A dynamic model of the pollution impact of dioxin/furan on the environment, society and economy

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Abstract

Dioxin and furan have both long and short-term adverse effects on living organisms. This research aims at developing a computational model to determine the impact of dioxin/furan pollution on the environment, the society and the economy in order to provide a rational basis for policy development. The approach was to develop and validate a dynamic model of dioxin/furan emissions in Cilegon, West Java, Indonesia. Key components of the model include: (a) estimation of the emission of dioxin/furan discharged from the metal industry; (b) estimation of the concentration of dioxin/furan in the air; and (c) using the estimations from (a) and (b), a dynamic sub-model, to estimate the impact of dioxin/furan on social, economic and environmental factors when alternative controls are implemented. Model results demonstrate that dioxin/furan emissions in the assessed area are elevated beyond the limit that can cause environmental degradation. If things remain status quo (i.e. no new emission reduction policy), the predicted model outcomes from 1995 to 2025, indicates there would be an emission increase of 278%, a decrease in the air quality by 45.16%, 1,092 potential cancer cases, and the social costs of IDR (Indonesian Rupiah) 5,863–358,162 billion. However, if there was an emission control policy that helped to reduce emissions by 46.1%, then there would be significant improvements, such as a decrease in air quality of only 0.63–3.75% and 69% reduction in cancer cases. The conclusion, is that there should be a policy to control dioxin/furan emissions and, further, that significant reductions will result in significant social benefits.
Keywords: dioxin, furan, pollution, dynamic model.

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1 Introduction

Dioxins and furans (dioxin/furan) are persistent compounds that are released as a byproduct of industry, combustion or other sources. Dioxins and furans are two different compounds, but the physical and chemical properties are almost the same. The impact of pollution from these compounds provides long- and short-term consequences for the health of living organisms or the environment. Furthermore it can cause social and economic losses.

Dioxins/furans are generated as a byproduct of combustion processes and some chemical processes [1]. The formation of dioxins/furans can occur through the combustion of chlorine containing materials such as organic waste materials and paper products. Researchers from the National Risk Management Research Laboratory, US-EPA, found that the burning of domestic waste combustion with low temperatures could lead to toxic dioxins/furans that are higher than in the controlled incinerator. Therefore in the U.S. it is forbidden to burn garbage in the open air. In Indonesia, it was estimated that in 2000 the total emissions of dioxin/furan was 21.126 g TEQ *(Toxic Equivalent)* [2]. This amount is quite high when compared with other countries. The largest source of dioxin/furans emissions in Indonesia was the generation of energy and heating (66%), followed by pulp and paper industry (21%), burning out of control (7.7%), metal and non-metal industry (4.5 %), and combustion of the mineral industry, transportation and garbage disposal [2]. The majority of dioxin/furan is discarded into the air (71.4%).

The persistent nature and toxic accumulation of dioxin/furan pollution have a major impact on the environment, health (social) and economy. To deal with the negative impact, some countries apply the policy of tolerance threshold concentration of dioxin in the human body. According to Ackerman [3], when exposed to dioxin concentration 1 pg/body weight/day, the risk of getting cancer is 1%. Similarly to the ambient concentration standards, the policy varies widely. The standard concentration of ambient dioxins/furans according to the WHO is 0.11 pgTEQ/m^3 [4]; according to research by Rao and Brown [5], it is 1 pgTEQ/m^3; while in Japan it is 0.6 pgTEQ/m^3 [6]. In this regard, Indonesia has not set a standard ambient concentration and tolerance thresholds for dioxins/furans.

The existence of pollution also has economic implications, specifically abatement costs. These costs are the extra cost that must be paid by a company to reduce the level of pollution. These reduction costs can be linked to changes or improvements in technology (e.g., adding a dust filter), scheduling (e.g., reducing hours of operation) or changes in raw materials [7, 8].

A major constraint related to dioxins/furans analysis, is the cost associated with both the requirement technical equipment, supplies, and technical expertise needed to conduct this analysis. Concentration levels for dioxins/furans are very minute and require very sensitive instruments to accurately detect these chemicals. To overcome this constraint, a modeling approach is a viable solution that is both time and cost efficient. Models are rarely used to study levels of dioxins/furans and its calculated impact of pollution on the economy. Despite the clear importance of dioxin/furan pollution, there has been little attention paid through either research policy toward this problem in Indonesia, the world's fourth largest country. Previous research on dioxin/furan consists of several studies that focus on the pollution source, emission and concentration estimation, impact emission for health, environment, and the economy. This study estimates the comprehensive environmental, social, and economic impact of dioxin/furan emissions in one model. This estimate uses a dynamic system model of the iron and non-iron (metals) industry.

Studies of modeling for dioxins/furans have not done much. Development of dioxin/furan pollution models have not been publicized very much. Development of dioxin/furans pollution models that have been made include the following aspects: the source of pollution, emission or concentration estimation, the impact of pollution on health, the impact of pollution on the environment and the impact of pollution on the economy. Study pollution dioxins/furans in various media have been conducted among others through the water by Kobayashi *et al.* [9], and Soesilo [10] and air by Rabl and Spadaro [11], Rufo and Rufo Jr. [12] and Smit [13]. Dioxin/furans emissions modeling calculations and the estimated concentration have been made by Kobayashi *et al.* [9]; Rufo and Rufo Jr. [12]; and Rabl and Spadaro [11]; Smit [13]. Estimated emissions of dioxins/furans by taking into account the uncertainty in emission factors and activity data by Pulles and Kok [14] and Hart *et al.* [15]. Study the impact of dioxin/furans pollution to health by Rabl and Spadaro [11], and Rufo and Rufo Jr. [12], environmental impact assessment by Soesilo [10], assessment of economic impact by Rabl and Spadaro [11], and Rufo and Rufo Jr. [12] and model the impact of policies by Soesilo [10].

2 Materials and methods

Data was collected through primary and secondary data collection methods. Primary data collection was done by giving questionnaires and conducting interviews with industry officials. Secondary data collection was conducted to determine the various data available from the production obtained from the Central Bureau of Statistics and Meteorology and Geophysics Agency or the industry itself.

The model that was developed for this research was a comprehensive dynamic system. In general, the model consists of three sub-model algorithms:

a) Dioxin/furan emission sub-model

Emissions of dioxins/furans into the environment per year, (expressed in gTEQ/year) is strongly influenced by the activity, the quantity of production or raw materials that is used. The equation is: [16, 17].

$$E_{yr} = A_{yr} * EF \tag{1}$$

E_{yr} = Emissions/year (g TEQ/year)

A_{yr} = Activity data per year which is the quantity of raw materials or products produced (kg/year)

EF = emission factor, mass emissions of dioxins per unit of activity levels, expressed in μg I-TEQ per unit of raw materials or products.

Determination of emission factors can uses Standardized Toolkit that issued by UNEP [16].

(b) Dioxin/furan concentration sub-model

Sub-models used to estimate pollution concentrations of dioxins/furans through the dispersion model. Dispersion model used is the ISC model, which is a model that has modified Gaussian dispersion equation [11, 12].

(c) Dioxin/furan impact sub-model

Sub-model used to estimate the impact of dioxin pollution/furans by using dynamic models. In the dynamic models, counting the number of cancer case used equation [12]:

$$\text{INH (mg/kg/day)} = \frac{(\text{Ca x IR x ET x EF x ED x ABS})}{(\text{BW x AT})} \tag{2}$$

INH = inhalation exposure
Ca = ambient concentrations
IR = inhalation rate
EF = exposure frequency
ET = exposure time
ED = long exposure
ABS = absorption fraction
BW = body weight
AT = average time of dioxin exposure

3 Results and discussion

3.1 Dioxin/furan emission sub-model

Based on the equation (1), estimates of dioxin/furan emissions from iron metal manufacturing industries and non-iron from 1995–2004 was 9.38–13.54 gTEQ from total production between 1.87–2.15 million tons, but in 1996, there was surge in emissions significantly. Emissions dioxins/furans in the environment is cumulative, so even if there were small emissions these also need to be taken into account. The total emissions from 1995–2004 are shown in Figure 1.

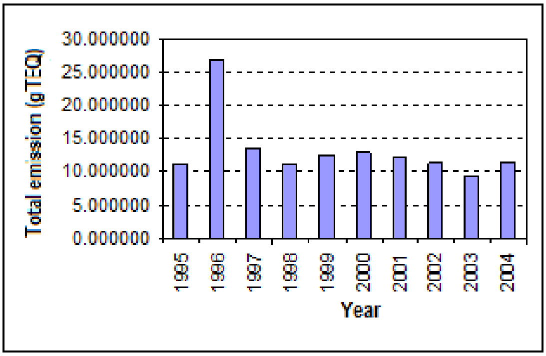


Figure 1: Estimated emissions of dioxins/furans in Cilegon.

3.2 Dioxin/furan concentration sub-model

Based on emissions, the concentration of dioxins/furans is calculated through the Gaussian equation. The concentration of dioxins/furans is strongly influenced by meteorological factors, including wind direction, speed and temperature. When the relationship between concentrations and emissions was examined, through SPSS, the model equation for the concentration and emissions are cubic model with R^2 is 97.0%, b0 = 71,474.7; b1 = 0; b2 = b3 = -114.66 and 12.4637. These coefficients are used as a constant relationship between emissions and concentrations in a dynamic system.

3.3 Dioxin/furan impact sub-model

Theoretically, the greater of production of dioxin/furan the emissions released will also be higher, then the concentrations in the ambient is also high. Those of all will give a negative impact on the environment, the degradation rate increased or the air quality diminishing. The higher of the ambient concentration will significantly affect the potential of cancer cases and deaths. Of course the existence of environmental degradation and cancer cases will have an impact not only on the social, but also to the economy. Economically, increased emissions will cause increasing social cost, so that the net benefits would be reduced. But on the other hand, increased production will provide increased benefits to the industry, which will increase the local GDP. Therefore, dynamic models for impact of dioxin/furan pollution consist of: a) the production; b) the environment impact, such as emissions, ambient concentrations and the rate of degradation; c) the social impact, such as the potential cancer, deaths and social cost; d) the economic impact, such as the *abatement cost,* net benefits, and net profit.

The software used in dynamic system is VENSIM. Stock Flow Diagram (SFD) of dynamic systems is in Figure 2.

3.3.1 Estimation of environmental impact

The impact of emissions on the environment, were analyzed for the presence of changes in the model variables: total emissions, ambient concentration, and the degradation rate or reduction of air quality. Emission reductions of 30.3%, 40.7%, and 46.1% would give a significant impact for total emissions changes (Figure 3(a)); concentration in the ambient (Figure 3(b)); and the rate of degradation (Figure 3(c)). A 46.1% emission reduction would reduce the rate of degradation by 0.63–3.75%. The rate of degradation is relatively stable due to changes in ambient concentrations is very small, whereas the concentration in the ambient standards remain. Emission reductions of 46.1% will also reduce the ambient concentration by 5.61–80.01%.

Based on *the status quo* results for the total emission (Figure 3), estimated increase in emissions of dioxins/furans will be very fast when there is no reduction in emissions. Increased emissions of 278% occurred from the amount of 11.01 gTEQ emissions in 1995 to 41.69 gTEQ in late 2025.

Of course, this will result in ambient concentrations. Ambient concentration ranges from 0.57 to 5.92 pgTEQ/m^3 from the years 1995–2025.

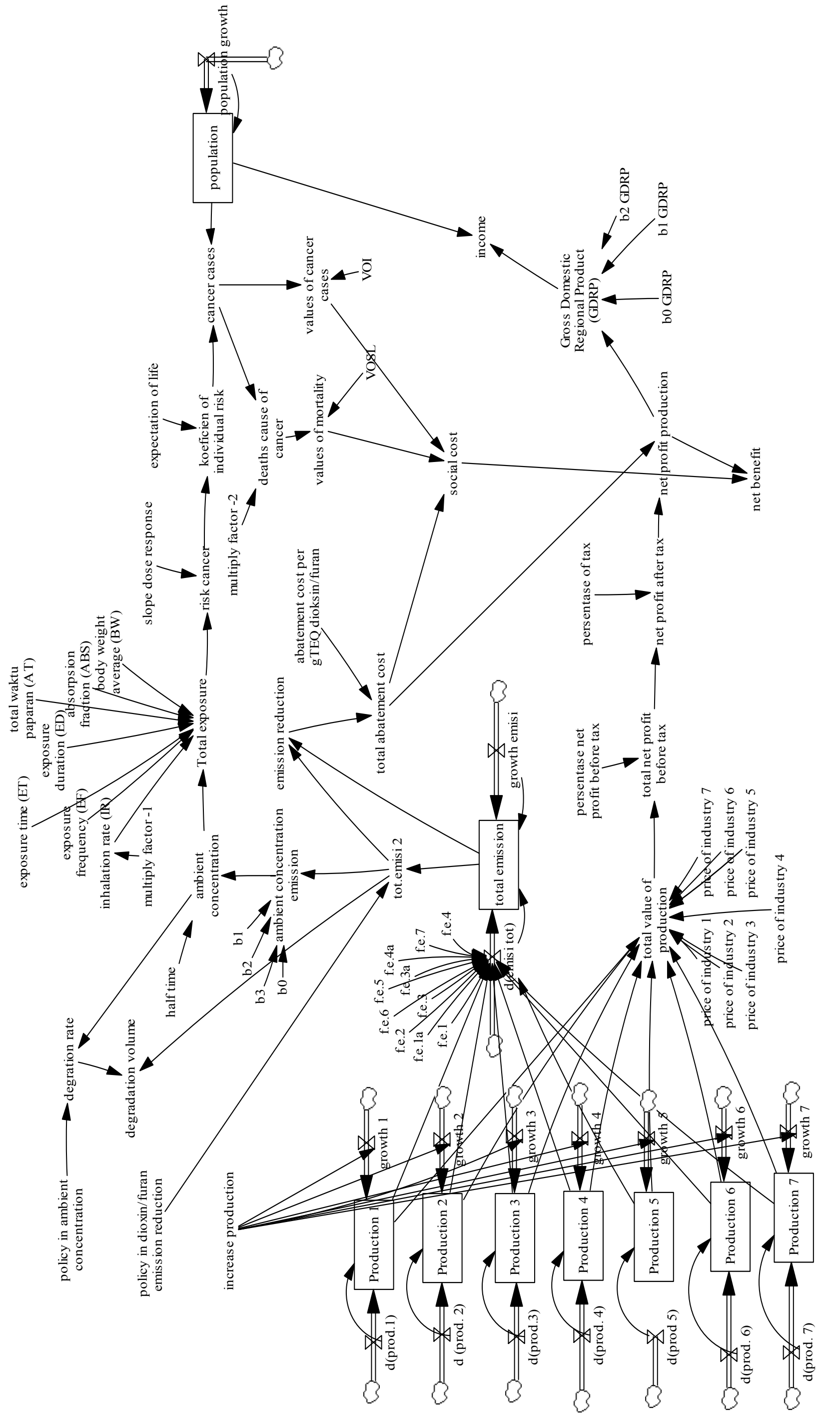
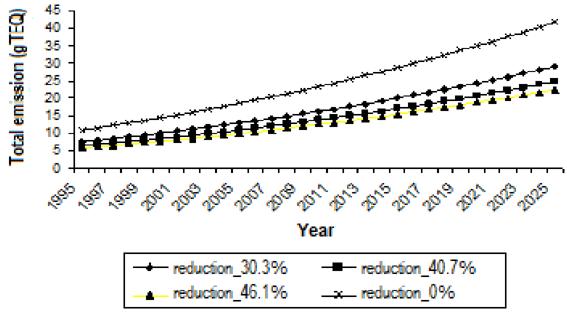
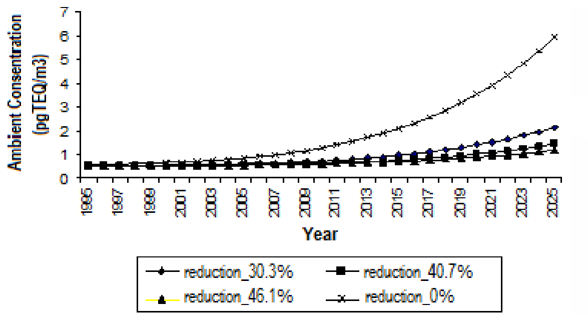


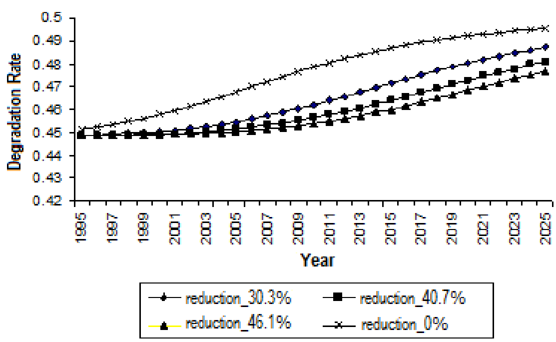
Figure 2: SFD of the impact dioxin/furan pollution.



(a)



(b)



(c)

Figure 3: The results of simulation (a) the total emission, (b) concentration in the ambient and (c) the rate of degradation with various emission reduction.

Using both the WHO and the Rao and Brown standards [5], the concentration of dioxins/furans in the targeted geographical location (Cilegon), has exceeded the threshold from 1998. Indonesia has yet to set a concentration threshold for dioxins/furans in the ambient.

The degradation rate was calculated by determining the concentration in the ambient standards. Using WHO's standard, the environmental degradation of air from 1995 to 2025 range between 0.45–0.49. Using the Rao and Brown standard, the rate of degradation or decrease in air quality ranges from 0.15–0.46. The determination of the concentration in the ambient is very important to determine the level of environmental degradation and deterioration of air quality.

3.3.2 Estimation of social impact

Based on model results, potential cases of cancer occurs in 0.000301–0.003147% of the total population. Each year, growth in the number of cancer cases is at least 1 person, but from 2009 the growth in the number of cancer cases is more than 2 people each year. Based on the status quo data, between the years 1995 and 2004, the number of total estimated potential cancer cases caused by emissions of dioxins/furans were 64 cases. The number of cancer cases from 1995 to 2025 was 1092 cases of the total population. When compared with studies that have been done by Rufo and Rufo Jr. [12], estimated cancer cases caused by the emissions of dioxins/furans from incinerators in 2000–2014 is 2347 cases or 0.00192–0.00349% of the total population of 7.04–9.93 million. The estimation of cancer cases caused by metal and non-metals in the iron industry in the studied area had a smaller impact than the incinerator estimation.

According to previous research, if many cases of cancer occurs due to dioxins/furans, then 16% of the cases will result in death [12, 18]. This rate is used to estimate mortality. The high estimate of the potential cancers would have implications for the socio-economic and the value of statistical life (VOSL) as well as the value of injury (VOI). In Indonesia, VOSL value is very low when compared with the VOSL from other countries. When quantified, based on the model output, the health value due to cancer cases and deaths that occur due to emissions of dioxins/furans from the year 1995–2025 is IDR 5.86–177.00 billion.

Estimated potential cancer cases and deaths will be diminished by the reduction of emissions. If there is no reduction in emissions, the estimated potential cancer deaths from 1995–2004 is as many as 10 people total. Each year, there was a death of 1 person due to dioxin/furans emissions. If using an emissions reduction of 30.3%, 40.7%, and 46.1% until the year 2025, the result will be a reduction in the potential death and potential cases of cancer as shown in Table 1. A 46.1% emission reduction would reduce the potential for cancer by 69%.

Table 1: The results of the simulation estimates the potential cancer cases and deaths by assumption of emission reductions in 1995–2025.

	The number of cases with the assumption of emission reductions:			
	0%	30.3%	40.7%	46.1%
Cancer cases	1092	485 (-55.6%)	377 (-65.48%)	336 (-69.23%)
Deaths	175	78 (-55.43%)	60 (-65.71%)	54 (-69.14%)

The relationship between the potential cancer cases with ambient concentrations is shown in Figure 4. If policy interventions are not developed to control emissions of dioxins/furans, ambient concentration will increase, and cancer cases will increase linearly. Dioxins/furans are substances that are harmful to the body. Even if in minute quantities, these chemicals may be toxic to the body, and can accumulate in fat tissue.

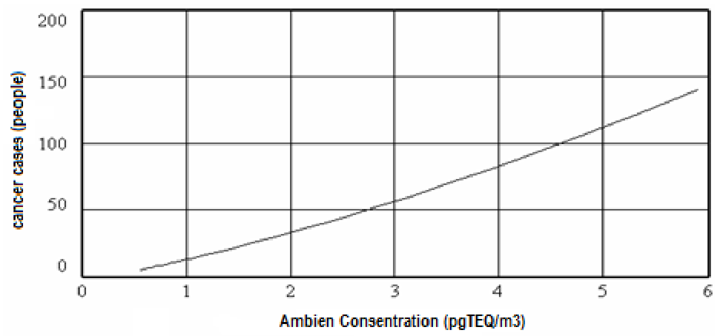


Figure 4: The results of the simulation between the concentration in the ambient with cancer cases.

Emissions reductions also impact social costs (Figure 5). Calculation of social cost is not simply based on the estimated cancer cases and deaths, but also includes abatement costs. Although the estimated potential cancer cases and deaths may decrease, abatement costs to the industry may have a considerable impact that need to be taken into account when estimating social costs. The greater the emission reductions, the greater the abatement costs. In the first few years of the model run, there are additional social costs but after that time period the social costs become smaller than the status quo.

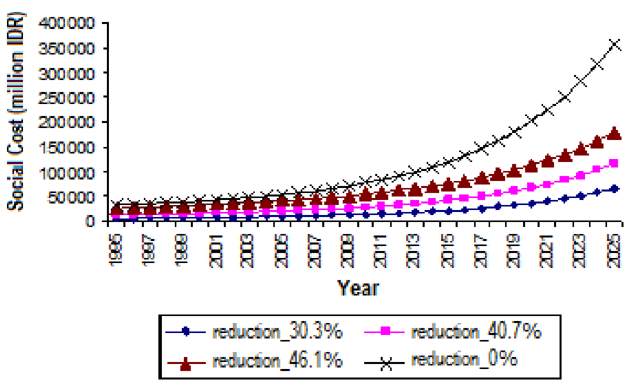


Figure 5: The results of simulations with different social cost of emissions reduction assumptions.

Social costs before the reduction in emissions from 1995–2025 is IDR 5.86 to 36.16 billion, whereas the social cost of reducing emissions after the 46.1% is 13.11 to IDR 64.06 billion. If production increased 3.8%, there would also be an overall increase in the social cost. This cost would be based on increased production, ambient concentrations, and ultimately cancer cases and deaths.

The existence of dioxin/furans emissions provides valid estimates in which to base the social impacts that need to be considered, especially in factors such as cancer and mortality. Even though it takes a long time for the effects of this substance to materialize in society, the emissions of dioxins/furans must not be ignored. This toxin may be accumulative, and as such, it could have a significant negative impact on future generations.

3.3.3 Estimation of economic impact

Assumption emission reductions and increased production will have implications on economic factors, which examined the total variable abatement cost, production profits, and net benefits. Reduction of industrial emissions can be done partly by technological development, which affects the cost. Emission reductions will also be followed by the abatement cost to be incurred by the industry to improve the environment. The abatement cost per gTEQ depends on the technology used.

The total abatement cost would be increased from 1995–2025, the greater emission reductions, the total abatement costs have also increased (Figure 6). The more emission that are reduced, the higher the abatement cost which caused by technology used. The level of emission that can be reduced is associated with the technology used, which would require higher cost.

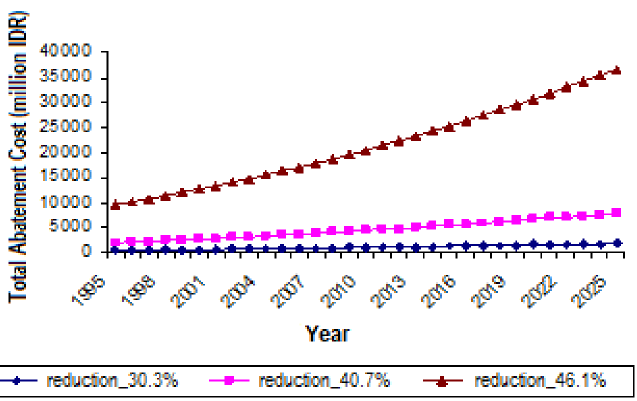


Figure 6: The results of the simulation the total abatement cost with the assumption of emission reductions.

Similarly, an increase in production will also increase the total abatement cost. Increased production led to increased emissions, which should be reduced, therefore increase total abatement cost.

The budget for the total abatement cost will reduce the industry net profit, due to the additional cost industry to reduce emissions of dioxins/furans. Abatement cost based on the simulation has little value when compared with a net profit of the industry. Net profit before industrial emissions reductions in 1995–2025 ranged from IDR 178.06–422.36 billion and if there was 46.1% reduction in emissions, the net profit to be IDR 170.49–393.69 billion or less 4.25–6.79%. Abatement cost at 46.1% reduction is IDR 7.57 to 28.68 billion (Figure 6). As a comparison, in the UK abatement cost to reduce emissions of dioxins from 276 to 225 gTEQ/year in 2000 was £0.146 million/year, equivalent to IDR 20.8877 billion [19]. Abatement costs resulting from this research is still smaller than in UK. This is because in the UK, emissions reduction happens quite big that is 51 gTEQ, whereas this research to reduce emissions in 1995 just for 4.48 gTEQ.

Based on abatement cost estimation, the industry is expected to reduce emissions and pay the abatement cost because it would not significantly decreased industry profits. Estimation of the potential cancer cases and deaths from the emission of dioxins/furans may also be reduced by reductions in emissions. By doing the emission reduction, the industry takes care about the environment.

Net benefit is the difference between net profit industries with social cost, increasing the social cost generated net benefits diminish. Social cost ranges only 7.69–16.27% of net profit in 46.1% emission reduction. This can be compared with the environmental costs incurred pulp and paper industry which is around 5–10% of the cost of establishing a new factory, these costs are substantial costs. Actually, the industry will not have much reduced benefits if the social cost is paid. Problems arose when the industry was not willing to pay abatement costs and the social cost. In this case, the role of government is to monitor and control the industry in order to release funds for the social cost or cost abatement.

Based on the simulation without any emissions reduction, for the variable net benefit, from 1995 continued to increase net benefits, from IDR 172.19–298.61 billion. But since 2019 there was a decrease of net benefit (Figure 7). This happens because social cost from then was very high, so the difference in net profit and social cost is less. Emissions reductions will increase the net benefits.

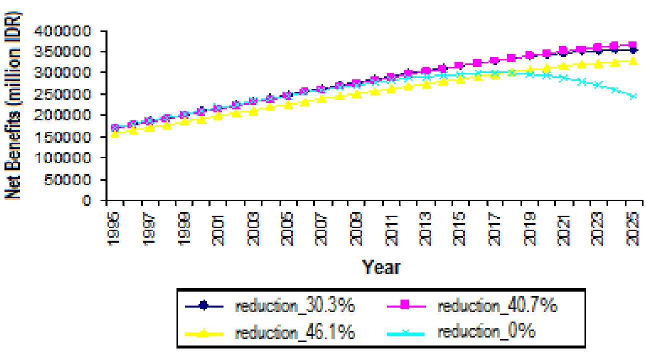


Figure 7: The results of the simulation net benefits with a variety of assumptions reduction.

4 Conclusion

Based on the analysis that has been done in this research, several conclusions can be summarized as follows:

1. Factors that influence the amount of emissions dioxins/furans into the air is the amount of production and emission factors that are dependent on the technology used.
2. Impact of dioxin/furans emissions in the environment, social and economic can be estimated by the models that have been built.
3. Based on the dynamic model, until 2025, emissions of dioxins/furans have passed the threshold so that the air quality has declined, which result in increasing potential cancer potential cancer cases and social cost.
4. The existence of emission reduction policies which will be able to reduce the negative impact is significant.

Suggestions for consideration by policy makers, based on research results, include: 1) develop a program to raise the awareness of dioxin/furans emissions in the community, so that the community cares about this pollution; and 2) development of policy relating to the of dioxins/furans emission in order to reduce emissions of dioxins/furans.

References

[1] US Environmental Protection Agency, *EPA's reanalysis of key issues related to dioxin toxicity and response to NAS comments*, Volume 1, February 2012, pp. I–1, http://www.epa.gov/iris/supdocs/dioxinv1sup.pdf.

[2] Akhmadi, S.S., *Estimasi emisi dioksin dan furan*. In Enabling Activities to Facilitate Early Action on the Implementation of the Stockholm Convention on Persistent Organic Pollutants (POPs) in Indonesia. Workshop Hasil Inventarisasi POPs. UNIDO. KLH. Jakarta, pp. 6.1–6.48, 2003.

[3] Ackerman, F., The outer bounds of the possible: economic theory, precaution, and dioxin. *Organohalogen Comp* 65: pp. 378–381, 2003.

[4] European Commission, Community strategy for dioxin, furan and polychlorinated biphenyls, COM (2001) 593 final, 2001. http://europa.eu.int/eur.lex/en/com/pdf/2001/com2001_0593en01.pdf.

[5] Rao, H.V. & Brown, D.R., Connecticut's dioxin ambient air quality standard. *Risk Analysis* Vol. 10(4): pp. 597–606, 1990. http://tobaccodocuments.org/pm/2025546090-6099.html.

[6] Environment Agency of Japan, *Law concerning special measures against dioxins*, (Law No. 105 of 1955. Promulgated on July 16, 1999). Office of Environmental Risk Assessment, Environmental Health and Safety Division, Environmental Health Department. Japan.

[7] Hung, M.F. & Shaw, D., *Economic growth and environmental Kuznet curve in Taiwan: a simultaneity model analysis*. http://www.sinica.edu.tw/econ/dshaw/download/ekc.pdf.

[8] Fauzi, A., *Ekonomi sumber daya alam dan lingkungan teori dan aplikasi*. Jakarta: PT Gramedia Pustaka Utama, pp. 199–205, 2004.

[9] Kobayashi, N., Nakata, K., Eriguchi, T., Horiguchi, F., Nakanishi, J., Masunaga, S., Application of a mathematical model to predict dioxin concentration in the Tokyo Bay Estuary. *Organohalogen Comp* (66): pp. 2366–2372, 2004.
[10] Soesilo, T.E.B., *Pengendalian limbah dioksin dengan pemanfaatan bahan pemutih ramah lingkungan*. Desertasi Program Doktor dalam Ilmu Lingkungan. PS Kajian Ilmu Lingkungan Pasca Sarjana Universitas Indonesia. Jakarta, 2005.
[11] Rabl, A. & Spadaro, J.V., Health risk of air pollution from incinerators: a perspective. *Waste Man Res* (16): pp. 365–388, 1998.
[12] Rufo & Rufo Jr. *Clean incinerator of solid waste: a cost-benefit analysis for Manila*, Economy and Environment Program of Southeast Asia. Singapore, 2004.
[13] Smit R., *Dioxin emission from motor vehicles in Australia – Technical Report No. 2,* Australian Government Department of the Environment and Heritage, http://www.deh.gov.au/industry/chemicals/dioxins/report-2/dioxinemissionfromroadtraffic.html.
[14] Pulles, T. and Kok, H., *Dioxin Emission in Central Europe: Uncertainties and Projections*, TNO Built Environment and Geosciences, TNO Report R&I-A R. The Netherlands. http://www.espreme.ier.uni-stuttgart.de/workshop/papers/Pulles_et_al_Uncertainties%20in%20Dioxine%20Emission%20Inventories.pdf.
[15] Hart, A., Holmes, M., Smith, G., Rose, M., Macarthur, R., White, S., *Accounting for uncertainty in risk analysis of dioxins in seafood,* Central Science Laboratory. UK. http://www.jifsan.umd.edu/presentations/csljifsan2003/andy_hart_2003.pdf.
[16] UNEP Chemical, *Formation of PCDD and PCDF – an overview*, Geneva, Switzerland. http://www.pops.int/documents/meetings/bat_bep/1st_session/EGB1_INF12doclist.pdf.
[17] Environment Protection Agency, *Evaluating Atmospheric Releases Dioxin-Like Compounds from Combustion Sources,* http://www.epa.gov/ncea/pdfs/dioxin/nas-review/pdfs/part1_vol3/dioxin_pt1_vol3_ch03_dec2003.pdf.
[18] Kishimoto, A., Oka, T., Yoshida, K., Nakanishi, J., *Socio economic analysis of dioxin reduction measures in Japan,* http://risk.kan.ynu.ac.jp/rmg/ws2001/Kishimoto_slide.pdfabst(E).pdf.
[19] Entex, Department for environment, food, and rural affairs, Development of UK cost curves for abatement of dioxin emission to air, http://www.defra.gov.uk/corporate/consult/dioxin-two/report2.pdf.