LCA Analysis on Improving Scenario of Domestic Solid Waste Management in Padang City based on the case in Kitakyushu City

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Abstract. The implementation of domestic solid waste management in Padang City conducted by the government still uses a conventional method, including collection-transportation-disposal system with only about 5% of solid waste recycling rate. In Japan, Kitakyushu City manages its domestic solid waste appropriately by recycling the solid waste into beneficial products and applying sea reclamation landfill for solid waste residues from the final treatment process. By conducting Life Cycle Assessment (LCA) analysis, this study examines the appropriate improved scenario of domestic solid waste management in Padang City through evaluation and improvement of the existing implementation and the shortcomings of Padang City based on the case study in Kitakyushu City, comprising four scenarios. Scenario 0 presents the existing condition; scenarios 1, 2, and 3 present the improvement of Scenario 0 in recycling percentage rates and technology implementation in a row by composting, incineration, and anaerobic digestion. CML 2001 is used to assess the environmental impact of Global Warming Potential, Acidification Potential, and Eutrophication Potential. This study implies that Scenario 1 is the most suitable scenario for improving domestic solid waste disposal in Padang City because of the low environmental impact as the smallest normalization score of 5.81x10^-10.

1. Introduction
Solid waste is an issue for many cities in Indonesia because of the increase in solid waste generation and improper management. The increase in solid waste every year is related to the increasing number of people and their consumptive habits [1]. The average solid waste production in Indonesia reaches the number of 64 million tons per year. 69% of the solid waste was transported to a landfill. Furthermore, the other 35% was open burned and thrown away by the community into the river [2]. Most domestic and non-domestic solid waste is not in sorting from source [3]. The big rivers in Padang City were polluted by the solid waste generation thrown away by the community. It shows the lack of community awareness to properly manage domestic solid waste properly from source [4].

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Kitakyushu City in Japan is one of the best practices of domestic solid waste management. It has the Eco-Town Project as its transition catalyst from an industrial city to a green city[6]. The Kitakyushu Eco-Town Project is a comprehensive solid waste management technology, education, and research facility that points out sustainability concepts through environmental conservation to construct a resource-recycling-based society[7]. This comprehensive system is completed with the appropriate technology, tight regulation, and involvement of multisector, including private, government, academics, NGO's, and community. In contrary to Padang City, Kitakyushu City manages their domestic solid waste appropriately, recycles into beneficial products, and uses sea reclamation landfill to dispose the final residue of solid waste processing.

This study examines the appropriate improving domestic solid waste management scenario in Padang City by Life Cycle Assessment (LCA) analysis. Improving scenario as technical strategies are obtained through developing the existing implementation and the shortcomings of Padang City based on the case in Kitakyushu City. This study could also recommend the City of Padang related to a domestic solid waste management issue.

2. Materials and methods

2.1. LCAMethodology

LCA is a technique for assessing environmental aspects and potential impacts of a product from the raw material of production, use, and disposal. Some categories being considered in LCA are resource use, human health, and ecological consequences. LCA is used for identifying opportunities to improve their life cycle of environmental aspects, decision-making in governmental, industry, and NGO organizations, selecting the relevant indicators of environmental performance and marketing [8].

The researcher has used LCA for many studies related to municipal solid waste management that eventually assess two or more processing or system [9][10][11][12][13][14]. Specifically, LCA is used to assess the input and output flows of environmental impact and release some suggestions for improving the process [15]. LCA software as Gabi 5 Education was used in this study. Gabi 5 Education is developed by ThinkStep Company, located in Boston, Germany. LCA methodology comprises four stages, as follows:

1. Goal and Scope Definition

This stage clearly describes the goal and scope of the study. The goals should determine why the study was conducted, who the target of this study. The functional unit is needed to be decided because it is used to assess all LCA Analysis processes. The scope defines the limitation that shows how deep the analysis is conducted [16].

This analysis aims to assess and determine the best scenario applied in Padang city using the LCA method. The input of each process and flow that happened to the system was based on solid waste flow from source to landfill and whether the best scenario for Padang City is. The assessment was performed for Scenarios conducted by the government involving the community and scavengers in 2023, although the industry involvement was not be assessed. This study limited the analysis to discuss only the flow and transformation of solid waste. However, the raw material for the facilities and infrastructures would not be discussed. The functional unit used in this study is the 1-ton solid waste generation. The assessment was conducted by comparing emission released for each scenario and the solid waste reduction process by applying processing technology. The smallest solid waste to landfill and the lowest environmental risk would be the best scenario.

2. Inventory Analysis

Inventory analysis is conducted by collecting supporting data for LCA analysis, called inventory data. The inventory data may include input and output flow, such as material needed and released, emission, and energy consumed and produced [16]. The data are collected from several references related to this study, such as existing conditions, journals, manual books, also articles. Scenario schemas are also being considered to collect inventory data. In this stage, the impact assessment method is
determined. This study uses CML 2001 as the method, developed by the Institute Environmental Science of Leiden University.

Domestic solid waste in Padang City classifies into organic and inorganic waste, also into wet waste and dry waste [17]. Wet waste, known as solid waste for composting in this paper, comprises food waste, wood, and yard waste. However, dry waste, known as solid waste for recycling, includes all solid waste types except wet waste and other solid waste. Both wet waste and dry waste have a recycling potency of 65.16%. Wet waste has a significant recycling potency of 59.86%, while dry waste has a relatively small 5.3% recycling potency [17].

The mileagé of collection and transport was assumed similar for all scenarios. This study adopted mileage from Komala, Aziz, & Ramadhani [18] using the farthest distance of 54 km. This mileage assumed 27 km for collection and 27 km for transport. The solid waste collection used gasoline-fueled vehicles with an energy consumption of 433.33 kWh, and solid waste transport used diesel-fueled trucks with an energy consumption of 171.43 kWh. The other inventory data used is adopted from Gabi 5 Education Software, some researches, and manual books [19][20][21][22][23][24].

3. Impact assessment
Impact assessment is modeled in Gabi 5 Education through the input of the inventory data. The impact category for this study selecting from CML 2001 comprised Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP). The three categories were chosen because many related studies discussed these impacts, and they had significant effects on the environment and humans. Global warming potential analyzes contribution compounds to global warming, including CO₂ (Carbon dioxide) and CH₄ (Methane). Global warming potential is defined as kg CO₂ unit. Therefore, other compounds would be converted to a kg CO₂ equivalent. However, acidification potential analyzes contribution compounds for acidification, including SOₓ, NOₓ, HF, and HCl. Acidification potential is defined as kg SO₂ unit so that other potential compounds would be converted to kg SO₂ equivalent. Besides, Eutrophication potential analyzes contribution compounds for eutrophication, including nitrogen and phosphor. Eutrophication potential is defined as kg PO₄³⁻ unit, and other potential compounds would be converted to kg PO₄³⁻ equivalent.

| Impact Categories | Factor       |
|-------------------|--------------|
| CML2001 - Apr. 2015, Acidification Potential (AP) | 4.18E-12   |
| CML2001 - Apr. 2015, Eutrophication Potential (EP) | 6.32E-12   |
| CML2001 - Apr. 2015, Global Warming Potential (GWP 100 years) | 2.39E-14   |

Source: Gabi Education Database, 2018

| Impact Categories | Factor |
|-------------------|--------|
| CML2001 - Apr. 2015, Acidification Potential (AP) | 6.1    |
| CML2001 - Apr. 2015, Eutrophication Potential (EP) | 6.6    |
| CML2001 - Apr. 2015, Global Warming Potential (GWP 100 years) | 9.3    |

Source: Gabi Education Database, 2018

These three impacts were normalized and scored to determine whether the best scenario would be offered. Normalization is a tool to manage the inconsistency of inventory data available. It is used by multiplying the result of impact assessment to the normalization factor in table 1. However, scoring is used to assess affection for each impact on affection for all impacts by multiplying the result of normalization to scoring factors in table 2.
4. Interpretation
Interpretation is used to analyze and recommend improving the selected scenario to minimize the environmental impact[16].

3. Results and discussion

3.1. Case Study
Kitakyushu City conducts comprehensive solid waste management, beginning with solid waste sorting based on its treatment. Type of solid waste includes kitchen waste, can and glass bottle, PET plastic bottle, package and plastic, lamp, used vegetable oil, home appliance, and paper.

Kitchen waste would be treated in Kitchen Waste Building by using incineration technology that releases ashes as its residue. Can and glass bottles would be processed in the Can and Glass Bottle Building through compacting (for the can) and crushing (for glass bottle). The product of this process would be processed in another Recycling Building to release beneficial products. PET Plastic bottle would be processed in PET Plastic Bottle Recycling Building into pellets and flakes transferred to another recycling building to produce the new PET Plastic Bottle and another beneficial product (coat, ball, sneaker). Package and plastic would also be treated in its recycling building to compact the waste and be transferred to another recycling building. Others would be treated in their recycling building.

Figure 1. Schema of Technical Aspect of Domestic Solid Waste Management in Kitakyushu City

The residue of all treatment (ashes) would be transported to a landfill. Kitakyushu City has a Sanitary Landfill System in Hibikinada Landfill by adopting the sea reclamation method. However, it does not need more area to dispose of the residue, yet it creates new land. This landfill has seawater treatment for considering the probability of solid waste residue contamination to seawater. Schema of Technical Aspect of Domestic Solid Waste Management that Kitakyushu City used generally can be seen in figure 1.

On the other hand, Padang city made an effort to group the solid waste into organic and inorganic waste, but domestic solid waste is not sorted in practice. Solid waste is transferred to a temporary container (TPS) and treated (for small percentages) by composting in Solid Waste Processing Station based on Reduce Reuse Recycle (TPS3R) and recycling in the solid waste bank and by scavengers. Untreated solid waste and treatment residue would be transported to a landfill. Padang City has a
Controlled Landfill System that uses a large area. Schema of Technical Aspect of Domestic Solid Waste Management that Padang City used generally can be seen in figure 2.

Figure 2. Schema of Technical Aspect of Domestic Solid Waste Management in Padang City

According to appropriate conditions in Kitakyushu City, we adopted some technical strategies to improve the quality of domestic solid waste management in Padang City by arranging four scenarios adjusted to the City of Padang capability. The scenarios would be described for the next five years of projections. The details can be found in the next section.

3.2. Scenarios
There are four different scenarios, including the existing domestic solid waste management practices in Padang City.

Scenario 0 (Existing Scenario): Solid waste was being collected in mixed conditions. It caused inconvenience for management and processing that carried out. However, the unmanaged solid waste percentage was still relatively high, namely 35% of the total domestic solid waste generation. The community treated it through burning or throwing away into the river. Besides, the remaining 65% of solid waste was handled by the government. The diagram of Scenario 0 is illustrated in Figure 3.

The existing condition adopted the collection-transport-disposal system, which means that solid waste generation from the source would be directly collected and transported to the landfill. Solid waste processing was conducted through a small percentage. Composting was carried out at 2% while recycling by the informal sector (scavengers) was 3%. Meanwhile, the other 60% and the residue from the composting were transported to the landfill.

Scenario 1: The solid waste collection was divided into three types: waste for composting (compostable waste), waste for recycling (recycled waste), and other waste. This condition was structured to facilitate the management and processing carried out. The percentage of unmanaged solid waste was reduced by 2% per year [26]. Because the scenario calculation assumption is in the next five years (2023), the total solid waste reduction is 10% of the existing condition. Unmanaged solid waste decreases to 25% of the total domestic solid waste generation. The government handles the remaining 75% by involving the informal sector (scavengers) and the community. The diagram of Scenario 1 is illustrated in Figure 4.

Scenario 1 performs solid waste processing by composting and recycling. Solid waste processing is carried out in two sites, composting at TPS3R and recycling at TPS and Solid Waste Bank. Composting and recycling are assumed to increase by 0.14% per year [26]. Therefore in 2023, the processing percentage will increase to 1.4% at each solid waste processing site. Composting at TPS3R is 3.4%, while recycling is 4.4%, at the Solid Waste Bank by 1.4% and in the informal sector 3%. However, the untreated solid waste (67.2%) and solid waste processing residue are transported to the landfill equipped with landfill gas recovery facilities.

Scenario 2: The solid waste management assumption applied is similar to Scenario 1 except the increase in composting percentage. This scenario uses incineration to process solid waste by a higher
percentage without involvement from the community. The diagram of Scenario 2 is illustrated in Figure 5.

Scenario 2 performs solid waste processing by incineration, composting, and recycling. Incineration and composting are carried out at TPS3R and recycling at TPS and Solid Waste Bank. Incineration is assumed to accommodate 50% of the total managed compostable solid waste, about 25.8%. This assumption is selected through the consideration for applying new technology in a short period (5 years) has not been able to perform in a high percentage directly.

Composting at TPS3R is 2%, while recycling is 4.4%, at the Solid Waste Bank (1.4%) and in the informal sector (3%). However, the untreated solid waste (42.8%) and solid waste processing residue are transported to the landfill without landfill gas recovery facilities. The landfill gas facility is not implemented due to the considerable investment of incineration being used.

Scenario 3: The solid waste management assumption applied is similar to Scenario 1. However, Scenario 3 uses anaerobic digestion to process some compostable solid waste. Scenario 3 diagram is illustrated in Figure 6.

Scenario 3 performs solid waste processing by anaerobic digestion, composting, and recycling. Anaerobic digestion and composting are carried out at TPS3R with the percentage in a row by 1.4% and 2%. While recycling (4.4%) is carried out at TPS (by informal sectors 3%) and Solid Waste Bank (1.4%). However, the untreated solid waste (67.2%) and solid waste processing residue are transported to the landfill equipped with landfill gas recovery facilities.

**Figure 3. The Diagram of Scenario 0**

**Annotation:**

- __________ Mixed Solid Waste
- __________ Compostable Solid Waste
- __________ Recyclable Solid Waste
- __________ Residue
Figure 4. The Diagram of Scenario 1

Figure 5. The Diagram of Scenario 2
3.3. Impact Assessment

Environmental impact assessment for each scenario used the CML 2001 method by the Institute Environmental Science of Leiden University. CML 2001 was chosen because it could adequately assess the impact of midpoint indicators by applying ISO 14040. Impact categories assessed were global warming potential (GWP), acidification potential (AP), and eutrophication potential (EP). The results of the impact assessment are described as follows:

As described in Figure 7, Scenario 0 has the highest GWP of 6,970 kg CO₂-eq. It is caused by Scenario 0 having no proper solid waste management system with un-handling solid waste 35%, processing solid waste 35%, and 60% dispose of in a landfill without gas recovery facility.
Unavailability of gas recovery facility directly indicate all the pollutant of the landfill (CO₂ and CH₄) contribute to GWP affects the atmosphere. It is getting deplorable because CH₄ has impact twenty-eight times bigger than CO₂. This condition also happens in Scenario 2, and it becomes the second-highest GWP 5,300 kg CO₂-eq. The incineration process also releases CO₂ gases. However, this CO₂ does not affect global warming because CO₂ tends to be biogenic carbon and recycled in the environment. Different from CO₂ released from burning fossil fuel (gasoline and diesel fuel) that tend to non-biogenic carbon. Non-biogenic carbon potentially affects global warming [26]. Scenario 1 has the lowest GWP 2,430 kg CO₂-eq and Scenario 3 has GWP 2,490 kg CO₂-eq. Both scenarios can minimize the GWP rate using solid waste handling technology, including anaerobic digestion, composting, and gas recovery facility in the landfill. The gas recovery facility significantly helps the GWP because air pollutants would be converted to electricity.

![Figure 8. Acidification Potential for all scenarios](image)

Figure 8 shows the Scenario 0 has the lowest AP rate of 0.170 kg SO₂-eq. It is caused by minimalization using fueled facilities that released emissions. Scenario 3 has the highest AP rate of 0.280 kg SO₂-eq. This AP rate is dominated by emission released from using fueled facilities. Acidification can impact the environment because of the acid characteristic. Acidify the environment cannot support much life of nature. For instance, acid rain is caused by air acidifying, and it is potentially dangerous to the biotic and the abiotic environment. The leading cause of acidification is SOₓ, NOₓ, HF, and HCl contained in solid waste. The sources are also from the collection and transport process.
As described in Figure 9, Scenario 3 has the highest EP rate of 0.872 kg PO$_4$$_3^-$ eq. Many water emissions are released from un-handling solid waste, anaerobic digestion wastewater, and most solid waste untreated properly. Scenario 2 has the lowest EP rate of 0.553 kg PO$_4$$_3^-$ eq caused by an incineration process with low wastewater and minimal solid waste disposal to landfill. The high EP rate can affect the unbalance of the ecosystem. As the high of nutrients in the water can trigger the increase of poisoned phytoplankton, it can decrease the water's oxygen rate and kill aquatic. It is called alga blooming that colors the water green.

**Figure 9.** Eutrophication Potential for all scenarios

**Figure 10.** The Result of the Normalization of the four scenarios based on GWP, AP, and EP
After gaining the result of the assessment for each scenario, then normalization is conducted. The result of normalization is in Figure 10. Determination for the best scenario is performed by using the scoring method. The smallest score is the best scenario instead. The result of scoring is in Figure 11. According to this graphic, scenario 0 has an excellent score of $1.58 \times 10^{-9}$, scenario 1 has the smallest score $5.81 \times 10^{-10}$, while scenario 2 and 3 have each score of $1.21 \times 10^{-9}$ and $5.97 \times 10^{-9}$. Therefore, scenario 0 becomes an imperfect scenario. As an impact assessment result, it is not recommended because of its high environmental impact. However, scenario 1 becomes the appropriate scenario as its small environmental impact and recommend to be applied in Padang City.

3.4. Interpretation

Since scenario 1 is the appropriate one according to Scoring on LCA Analysis, it has an environmental impact on its every single process instead. The recommendations are offered to improve Scenario 1, including Landfilling, Composting, and Collection and Transport. Landfilling can be improved by maximizing wastewater (leachate) treatment so the impact could be adequately managed and improved gas hopping and treatment efficiency in landfill gas recovery facilities. Composting could minimize the emission by improving composting efficiency and using a better bio-activator to cut the composting times. The recommendation for Collection and Transport is to convert high emission fuel to a low emission fuel (high combustion efficiency). Furthermore, applying pollution control for collection and transport facility become one of recommended suggestion to conduct.

Conclusion

We adopt some technical strategies from Kitakyushu City to improve the domestic solid waste management in Padang City by arranging four scenarios adjusted to the City of Padang's capability. LCA analyzes the four scenarios for the next five years of projections (2023). Based on the LCA analysis score, Scenario 0 is the poorest due to inappropriate for the environment as the score of $1.58 \times 10^{-9}$. However, Scenario 1 is an appropriate scenario to be applied in Padang City score of
5.81x10^{10}. The recommendation given for the selected scenario includes landfilling, composting, and collection and transport aspects due to the environmental impact of theirseverysingle process.

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