Simulation of Green Operations Supply Chain in Waste of Plastic

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Abstract. Plastic use is a threat to environment due to the high amount of chemical material required in production process, as well as incorrect usage and disposal product. Most of this waste is disposed in landfill. Waste incineration is one of waste management widely used in many sector. Incineration of plastic waste is energy efficient and may be considered as recovery operation. This study proposed to analyze the result of waste incineration process of plastic waste, then it compare with the landfill of plastic waste. The result of the simulation indicates that waste incineration process generate the dangerous environmental impact, these are marine aquatic ecotoxicity, marine sediment ecotoxicity, acidification, ionizing radiation. This study found that waste incineration is suitable if the purpose are reducing the amount of waste and recovery energy or heat, however, the environmental impact produced by waste incineration process need to be considered in process selection.

Keywords-component; waste incineration; green operation supply chain; plastic; waste

1. Introduction

The companies should be considered the most important link in the process of implementing green supply chain on the product because the public becomes more aware of environmental issues and global warming. Companies has to focus about how green their manufacturing processes and supply chain are, their carbon footprint and how they recycle [1]. Reference [2] defined green supply chain management as integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life. This study focus on a part of green supply chain management, it is green operations. Green management related to all aspect related with manufacturing, usage, handling, logistic, and waste management once the design has been finalized [2,3] as shown in Fig. 1.
In terms of green operation supply chain, on environmental sustainability ground, plastic production process requires less manufacturing energy than other packaging material [4][5] but, plastic use is a threat to environment due to the high amount of chemical material required in production process, as well as incorrect usage and disposal product [6]. The use of plastic is increasing in modern society. Plastic makeup an estimated 10% of household waste, most of which is disposed in landfill [7,8]. Indonesia, as the 4th most populous country globally, has the high demand of plastic. Reference [9] said that the plastics demand in Indonesia is dominated by packaging sector (55%) followed by other sector as shown in Fig. 2. Polyethylene terephthalate (PET) is a plastic material widely used as plastic material in packaging [10]. The problem of PET waste is not biodegradable which the bulk of this will persist for decade or centuries in the earth [11].

Waste incineration is one of waste management widely used in many sector. Incineration of municipal solid waste is energy efficient and may be considered as recovery operation [12]. However, besides the production of electricity and heat, waste incineration is also generate the negative impact to environment and human, such as the bottom ash and air pollution [13][14]. But, the objective of waste management is to deal with society’s waste in economically and environmentally sustainable way. Then, thermal treatment and disposal can be a valid option for reducing the volume of waste in landfill, as well as allowing for waste hygienization [15]. Based on the problem of municipal solid waste, especially on PET plastic waste, this study proposed to simulate the environmental impact of waste incineration to find out and analyze the impact resulted by this process by using life cycle assessment. Life cycle assessment is a technique for assessing the environmental aspects associated with a product over its life cycle[16].
2. Methodology

2.1. Goal and System Boundary
This study is conducted by following the framework of LCA which has been standardized by ISO 14040. The goal of this study is to obtain the waste incineration of PET impacts to ecological systems. The boundary of the simulation is only focused on waste incineration process without consider the collection and transportation process. The simulation is conducted by using openLCA software.

2.2. Life Cycle Assessment
Life cycle inventory is established from the input of the waste incineration process. Model graph of material input shown in Fig. 3. The reference used of this process is mass of PET waste. The database of material used based on European Commission (ELCD 3.2 Green Delta V.2.17). LCIA Method 2.0.2 database is used to evaluate and analyze the impact assessment of waste incineration. Life cycle impact assessment (LCIA) is one of basic steps in life cycle assessment (LCA) methodology.

![Fig. 3. Model Graph of Material Input on Waste Incineration Process](image)

3. Result and Discussion

3.1. Input and Output of Material
Input of the material is the number of origin material used in waste incineration process. The input scenario of this research is 100 kg of PET. Summary Input of material is available in Table 1. Total material input in waste incineration process is about 63 materials, where natural gas is the highest input contributor with quantity 638.6064948 MJ and followed by other material. The output of this process is calculated after the simulation conducted. The summary result of output waste incineration process is shown in Table 2. Total material output of waste incineration process about 333 materials which is overburden (deposited) as the highest output of this process with quantity of 313.2084598 kg
### Table 1. Material Input PET Waste Incineration

| Material       | Category      | Sub-Category | Ref. Unit | Amount     |
|----------------|---------------|--------------|-----------|------------|
| Energy         | Resource      | in air       | MJ        | 111.7867945 |
| Brown coal     | Resource      | in ground    | MJ        | 178.779205  |
| Hard coal      | Resource      | in ground    | MJ        | 558.8886947 |
| Natural gas    | Resource      | in ground    | MJ        | 638.6664948 |
| Peat           | Resource      | in ground    | MJ        | 24.02156087 |
| Uranium        | Resource      | in ground    | MJ        | 427.4419891 |
| Water          | Resource      | in water     | kg        | 473.5521624 |

### Table 2. Material Output PET Waste Incineration

| Material                  | Category      | Sub-Category | Ref. Unit | Amount     |
|---------------------------|---------------|--------------|-----------|------------|
| Overburden (deposited)    | Deposited goods | Stockpile goods | kg       | 313.2084598 |
| Argon-81                  | Emission to air | unspecified | kBq      | 1.992194525 |
| Carbon-14                 | Emission to air | unspecified | kBq      | 0.913990829 |
| Hydrogen-3, Tritium       | Emission to air | unspecified | kBq      | 3.881848954 |
| Krypton-85                | Emission to air | unspecified | kBq      | 33645.5518  |
| Radon-222                 | Emission to air | unspecified | kBq      | 490.5037462 |
| Water vapour              | Emission to air | unspecified | kg       | 212.3852623 |

### 3.2. Environmental Impact

Environmental impact of PET waste incineration was assessed by using LCIA method 2.0.2 where CML 2001 (all impact categories) was used as impact method assessment and World, 1995-CML 2001 as normalization and weighting set. Based on the calculation process, found that there are four highest impact produced by waste incineration process, these are marine aquatic ecotoxicity, marine sediment ecotoxicity, acidification, and ionizing radiation as shown in Fig. 4.

![Result of Simulation](image1.png)

**Fig. 4.** Environmental Impact of Waste Incineration Process

![Sankey Diagram](image2.png)

**Fig. 5.** Sankey Diagram

Based on the simulation result, waste incineration contribute about 50 impact category where the four highest is shown in Fig. 4. Sankey Diagram, Fig. 5, is an approach to read the result of
simulation process. The highest indication is indicated by the red color with the contribution more than 80%, and it is followed by the blue color and green color.

Refer to Sankey diagram, marine aquatic ecotoxicity is the highest contributor to the environment with quantity of 2887.196 kg 1,4-DB eq before normalization and 5.63003E-12 after normalization process. Marine aquatic ecotoxicity are poisonous substances released into the environment, especially to the water, that are toxic organisms [17]. Acidification on this result can refer to acidification of soil and surface waters as result of elevated sulphur and nitrogen [18]. Acidification is usually caused by the high atmospheric pollution. It is means that the waste incineration process has the high pollution on atmospheric. On this simulation, the amount of acidification resulted by the process is 0.805442 kgSO2 eq before normalization and 2.50492E-12 kgSO2 after normalization.

Ionizing radiation define as high energy particles that resulted by freeing electrons from molecules as they pass through the molecule, this cause ionization [19]. Ionizing acidification is very dangerous for human being because of its effect. It can cause diminished spermatogenesis and testosterone, pubertal failure, ovarian failure, or premature menopause for women [21]. Number ionizing radiation produced by waste incineration process before normalizing is 3.14E-7 DALYs (Disability Adjusted Life Years) and 2.35E-12 DALYs (Disability Adjusted Life Years) after normalizing.

3.3. Landfill PET Waste

By using the same procedure and criteria on simulation, the result of landfill PET waste is shown in Table 3.

| Impact category                          | Reference unit       | Result        |
|-----------------------------------------|----------------------|---------------|
| Marine aquatic ecotoxicity infinite - CML 2001 (all impact categories) | kg 1,4-DB eq        | -79.31753927  |
| Marine sediment ecotoxic. infinite - CML 2001 (all impact categories) | kg 1,4-DB eq        | -57.59386939  |
| Acidification - CML 2001 (all impact categories) | kg SO2 eq           | -0.023898637  |
| Ionising radiation - CML 2001 (all impact categories) | DALYs                | -7.58514E-09  |

The result of table 3 show that the environmental impact of landfill PET waste is lower than the waste incineration. The amount of each impact category is very low and it did not damage the environmental ecology. On landfill scenario, marine aquatic ecotoxicity’ quantity is -79.31753927 and its very safe for the environmental than the impact to marine aquatic ecotoxicity resulted by waste incineration scenario. But, the problem of landfill is the volume of waste in land and there is no treatment to solve the kind of problem.

4. Conclusion

After the simulation process, this study found that, even the waste incineration is one of waste management option to reduce the volume of municipal solid waste, especially PET, and other contribution of waste incineration, such as energy recycling and heat, in other side, waste incineration is very harmful to the environment due to its impact. The waste incineration has about 50 impact to the environment and there were four highest impact, these are marine aquatic ecotoxicity, marine sediment ecotoxicity, acidification, and ionizing radiation. The four impact of waste incineration have serious impact not only on environment, but also on human being. By comparing the landfill PET waste and waste incineration, landfill option has lower impact for the environment.
Then, if the purpose is the recycle of energy of heating, waste incineration is better than landfill, however, the waste incineration generate high environmental impact. Based on this study, the waste incineration can not be included as a part of sustainable solution because it has a trade off between the advantages and the serious disadvantages.

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