Data were obtained apart from secondary data and expert justification [6].

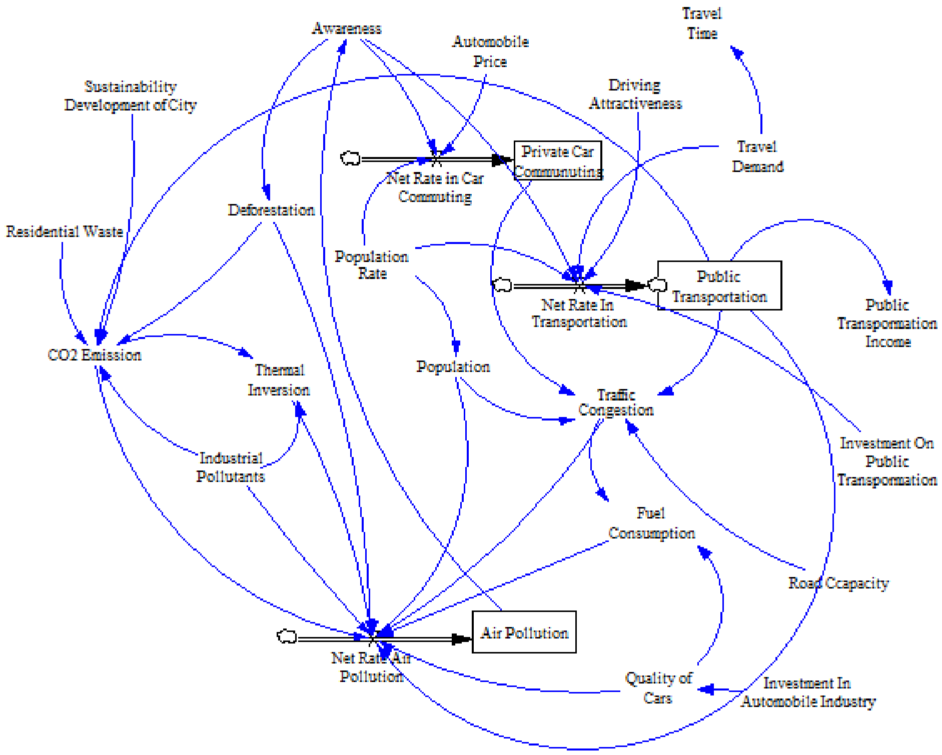


Figure 4. Stock and Flow Diagram of Air Pollution

Stock and Flow Diagram (Figure 2) above consists of three variables and three channels for modeling. The three channels are the level of public transportation, the level of travel by private vehicle, and the level of air pollution. The equations of the three channels are:

$$Rate\ of\ Air\ Pollution\ (t) = Net(0) + \frac{\int_0^t \left(\begin{array}{c} (Industrial\ Pollutants + CO2\ Emission + Thermal\ Inversion + Air\ Pollution) + \\ (Population + Traffic\ Congestion + Fuel\ Consumption) \end{array} \right) d(t)}{\int_0^t (Public\ Transportation + Quality\ of\ Cars + Sustainability\ Development\ of\ the\ City) d(t)}$$

$$Net\ Rate\ of\ Private\ Car\ Commuting\ (t) = Net(0) + \frac{\int_0^t (Private\ Car\ Commuting\ x\ Population\ Rate\ x\ Travel\ Demand\ x\ Driving\ Atractiveness) d(t)}{\int_0^t (Automobile\ Price + Awareness) d(t)}$$

$$Net\ Rate\ of\ Public\ Transportation\ (t) = Net(0) + \frac{\int_0^t (Public\ Transportation\ x\ Population\ Rate\ x\ Travel\ Demand\ x\ Investment\ on\ Public\ Transportation) d(t)}{\int_0^t (Net\ Rate\ in\ Car\ Commuting\ x\ Driving\ Attactiveness\ x\ Awareness) d(t)}$$

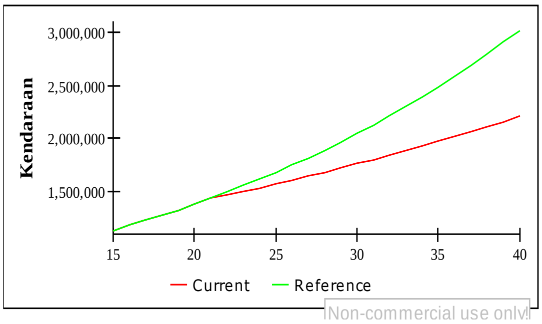
Net (0) is a variable value based on secondary data. The integral form between 0 and t shows the accumulation of each variable from 2015 to 2040. For example, the Net Rate of Air Pollution forecast is calculated through the actual concentration added to the integral function between positive variables in the Net Rate divided by the interactions between negative variables at the Net Rate. The relationship between variables has been previously described above. The specifications of all parameters can be seen in Table 2, along with the units. Any variable for which there are no units will be considered as relative factors. This relative factor is used when a variable is incomplete or has no units. The value of this variable is determined by expert justification.

Table 6. List of Parameters (Variables) Used in Stock and Flow Diagram

Variable Type	Variable Name	Variable Value	Unit
Stock	Air Pollution	61.7	μg/m³
	Development of Public Transportation System	2.9	million passenger/year
	Private Car Commuting	5.5	million/year
Rate	Net Rate in Air Pollution		1/year
	Net Rate in Transportation		1/year
	Net Rate in Car Commuting		1/year
Auxiliary	Population Rate	0.0321	1/year
	Population	2076	million people
	Deforestation	0.067	million/year
	Thermal Inversion	1.3	Celsius/m³
	Industrial Pollution	-0.05	million-ton reduction/year
	CO2 Emission	1.724	million ton/year
	Traffic Congestion	1.9	trip/km
	Fuel Consumption	1.05	lit/year
	Investment in Automobile Industry	0.13	million dollar/year
	Investment in Public Transportation	0.19	million dollar/year
	Public Transportation Income		million dollar/year
	Road Capacity	6.85	kilometer
	Travel Demand	0.7	million passenger/year
	Travel Time		
	Driving Attractiveness	1	
	Awareness	1	
	Automobile Price	1	
	Residual Waste	0.862	million ton/year
	Sustainability of the City	1	
	Quality of Cars	1	

Solutions Implemented by the City Government of Depok

One solution that the authorized government needs to do is the creation of an effective mass vehicle facility. The reduction in private vehicles will have a positive effect on the content of pollutants in the air. One of the effective solutions is rail-based mass vehicles such as Mass Rapid Transportation (MRT). Comparison of existing vehicle data when mass transportation facilities are not built and when mass public transport facilities have been built, as well as the optimal use of mass facilities, can be seen in Figure 5. After mass transportation, the number of vehicle ownership will decrease. In 2021, the MRT will be simulated so that the number of vehicles will decline.



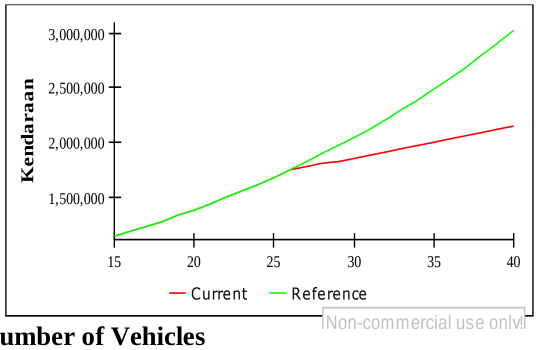


Figure 5. Comparison of Number of Vehicles
Left: MRT Scenario, Right: Optimal Utilization of MRT

Planning and activity control must be carried out continuously for optimization during its implementation. In 2026, an evaluation will be carried out so that the quality and quantity of the MRT can be increased optimally. The result will be a significant reduction in private vehicles. Before implementing mass public transportation, private vehicles will be predicted to be more than 3 million units in 2040. However, after mass public transportation, it will decrease to 2 million units in 2040. Considering further pollution reduction, the evaluation of mass transportation in 2026 will affect the reduction of private vehicles back. This will lead the number of private vehicles is less than 2 million units in the city of Depok by 2040. Based on the simulations that have been carried out, it is expected that the pollutants contained in the air due to exhaust gases generated by motorized vehicles will be reduced.

Air pollution is a problem that can be handled gradually so that the final result can be obtained years later. Thus, the selection of sustainable policies as an effort to mitigate air pollution is very important. If one of the contributing factors in it (CO_2 emissions, pollution from industrial emissions, etc.) can be reduced, air pollution can decrease drastically. The stability that arises in Figure 5 can occur if the awareness of the population to comply with government policies appears. Research with similar results was also applied in the cities of Tehran and Mexico [3, 7].

Conclusion

This study discusses the significant variables investigated and the policies that apply to air pollution in the City of Depok. Based on the number of variables between relationships, simulations using a dynamic system can be carried out. As an initial approach to system dynamics, CLD is structured to identify potential factors. Then, stock and flow diagrams are arranged to determine the interaction between variables. The most suitable policy flow for the city of Depok is the development of public transportation. The policy scenario shows that If the MRT is implemented massively, the number of private vehicles used by residents will decrease by 1 million units from the initial condition of 3 million units. This system dynamics model can also be adapted for other cities, including being correlated with policies related to the environment's carrying capacity.

References

[1] BPS Kota Depok. 2021.

[2] Dinas Lingkungan Hidup dan Kebersihan Kota Depok. 2018.

[3] Hosseinabad, E.R. and Moraga, R.G. 2017. A System Dynamics Approach in Air Pollution Mitigation of Metropolitan Areas with Sustainable Development Perspective: A Case Study of Mexico City. J. Appl. Environ. Biol. Sci, 7(12)164-174.

[4] Kuai, P., Li, W., Cheng, R., Cheng, G. 2015. An Application of System Dynamics for Evaluating Planning Alternatives to Guide a Green Industrial Transformation in a Resource-Based City. Journal of Cleaner Production (xxx)1-10.

[5] Naddeo, V., Belgiorno, V., Zarra, T., Scannapieco, D. 2013. Dynamic and Embedded Evaluation Procedure for Strategic Environmental Asessment. Land Use Policy 31(605-612).

[6] Randers, J., 2000. Guidelines for Model Conceptualization, Modeling for Management 11: Simulation in Suport of System Thinking, Darmouth Publishing Co. Ltd. Vermount, USA.

[7] Vafa-Arani, H., Jahani, S., Dashti, H., Heydari, J., Moazen, S. 2014. A System Dynamics Modelling for Urban Air Pollution: A Case Study of Tehran, Iran. Transportation Research Part D(31)21-36.