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Research paper

Dynamic Simulation Model for Predicting the Value of Health Degradation that Caused by Air Pollution of the NO_2 Gas

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Abstract

In Jakarta the majority of energy comes from fossil fuel burning, which also emitting the NO_2 gas as air pollution. NO_2 gas that inhaled by humans will damage the respiratory system called Respiratory Symptomps Disease (RSD). This research aims to predict the value of health degradation which comes from NO_2 gas air pollution by developing a dynamic simulation model. When the ambient concentration of NO_2 gas exceeds the standard, some of Jakarta residents will get RSD. The value that has to be paid by Jakarta residents who will get this disease is predicted by the dynamic simulation model. The result of this research is that started the year 2018 there will be 973 Jakarta residents who have RSD from NO_2 air pollution gas and will continue to increase until 109,263 in 2025. In 2025 the citizens of Jakarta which will be get RSD caused by NO_2 gas as air pollution will have to pay approximately US $ 30.5 M, or about 12.5 percent of the GDRP.

Keywords: *air pollution, ambient concentration, dynamic simulation, nitrogen dioxide (NO_2) gas, Respiratory Symptoms Disease (RSD)*

1. Introduction

Population growth is always accompanied by a desire to improve the quality of life and in line with the energy needs. In Indonesia total energy supply is met by fossil fuel burning [1]. Fossil fuel burning not only produce energy, but also emits some pollutants to the ambient air, one of them is NO_2 gas. Researches by [2] and [3] conclude that in the capital city of Indonesia, Jakarta, there were some health degradation cases which are caused by NO_2 air pollution, such as Respiratory Symptoms Disease (RSD). RSD comes from NO_2 gas that is inhaled and destruct the breathing system. In some case the excess of NO_2 gas concentrations in the ambient air will cause emphysema. In this research the value of health degradation that caused by NO_2 gas air pollution in Jakarta was predicted using the dynamic simulation model.

2. Materials and methods

In this research the development of the model is done by using software Vensim. The dynamic simulation model developed in this research based on the research done by [4] that mentions the concentration of NO_2 in ambient air be affected by: 1) The population of Jakarta, is expressed with variable "residents" in units of million persons; 2) The income of the population per year, with a variable declared the "Gross Regional Domestic Product (GRDP)" in units of millions of dollars; 3) The number of vehicles in Jakarta, expressed with a variable "number of motor vehicle" in units of million; 4) Production of electricity is expressed with variable "electricity production" in units of billion KWh; and 5) The amount of rainfall is expressed with variable "rain" in units of thousands mm. The relation of the concentration of NO_2 in ambient air with those variables can be represented by the mathematical equation (1):

$$\begin{aligned}\text{Ambient concentration of } NO_2 &= -0.17019 \\ &+ 0.019162\,\text{residents} + 0.033731\,\text{GRDP} \\ &+ 0.46410\,\text{vehicle} + 0.038314\,\text{electricity} \\ &+ 0.81404\,\text{rain}\end{aligned}$$

[5] stated that part of NO_2 gas in ambient will be converted to be secondary PM_{10} by the mathematical equation (2):

$$[\textit{Ammonium nitrate}] = 0{,}377/1877{,}55 * [NO_2]^{0{,}63} * 100/89$$

Where:

- [Ammonium nitrate] = concentration of ammonium nitrate ($\mu g.m^{-3}$)
- $[NO_2]$ = concentration of NO_2 ($\mu g.m^{-3}$)
- 1877.55 = conversion factor of concentration of NO_2 from ppm to $\mu g.m^{-3}$

[6] stated that most of NO_2 gas emissions come from anthropogenic activities, only 11% is produced naturally. So that, in this dynamic simulation model the ambient concentration of NO_2 gas subtracted by 11%. Not all ambient NO_2 gas concentration will be accumulated in the air, that will be reduced by time that is called as the half-life time. The half-life of NO_2 gas ambient is 50 days [7].

Not all of the Jakarta residents will have health problems caused by NO_2 exposures ambient gas, [2] mention only 12,6%. In the dynamic simulation model that developed this percentage was

input as a variable of "proportion of exposured resident". The mathematical equation (3) represents the relation between NO_2 ambient gas concentration with the amount of the Jakarta resident who will get RSD:

$$NRSD(t) = 6{,}02 * \left[\frac{NO_2(t) - NO_2st}{NO_2st} \right] * \Pr A(t) * P(t) / 1877{,}55$$

Where:

- NRSD(t) = number of residents who have RSD in year-t
- $NO_2(t)$ = concentration of NO_2 gas (ppm) in year-t = $NO_2(2014)$ = 0.02 [8]
- NO_2st = standard concentration of NO_2 gas per year
- PrA(t) = percentage of adults in year-t. Based on data from [9], PrA(2015) = 75.2%, in the dynamic simulation model this variable was mentioned as "adult proportion".
- P(t) = number of Jakarta population in year-t = 10.177.924 in 2015 [8]
- 1877.55 = conversion factor of concentration of NO_2 from ppm to µg/m^3

From the equation (3) it is clear that the NO_2 gas pollution will take effect on the Jakarta resident health when the concentrations are above the standard. The standard of NO_2 ambient gas concentration be regulated by Jakarta Governor's regulation No 551 in 2001, that is 0,05 ppm.

To estimate the value of health degradation caused by NO_2 gas air pollution, it is assumed that the rate of hospital cost per day in Jakarta is 18.63 US $ [10]. [11] stated that the average of duration of the illness per year is 20 days. With the assumption that illnesses come from respiration in general are not needed hospital care in the first 5 days [12], so that the cost to take care of RSD illnesses comes from NO_2 gas air pollution from one person in Jakarta per year is 279.5 US $.

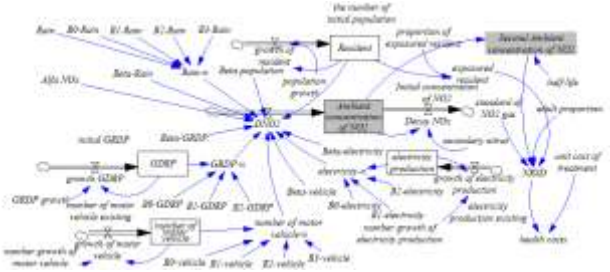

Figure: Stock-Flow Diagram of NO_2 Gas Air Pollution in Dynamic Simulation Model.

The development of model simulation in this research is input all of the equations and variables from the previous researches and the assumptions above in the stock-flow diagram (Figure 1). The existing condition data that are inputted to the stock-flow diagram is the Jakarta condition in 2015 obtained from [8], there are: 1) The number of initial residents is 10,177,924; 2) The initial GRDP is 108,35 M US $; 3) The number of motor vehicle existing is 17.524 million; 4) The electricity production existing is 45.746 billion KWh; and 5) Initial rainfall is 1.831 thousands mm. Based on the stock flow diagram developed simulations conducted in 2015 (preliminary data, INITIAL TIME) until 2045 (FINAL TIME). At the end of the simulation (2045) the prediction of the simulation is out of theory, so that the prediction data analyzed only until 2025.

3. Results and Discussion

The simulation of the dynamic model developed results are started in the year 2018 there will be 973 Jakarta residents who have RSD from NO_2 air pollution gas and will increase to be 109,263 persons by 2025. The simulation of an increasing number of respiratory illnesses (NRSD) against the time (year) produces the graph as can be seen in Figure 2:

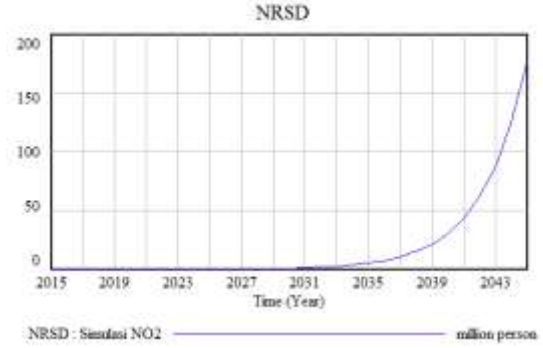

Figure 2: Impact of the NO_2 Gas Pollution Against the Number of RSD.

The costs for treating sick people caused by NO_2 gas air pollution will continue to increase, and the simulation results can be seen in Figure 3.

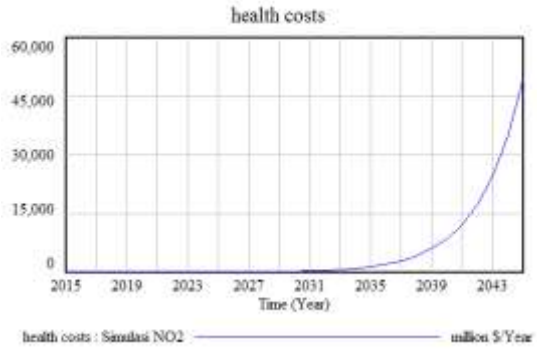

Figure 3: Impact of the NO_2 Gas Pollution Against the Medical Costs of RSD

The value of health degradation caused by NO_2 gas air pollution in Jakarta by 2025 is predicted around 30.5 M US $ or about 12.5 percent of GDRP in 2025.

Even though the NO_2 gas air pollution cannot cause the human death, but the value of health degradation caused by this air pollution reached big number. So that, it is important to maintain the emission number of NO_2 gas until the ambient concentration of NO_2 gas does not exceed the standard.

To reduce the NO_2 ambient gas concentration, it is important to know the factors that influence this concentration. The simulation model developed in this research stated that NO_2 gas ambient concentration is influenced by the amount of resident, GDRP, the amount of motor vehicle, electricity production, and rainfall. The result of the simulation is in line with the statement from [13] that the needs of human being to improve their quality of life is always in line with the energy needs. In this research the improvement of quality of life is represented by GDRP and the number of motor vehicle, and the energy needs are presented by electricity production.

In this research the relationship between the quality of life or the prosperity level with the pollution result compatible with researches done by [13]; [14]; [15]; [16]; which analyzed the relationship between the prosperity and environmental degradation and the result is the prosperity level affect environmental degradation in quadratic function. This function showed that in the early period of development to increase the quality of life, the pollution will increase in line with the prosperity, however, after reaching a certain point, the environmental degradation caused by the pollution will decrease even though the level of prosperity increased.

4. Conclusion

The first conclusion from this study is the form of demographic factors, economic, and social factors that affect ambient concentrations of NO_2 in the air, namely: population, income of the community expressed by the GDRP (Gross Domestic Regional Product), the number of motor vehicles related with the use of fossil fuel, and electricity production. In addition, ambient concentrations of NO_2 in the air are also influenced by climatic factors in the form of rainfall.

The results of simulations carried out in this study concluded that in Jakarta the sources of air pollution in the form of nitrogen dioxide (NO_2) gas mainly due to the use of motor vehicles. Starting in 2018 it is predicted there will be a number of 973 residents of Jakarta who get the respiratory illness symptoms from NO_2 air pollution gas, and the number will continue to increase until 109,263 in 2025. The economic costs associated with health problems that come from NO_2 gas air pollution is estimated to reach around 30.5 M US $, or about 12.5 percent of GDRP in 2025. If no control measures are carried out, then these costs will reach huge number. Prediction amount of considerable health cost of this research can be used as the basis for the consideration of the implementation of the policy on air pollution control.

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