Life Cycle Assessment of Medical Solid Waste Management

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ABSTRACT

Life Cycle Assessment (LCA) or environmental impact analysis is an instrument or measuring tool for environmental aspects of a product and potential environmental impacts during the product's life cycle. Although some industries have adopted LCA studies, LCA is still used in a limited way in service industries such as hospitals, especially in Indonesia. Common problems in hospitals are where medical waste disposal send to open dumping and limited processing services that can damage the environment. This matter became more complex when it was discovered that 2,900 hospitals in Indonesia have not managed medical waste properly. This research was conducted at the UGM Academic Hospital. This research aims to measure the environmental impact of medical solid waste management at the UGM Academic Hospital from cradle to grave. The results of the impact assessment in this research using the CML-IA Baseline methods with the functional unit of 1 ton of medical solid wasted, Global Warming Potential (GWP) impact was 36,179.9 kg CO2 eq, Human Toxicity impact was 2,715.7 kg 1.4-DB eq, Eutrophication impact was 9.40 kg PO4-3 eq, Acidification impact was 53.9 kg SO2 eq, and the Ozone Layer Depletion impact was 6.14x10-3 kg CFC-11 eq. The incineration process at UGM Academic Hospital is still carried out by partner companies. In this scenario assumed that UGM Academic Hospital has an incinerator. Results of this scenario, the important issue of this research is the impact of global warming potential (GWP) where the impact decrease by 421.5 kg CO2 eq per 1 ton of medical solid waste per year.

ARTICLE INFO

Received June 15, 2023
Accepted July 19, 2023
Available online September 11, 2023

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Keywords:
life cycle assessment; medical solid waste; hospital

1. Introduction

Climate change is a phenomenon of significant changes in climate, rainfall, and air temperature. Climate change has been caused by several impacts on the environment, one of which is an increase in air temperature (Julismin, 2013). Climate change occurs when the concentration of carbon dioxide and other gases in the atmosphere increased. Indonesia has stated its commitment to reducing greenhouse gas emissions. The target for reducing emissions in 2030 based on the Nationally Determined Contribution (NDC) is 834 million tons of CO2 eq on the unconditional target and 1.081 million tons of CO2 eq on the conditional target. According to this target, mitigation must be carried out in all sectors (energy, waste, industry, agriculture, and others) (Nur *et al.*, 2017). Life Cycle Assessment (LCA) or environmental impact analysis is an instrument to measure the environmental aspects of a product and potential environmental impacts during the product's life cycle. LCA can also be used to calculate greenhouse gas (GHG) emissions from the manufacturing industry and for the service industry for example hospitals and other service industries. Although it has been adopted by some industries in Indonesia, LCA is still used in a limited way in service industries such as hospitals. The LCA method is needed to assess the implementation of activities in the service industry including the health service industry or hospitals (Djati et al., 2018). Hospitals are public facilities that operate 24 hours a day. Hospitals consume large amounts of resources such as electricity, water, fuel, and paper, and produce solid waste every day. According to GHG emissions in healthcare from the 43 countries studied, Indonesia contributes 1.9% of emissions and the largest emissions contributor is the United States, which is 7.6% (Karliner et al., 2020). Common problems in hospitals are where the disposal of medical waste sent to open dumping and limited processing services that can damage the environment. This matter became more complex when it was discovered that 2,900 hospitals in Indonesia do not manage medical waste properly (Direktorat Penilaian Kinerja Pengelolaan Limbah B3 dan Limbah Non B3, 2018). Based on the PROPER document in 2022, there are only 2 hospitals in Indonesia that have joined PROPER, namely Sleman Hospital and Sardjito Hospital. PROPER is a company performance rating assessment program initiated by the Indonesian Ministry of Environment and Forestry (KEMENLHK) to see how obedient a company is in carrying out environmental controls. One of the criteria for PROPER assessment is conducting a life cycle assessment. UGM Academic Hospital located in the Special Region of Yogyakarta was chosen as the research location because they have not been able to process their own medical waste. UGM Academic Hospital does not yet have an incinerator so the medical solid waste treatment is carried out by PT. Wastec International is located in Central Java, Semarang. Sending waste to other places can cause gas emissions from transportation and also requires transportation costs (Ali et al., 2016*)*. PT. Wastec International is a hazardous waste management company where the main process is the destruction of waste using an incinerator. PT. Wastec International also collaborates with PT. Prasadha Pamunah Limbah Industri (PT. PPLI) to manage the incinerator waste ash. Several hospitals especially in Yogyakarta already have their own incinerators such as the Sardjito Hospital. So that they can treat medical waste themselves and not send it to other parties. Therefore, this research will measure the environmental impact of solid medical waste management. This research also compared the impact of the base scenario or current condition and the alternative scenario that assumed UGM Academic Hospital has an incinerator. The contribution of this research is to provide an overview of the environmental impacts arising from the management of medical solid waste in hospital, and also it is a contribution from researchers to the Gadjah Mada University for the scientific development. From this research, it is also hoped that every hospital especially in Indonesia is capable of conducting analysis of life cycle assessment so that it can also become part of PROPER.

2. Literature Review

Life Cycle Assessment research continues to grow rapidly to provide recommendations for environmental problems, especially in the service industry or hospitals. Some research about LCA in hospital waste has been published for the development of science in several countries.

According to the World Health Organization (2011), the majority of a hospital's waste, 75-90%, is non-infectious waste, meaning it can be treated as municipal solid waste. The remaining 10-25% is considered hazardous because it is either toxic, infectious, and radioactive (Chartier, 2014*)*. Incineration and autoclave sterilization are the two main ways to manage biohazardous medical waste in the United States. Ideally, recycling and reducing waste would decrease the amount of waste that would go to the landfill. That study shows that fossil fuel depletion and human toxicity potential in end-of-life analysis was the main issue. Some strategies can be used to reduce and recycle waste, such as commingled recycling across the hospital including the operating rooms, reprocessing medical instruments, etc. LCA can be used as a tool to educate and influence the government or policymakers and health care practitioners to decide in environmental development (Inskeep et al., 2014).

Medical waste has exploded since the COVID-19 pandemic and aroused great concern to medical waste disposal. In that study, five scenarios of medical waste disposal technologies in Zhejiang, China, i.e. rotary kiln incineration, pyrolysis incineration, plasma melting, steam sterilization, and microwave sterilization, were evaluated and compared by life cycle assessment methods. LCA results show that microwave sterilization + landfill generate the lowest impact, while the plasma melting was the worst impact. Electricity is the most significant contributor to the environmental impacts of the five technologies. When building a disposal plant, microwave sterilization followed by incineration is currently the best disposal scenario. The extracted steam from incineration plants can be further utilized in steam sterilization for energy cascade utilization (Zhao et al., 2021).

Disposal of medical waste must be considered a vital necessity to prevent the spread of the virus like COVID-19 (COVID-19). Life cycle assessment is a practical approach to measure and examine the environmental impact of each potential process during all stages of a product's life cycle, including materials mining, manufacturing, and shipping. The research conducted in Iran about medical waste management during COVID-19 using the LCA approach shows that LCA is an efficient way to estimate the environmental impacts arising from several scenarios. Unified waste management systems will be better options for many countries to the value-added products in addition to proper waste management. This contains the decrease of waste materials at the root of their production, division at source, efficient collecting and transportation, energy and compost production before their dumping in the landfill, and transforming recyclable waste materials (Nabavi-Pelesaraei et al., 2022).

The research was conducted at a hospital in Swath Pakistan District where the treatment of hospital waste was carried out in several scenarios including incineration, landfilling, and recycling with the functional unit is 1 t/day hospital waste. Results of the analysis from that study, the scenario of incineration and landfilling has a high environmental impact whereas the scenario of the waste recycling process has the lowest environmental impact. The recycling waste was the best alternative scenario to be applied to waste management in hospitals in Swath District, Pakistan. From that study, it can be concluded that the design of this waste treatment scenario is an alternative to mitigate emissions where these emissions have a great impact on the environment (Ahmad et al., 2019). Another case study on Pakistan is landfilling and incineration was the worst final disposal alternatives, whereas composting and material recovery is the good scenario. An integrated system (composting, incineration, and material recycling) was found as the best solution among the evaluated scenarios. That study can be used by the government for the formulation of an integrated hospital waste management plan (Ali et al., 2016).

3. Methodology

A literature study in this research was conducted to obtain information and theories that support this research. A literature study was carried out through several sources including journals, books, and other supporting information about life cycle assessments that had been carried out before, especially in hospitals. Observations were also made by visiting the UGM Hospital directly to make observations and then determine the research background, problem formulation, research objectives, research benefits, and research limitations.

Life cycle assessment is a systematic tool that can analyze the environmental impact of a product in all life cycle activities and the potential impact of the environment. LCA can present information on the environmental impact of a product's life cycle starting from the extraction of raw materials, the production process, the use of products, and waste from products resulting from an industrial activity. In the life cycle assessment, there are four stages, goal and scope definition, inventory analysis, impact assessment, and interpretation (ISO 14040:2006). LCA framework can be seen in Figure 1.

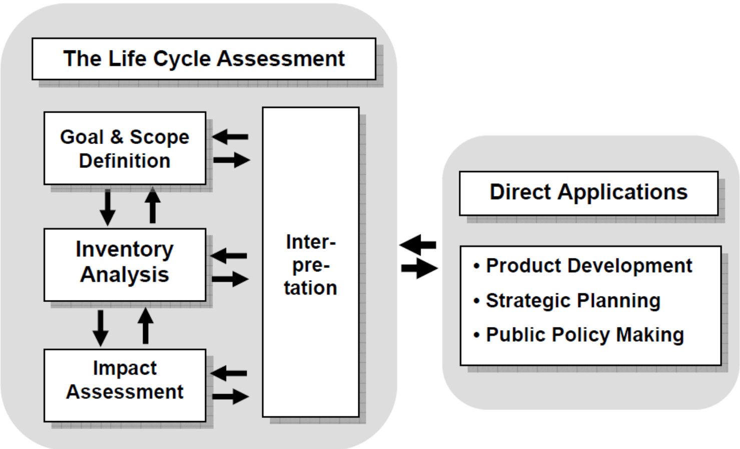

Figure 1. LCA Framework (ISO 14040 2004)

3.1 Goal and Scope

The purpose of this research is to measure the environmental impact of medical solid waste management at the UGM Academic Hospital from cradle to grave. This research also compared the environmental impact of the current condition and alternative scenarios. The scope of this research is illustrated in Figure 2.

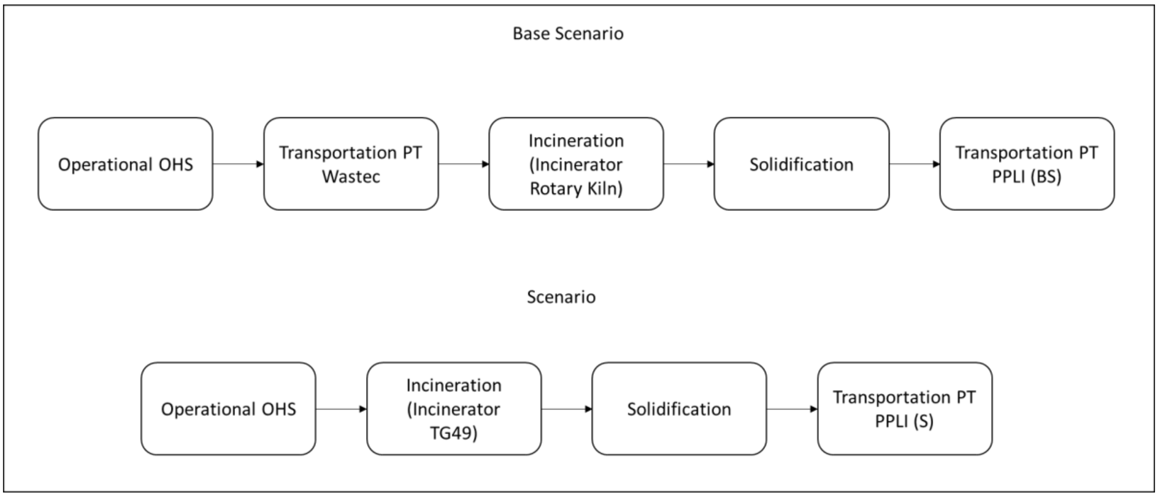

Figure 2. Comparison of The System Boundary of Base Scenario and Scenario

Based on Figure 2, the transportation process unit on base scenario was carried out twice, the first is shipping medical solid waste from UGM Academic Hospital to PT Wastec International and the second is shipping incinerator waste ash from PT Wastec International to PT PPLI. While in the alternative scenario transportation process unit was carried out once, shipping incinerator waste ash from UGM Academic Hospital to PT PPLI.

Table 1. Description of Unit Process

No	Unit Process	Description	Responsible
1	Operational OHS (*Occupational Health and Safety)*	Operational activities and handling of solid medical waste and medical waste segregation by the OHS.	Operational OHS UGM Academic Hospital
2	Transportation PT Wastec	The process of sending solid medical waste to a 3rd party (PT Wastec International) for waste treatment.	PT. Wastec International
3	Incineration (Incinerator Rotary Kiln)	The process of destroying solid medical waste uses a rotary kiln incinerator.	PT. Wastec International
4	Incineration (Incinerator TG 49)	The process of destroying solid medical waste uses a TG-49 incinerator.	Operational OHS UGM Academic Hospital
5	Solidification	The process of compacting the incinerator residue with a composition of 2/3 residue and 1/3 cement which has been mixed with water is then put in the drum.	PT. Wastec International (BS) Or Operational OHS UGM Academic Hospital (S)
6	Transportation PT PPLI (BS)	The process of sending incinerator residue from PT Wastec to a 3rd party (PT PPLI)	PT. PPLI
7	Transportation PT PPLI (S)	The process of sending incinerator residue from UGM Academic Hospital to a 3rd party (PT PPLI)	PT. PPLI

Table 1 describes the description of each process unit. The scenario of this LCA study is that UGM Academic Hospital has its own incinerator because the distance for delivering medical waste to PT Wastec is too far. This will certainly have an impact on increasing greenhouse gas emissions through transport trucks used to deliver medical waste. If UGM Academic Hospital has its own incinerator, it is not necessary to ship by truck. Delivery is only carried out when sending incinerator ash to PT PPLI and the incinerator ash must have been solidified when sent by truck because that is already a rule set by the government. So, the solidification process was carried out at UGM Hospital

Academic. Incinerator ashes should be placed in the secured landfill because they are categorized as toxic and hazardous waste. One of the big companies that is capable of managing incinerator ash is PT. PPLI.

The difference between incinerator rotary kiln and incinerator tg-49 can be seen by the capacity. The capacity of the rotary kiln incinerator is 800 kg of waste per hour while tg-49 is 45 kg of waste per hour. The difference between these two incinerator technologies also depends on combustion exhaust gas purification process. In rotary kiln incinerators using flue gas purification which requires some chemicals as well as water while on the tg-49 incinerator uses a wet scrubber which requires water and diesel fuel.

3.2 Life Cycle Inventory

Life cycle inventory analysis (LCI) involves data collection and calculation to quantify inputs and outputs of materials and energy associated with a product system under study. In this case, all inputs and outputs of a unit process and of a product system are related to the main output of the unit process and the final product of the product system, respectively. Here, “related to” means “dividing by” either the unit process main output or the final product of the product system. Inventory data was collected from UGM Academic Hospital, Intergovernmental Panel on Climate Change (IPCC) calculations, and various literature sources. Inventory data used is data from January to December 2022.

3.3 Functional Unit

The function unit is intended as a reference that connects input and output. This reference is necessary to ensure that the LCA results are comparable. Comparison of LCA results becomes very important when studies are carried out on several different systems, to confirm that the comparisons are made on the same basis. The unit of function in this LCA study is 1 ton of solid medical waste.

3.4 Life Cycle Impact Assessment

Life cycle impact assessment (LCIA) is an assessment of the resulting impact. This stage will explain the results of data processing obtained from the LCI stage which will then be seen what the impact on the environment is like. The determination of impact indicators in this study uses OpenLCA software using the CML-IA Baseline characterization. The CML-IA Baseline itself has been used by previous studies for the assessment of environmental impact categories in LCA studies. The impact categories assessed include Global Warming Potential, Eutrophication Potential, Acidification Potential, Ozone Depletion Potential (ODP), and The Human Toxicity.

3.5 Interpretation

Results of life cycle inventory analysis and life cycle impact assessments are analyzed with respect to various aspects such as completeness, sensitivity, and consistency. In addition, key issues that contribute significantly to the environmental impact of the product system are also identified. Key issues in this context can mean key processes, materials, activities, and components or even a life cycle stage., From these analyses, conclusions are drawn, and recommendations made as to the environmental aspects of the product, possible areas for improvement or key environmental information that could be communicated to the consumer, all depending on the goal of the LCA study. There are three key elements in life cycle interpretation as defined by ISO 14043. First is the identification of key issues, second is the evaluation (including checking completeness, sensitivity, and consistency), and third is the development of conclusions together with recommendations. All three elements defined in the ISO standard on life cycle interpretation are discussed here.

3.6 Assumptions and Limitations

1. In this study, the fraction of medical waste was not calculated due to limited data obtained, so this study focuses on the process of managing solid medical waste. The assumptions used in this study are the incineration process where for the initial scenario incineration process uses rotary kiln incinerator technology originating from China. This assumption is used because of PT. Wastec also uses this type of incinerator, namely the rotary kiln incinerator. For the incineration process in alternative scenario using tg-49 incinerator technology originating

from Japan. The reason for choosing the tg-49 incinerator is because it can be seen at the capacity of the incinerator that can burn approximately 400 kg of waste per day and when compared to the average waste production of UGM Academic Hospital, it is about 200 kg to 400 kg per day. Therefore, this tg-49 incinerator is suitable for use in UGM Academic Hospital. Then the next assumption is that the residue from the incinerator combustion results is assumed to be 10% of the total waste. This assumptions used are taken in the PERSI (Indonesian Hospital Association) book explaining research related to the incineration process at the Shinagawa Combustion Plant Tokyo where in 1 day of activity at the plant it can burn as much as 7,500 tons of waste and produce 760 tons of residue which is approximately 10% of the total waste (Direktorat Penilaian Kinerja Pengelolaan Limbah B3 dan Limbah Non B3, 2018). The solidification process follows the rules from the government of Indonesia (PERMENLHK No. P-56 of 2015). The last assumption is that CO_2 emissions are 0.415 kg per 1 kg of solid medical waste, this figure is obtained from the average value of CO_2 emissions from research on emissions produced by incinerators (ISO 14040:2006).

3.7 General Description of Medical Solid Waste Management in UGM Academic Hospital

Solid medical waste is collected from outpatient, inpatient, and other supporting installations. Then the solid medical waste is put into the yellow bin while the sharp medical waste is put into the safety box. The next step is to put the waste in a container to be taken to the TPS for B3 waste. After that, the waste is sent by truck to Semarang to be precise at PT. Wastec International is to be destroyed using an incinerator. The results of the incineration process produce residue or residual ash which is assumed to be as much as 10% of the total waste and then sent to a third party, namely to PT Prasadha Pamunah Waste Industry. Research related to the incineration process at the Shinagawa Combustion Plan Tokyo where in 1 day the activities at the plant can burn as much as 7,500 tons of waste and produce 760 tons of residue which are approximately 10% of the total waste

4. Results

4.1 Impact Assessment

Table 2. Life Cycle Impact Assessment on Each Process Unit of Base Scenario.

Indicator/Process Unit	OHS Operational	Transportation to PT Wastec	Incineration (Rotary Kiln)	Solidification	Transportation to PT PPLI	Unit
Acidification	48.78	1.14	3.36	0.036	0.60	kg SO_2 eq
Eutrophication	7.23	0.29	1.69	0.012	0.15	kg PO_4^{-3} eq
Global warming (GWP100a)	35,007.7	259.8	758.334	12.74	138.33	kg CO_2 eq
Human toxicity	1,526.8	183.1	905.316	2.93	97.52	kg 1,4-DB eq
Ozone layer depletion (ODP)	6.05E-03	4.10E-05	4.34E-05	5.76E-07	2.18E-05	kg CFC-11 eq

Source: OpenLCA Simulation

In this impact assessment section, the analysis is focused on the base scenario analysis because this is the current condition. Based on the OpenLCA simulation results in Table 2, for the OHS operational process unit, the highest impact is the global warming potential impact (GWP), which is 35,007.7 kg CO_2 eq, which is dominated by emissions into the air, namely CO_2 from the electricity production process. Then the impact of human toxicity is equal to 1,526.8 kg 1.4-DB eq which is dominated by emissions into water, namely selenium, nickel, benzene, and others from the electricity production process. Furthermore, the eutrophication impact is 7.23 kg PO_4^{-3} eq which is dominated by emissions to water in the form of nitrogen and phosphorus and emissions to air in the form of nitrogen oxides and ammonia from the electricity production process. Then the acidification effect is 48.78 kg SO_2 eq which is dominated by emissions into the air in the form of sulfur dioxide, ammonia, and nitrogen oxides from the electricity production process. The impact of depleting the ozone layer is 6.05×10^{-3} kg CFC-11 eq which is dominated by emissions into the air in the form of methane from the oil and gas production process.

For the transportation to PT. Wastec process unit, the highest impact is the global warming potential impact (GWP), which is 259.8 kg CO_2 eq, which is dominated by emissions into the air, namely CO_2 from the transportation process. Then the impact of human toxicity is 183.1 kg 1.4-DB eq which is dominated by emissions into water, namely thallium, molybdenum, and beryllium from the processing of copper mining tailings. Furthermore, the eutrophication impact was 0.29 kg PO_4^{-3} eq which was dominated by emissions into the air in the form of nitrogen oxides, nitrous oxide, and ammonia from the transportation process. Then the acidification effect is 1.14 kg SO_2 eq which is dominated by emissions into the air in the form of sulfur dioxide, ammonia, and nitrogen oxides from the transportation process. The impact of depleting the ozone layer is 4.1×10^{-5} kg CFC-11 eq, which is dominated by emissions into the air in the form of methane from the oil and gas production process.

For the incineration process unit, the highest impact is the Global Warming Potential impact of 758.334 kg CO_2 eq which is dominated by emissions into the air, namely carbon dioxide and nitrous oxide from the incineration process. Then the potential human toxicity impact is 905.31 kg 1.4-DB eq which is dominated by emissions into the air, namely thallium and cadmium from the incineration process. Furthermore, the eutrophication impact is 1.69 kg PO_4^{-3} eq which is dominated by emissions into the water in the form of phosphate and nitrate from the coal waste processing process in the electricity production process. Then the acidification effect is 3.36 SO_2 eq which is dominated by emissions into the air in the form of sulfur dioxide, ammonia, nitrogen dioxide, and nitrogen oxides from the incineration process. The impact of depletion of the ozone layer, which is equal to 4.34×10^{-5} kg CFC-11 eq, which is dominated by emissions into the air in the form of methane from the sodium hydroxide production process.

For the solidification process unit, the highest impact is the global warming potential impact (GWP), which is 12.7 kg CO_2 eq, which is dominated by emissions into the air, namely CO_2 from the cement production process. Then the impact of human toxicity is 2.93 kg 1.4-DB eq which is dominated by emissions into water, namely selenium from the processing of coal mining waste. Furthermore, the eutrophication impact is 0.012 kg PO_4^{-3} eq which is dominated by emissions into the water in the form of phosphate and nitrate from the waste treatment process in coal mining. Then the acidification effect is 0.03 kg SO_2 eq which is dominated by emissions into the air in the form of sulfur dioxide, ammonia, and nitrogen oxides from the cement production process. The impact of depleting the ozone layer is 5.7×10^{-7} kg CFC-11 eq, which is dominated by emissions into the air in the form of methane from the oil and gas production process.

For the transportation to PT.PPLI process unit, the highest impact is the global warming potential impact (GWP), which is 138.3 kg CO_2 eq, which is dominated by emissions into the air, namely CO_2 from the transportation process. Then the impact of human toxicity is 97.5 kg 1.4-DB eq which is dominated by emissions into water, namely thallium, molybdenum, and beryllium from the processing of copper mining tailings. Furthermore, the eutrophication impact is 0.15 kg PO_4^{-3} eq which is dominated by emissions into the air in the form of nitrogen oxides, nitrous oxide, and ammonia from the transportation process. Then the acidification effect is 0.6 kg SO_2 eq which is dominated by emissions into the air in the form of sulfur dioxide, ammonia, and nitrogen oxides from the transportation process. The impact of depleting the ozone layer is 2.1×10^{-5} kg CFC-11 eq, which is dominated by emissions into the air in the form of methane from the oil and gas production process.

4.2 Completeness Check

The objective of a completeness check is to ensure that all information and data required for life cycle interpretation are complete. In particular, the check aims at ensuring that identified key issues reflect life cycle inventory results as well as life cycle impact assessment results sufficiently and accurately. Most of the data used in the calculation of the OpenLCA software uses secondary data that comes from UGM Academic Hospital data and literature data. While the primary data used is data for calculating the transportation distance for sending solid medical waste to partner companies, and calculating GHG emissions using the 2006 IPCC calculation formula. All data that is used as input/output on inventory data is relevant or in accordance with the system boundary of this research.

4.3 Sensitivity Analysis

Sensitivity analysis aims to determine the level of importance of data that can be carried out by including or removing process units/subsystems, inputs and outputs. Sensitivity analysis was performed to assess the effect of parameter selection or the effect of data variation on this study. Expenditure and inclusion tests can be carried out based on important issues from the calculation results. One of the important issues in this research is the impact of GWP. A sensitivity analysis was carried out on the transportation subsystem expenditure to PT. Wastec in the initial scenario. Based on the calculation results, the results of the total GWP impact from the initial scenario are 36,176.9 kg CO_2 eq. If the transportation to PT. Wastec process unit is ignored (assuming UGM Academic Hospital has its own incinerator) so there is a decrease in the impact value of 259.81 kg CO_2 eq per ton of solid medical waste.

A sensitivity analysis is also carried out on the input of electrical energy in the OHS operational unit process where the use of electricity from an electricity government company (PLN) will be compared with a combination of PLN electricity with the use of solar panels. This analysis was carried out as a scenario for improving electricity consumption. The assumptions used in the manufacture of solar panels were the use of 5 inverters and 143 modules with an installed capacity of 56,100 Wp produces a total of 93,556 kWh/year of electrical energy (Johnke *et al.*, 2001). The assumption of energy produced by solar panels is equivalent to 3% of the total annual energy consumption in the OHS operational unit process, which based on PLN's regulation, solar panel utilization is limited to a maximum of 15%. In this sensitivity analysis, it is assumed that the solar panel module used is 0.36 m^2 in size and has a capacity of 50 Wp/module. To achieve a capacity of 56,100WP, 1,122 modules are needed. The area for solar panel installation is obtained from the module size area multiplied by the number of modules so that the solar panel installation area is 405.3 m^2.

Table 3. Emission Comparison of Electricity of PLN and Combination of Solar Panel

Indicator	PLN	PLN – Solar Panel	Unit	Emission Reduction
Global Warming Potential	35,007.7	34,583.4	kg CO_2 eq	1.2 %

From the results of the sensitivity analysis in Table 3, it can be seen that the results of a comparison between electricity from PLN and the combination of PLN electricity and solar panels in the OHS operational process unit, the results for PLN electricity are 35,007.7 kg CO_2 eq and the results for the combination of PLN electricity and solar panels are 34,583.4 kg CO_2 eq for a unit function of 1 ton of solid medical waste. These results indicate that the combined use of solar panels and electricity from PLN can reduce emissions of 424.3 kg CO_2 eq per ton of solid medical waste in 1 year.

4.4 Uncertainty Analysis

Uncertainty analysis is carried out if there is data with high uncertainty, assumptions, and low-quality data that develops in the calculation. This uncertainty analysis process is carried out with the aim of examining and knowing the effect of this uncertainty on the reliability of LCIA results. The results of examining this uncertainty can be in the form of a comparison of the mean or mean value with the standard deviation value or the coefficient of variation. If the standard deviation value is smaller than the average value, the better the distribution or variation of the data. Conversely, if the standard deviation value is greater than the average value, then the distribution of the data or the variation of the data is greater, so the data deviation can be said to be not good.

Table 4. Uncertainty Analysis

Impact category	Unit	Mean	Standard deviation	Minimum	Maximum
Acidification	kg SO_2 eq	59.10	9.34	43,05	83,50
Eutrophication	kg PO_4^{-3} eq	11.14	1.86	8,52	16,14
Global warming (GWP100a)	kg CO_2 eq	37,243	932	35,737	39,639
Human toxicity	kg 1,4-DB eq	4,126	812	2,989	6,326
Ozone layer depletion (ODP)	kg CFC-11 eq	8.66E-03	6.88E-03	4.02E-03	4.30E-02

Table 4 explains that the results of the simulation using monte carlo analysis show that each process unit has good data distribution, it because the standard deviation value is smaller than the mean value. Examination of uncertainty using monte carlo analysis in OpenLCA. The following are the results of the monte carlo analysis obtained from the LCIA results with 30 iterations. Monte Carlo simulation is a mathematical technique that predicts the possible outcomes of uncertain events.

4.5 LCIA Correlations with Goal and Scope of LCA

The results of the Life Cycle Impact Assessment or LCIA are in accordance with the objectives set in this study, namely, to provide information about the environmental burden or environmental impact resulting from solid waste handling activities at UGM Academic Hospital within the cradle-to-grave scope with a unit function of 1 ton of waste solid medical. From the OpenLCA simulation results using the CML-IA Baseline method, there are 2 impacts that contribute the most to the results of this assessment, namely the impact on GWP and the impact on Human Toxicity.

4.6 Data Quality

The data quality and results of the life cycle inventory are sufficient to carry out the life cycle impact assessment because they are in accordance with the objectives and scope of this study. The dataset used is quite relevant to the input and output of the OpenLCA simulation process.

5. Discussions

The results of the impact of the base scenario and alternative scenario are compared in Table 5. Then the life cycle impact assessment on each process unit in the alternative scenario can be seen in the appendix in Table 8.

Table 5. Impact Assessment Comparison Between Base Scenario and Scenario

Indicator	Base Scenario	Scenario	Unit
Acidification	53.94	52.49	kg SO_2 eq
Eutrophication	9.40	8.01	kg PO_4--- eq
Global warming (GWP100a)	36,179.9	35,758.4	kg CO_2 eq
Human toxicity	2,715.7	2,396.6	kg 1,4-DB eq
Ozone layer depletion (ODP)	6,14E-03	6,16E-03	kg CFC-11 eq

Source: OpenLCA Simulation

According to Table 5, acidification impact, decreased by 1.45 kg SO_2 eq (2.68%). Then the eutrophication impact decreased by 1.39 kg PO_4^{-3} eq (14.75%), Global warming potential impact decreased by 421.5 kg CO_2 eq (1.16%). The impact of human toxicity decreased by 319.1 kg 1,4-DB eq (11.75%). And the impact of ozone layer depletion has increased by 0,00001 kg CFC-11 eq (0.31%). A comparison of the results of this research (base scenario) with previous research, especially in the transportation (transportation to PT. Wastec) and incineration (rotary kiln) process unit on the impact of GWP can be seen in Table 6.

Table 6. Comparison with Previous Research

Process Unit	Research Result (Base Scenario)	Previous Research	
		Result	Source
Transportation	259 kg CO_2 eq	150 Kg CO_2 eq	(Ali *et al.*, 2016)
Incineration	758.33 kg CO_2 eq	424 Kg CO_2 eq	(Zhao *et al.*, 2021)

Based on Table 6, the results of this research generate a higher value in the transportation process unit that is equal to 259 kg CO_2 eq compared to the results from the previous research which is 150 kg CO_2 eq. Because this research uses a distance of 141 KM to go to the partner companies to treat the waste while the results from the previous research use a distance of 119 KM. For the incineration process unit, the results from the previous research generate a value of 424 kg CO_2 eq compared to the results of this research which is 758.33 kg CO_2 eq. This difference is due to differences in the system boundaries studied where previous research did not calculate the electricity production process (cradle), and other differences are caused by different inputs in inventory data.

The important issue of this research (base scenario) is the impact of global warming potential (GWP) where the impact decrease of 421.5 kg CO_2 eq per 1 ton of medical solid waste. This is in line with the research background to mitigate environmental impacts or reduce greenhouse gas emissions. From these results, it can be concluded that the alternative scenario can reduce the environmental impact. This research can be a consideration for UGM Academic Hospital to procure an incinerator.

Identification of important issues is determined based on the normalization results of impact categories using OpenLCA to get the most relevant impacts for further discussion on important issues (hotspots). Determination of the most relevant impact according to the normalization results of the CML IA Baseline, World 2000 method with the normalization factor.

Table 7. Contribution of LCI to LCIA (Base Scenario)

	GWP	HT	AD	EP	ODP
Transportation PT PPLI	0.387%	4.842%	1.158%	1.676%	0.338%
Cement	0.036%	0.145%	0.058%	0.134%	0.891%
Incinerator Electricity	0.543%	6.058%	1.544%	12.850%	0.056%
Urea	0.114%	1.569%	0.347%	0.670%	0.036%
Sodium hydroxide	0.080%	1.773%	0.290%	1.006%	3.562%
Active Carbon	0.024%	0.149%	0.097%	0.145%	0.003%
Sodium hypochlorite	0.022%	0.477%	0.077%	0.201%	0.082%
Solar	0.011%	0.084%	0.077%	0.056%	0.914%
Transportation PT Wastec	0.728%	9.095%	2.201%	3.240%	0.635%
Electricity OHS Operational	97.752%	72.377%	93.410%	77.100%	93.388%
Safety Box	0.072%	0.704%	0.135%	0.447%	0.033%
Medical Plastic	0.226%	2.682%	0.595%	2.458%	0.063%
Stericide	0.004%	0.045%	0.012%	0.016%	0.001%

Table 7 is a summary of the percentage contribution from life cycle inventory data to the life cycle impact assessment on Base Scenario analysis. Based on Table 7, it can be seen that in each impact category, the input of electrical energy is dominated by the OHS operational process unit because it originates from the production of electrical energy which is reviewed upstream (cradle).

6. Conclusion

Life cycle Assessment (LCA) is an efficient method for estimating and evaluating the impact of each process unit. From these results, we will know which part should be evaluated or developed. The limitations of this research are the input and output of the incineration process obtained from estimated journal literature data because researchers have not yet had access to data from partner companies. The results of this research can be evaluated and considered, especially for UGM Academic Hospital related to medical waste management. An economic feasibility analysis needs to be carried out for future research related to the procurement of incinerators. This study also suggests substituting the use of electrical energy from renewable sources such as the use of solar panels and other applicable technologies. Thus, it is necessary to carry out further studies related to energy audits at UGM Academic Hospital for the application of renewable energy.

Acknowledgment

We gratefully acknowledge the support provided by the UGM Academic Hospital and Faculty of Engineering of Gadjah Mada University, Special Region Yogyakarta, Indonesia.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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To Cite This Article: Malik, R. S. H., Azis, M. M., & Sopha, B. M. (2023). Life Cycle Assessment of Medical Solid Waste Management. *Journal of Industrial Engineering and Education,* 1(2), 83-96.

Appendix

- Life Cycle Impact Assessment

Table 8. Life Cycle Impact Assessment on Each Process Unit of Scenario

Indicator	OHS Operational	Incineration (tg-49)	Solidification	Transport to PT PPLI	Unit
Acidification	48.78	2.88	0.03	0,77	kg SO_2 eq
Eutrophication	7.23	0.55	0.012	0,2	kg PO_4^{-3} eq
Global warming (GWP100a)	35007,7	560.68	12.74	177.2	kg CO_2 eq
Human toxicity	1526,8	741.872	2.93	124.96	kg 1,4-DB eq
Ozone layer depletion (ODP)	6.03E-03	9.7504E-05	5.7569E-07	2.79E-05	kg CFC-11 eq

- Life Cycle Inventory

Table 9. Inventory Data OHS Operational Unit Process

Flow	Value	Unit
Input		
Electricity	4,197,277	kWh
Stericide	360	L
Polybag Black	421.2	kg
Plastic Black	1,078.7	kg
Polybag Yellow	1,620	kg
Plastic Yellow Infectious	2,651.4	kg
Plastic Yellow	1,367.55	kg
Polybag White	418.5	kg
Plastic Brown	81	kg
Plastic Purple	49.95	kg
Safety box 3L	4,068	kg
Safety box 5L	7,890	kg
Safety box 12,5L	7,425	kg
Water	61,560,000	l
Medical Solid Waste	84,654.80	kg
Output		
Jerrycan Stericide	11.116	kg
Medical Solid Waste	111,726.11	kg

Table 10. Inventory Data Transportation to PT Wastec Unit Process

Flow	Value	Unit
Input		
Medical Solid Waste	111,726.11	kg
Transportation	15,753.38	tkm
Output		

Medical Solid Waste	11,726.11	kg

Table 11. Inventory Data Incineration (Rotary Kiln) Unit Process

Flow	Value	Unit
Input		
Medical Solid Waste	111,726.11	kg
Electricity	19,228.06	kwh
Diesel	1,016.71	kg
Sodium Hypochlorite	425,68	kg
Sodium Hydroxide	3.754.00	kg
Calcium Hydroxide	9,831.90	kg
Water	214,514.13	kg
Active Carbon	268.14	kg
Urea	2,770.81	kg
Output		
Residue	111,72.61	kg
CO_2	46,366.33	kg
N_20	25.03	kg
CO	39.10	kg
NOx	156.42	kg
NH_3	3.13	kg
NO_2	87.36	kg
SO_2	86.73	kg
HCL	0.03	kg
Particle	16.97	kg
Total Hydrocarbon	16.81	kg
Hydrogen Fluoride	0.03	kg
Lead	0.09	kg
Chromium	0.02	kg
Cadmium	0.06	kg
Mercury	0.02	kg
Thallium	0.16	kg

Table 12. Inventory Data Incineration (TG 49) Unit Process

Flow	Value	Unit
Input		
Medical Solid Waste	111,726.11	kg
Electricity	1,986	kwh
Diesel	16,525.53	kg
Water	15,517.52	kg
Output		
Residue	11,172.61	kg
CO_2	46,366.33	kg
N_20	25.03	kg
CO	47.08	kg
NOx	156.42	kg

Flow	Value	Unit
NH_3	3.13	kg
NO_2	87.36	kg
SO_2	86.73	kg
HCL	0.03	kg
Particle	16.97	kg
Total Hydrocarbon	16.81	kg
Hydrogen Fluoride	0.03	kg
Lead	0.09	kg
Chromium	0.02	kg
Cadmium	0.06	kg
Mercury	0.02	kg
Thallium	0.16	kg

Table 13. Inventory Data Solidification Unit Process

Flow	**Value**	**Unit**
Input		
Incinerator Waste	11,172.61	kg
Drum	1,676	kg
Cement	5,586.31	kg
Output		
Total Drum Weight	18,435	kg

Table 14. Inventory Data Transportation to PT PPLI Unit Process

Flow	**Value**	**Unit**
Input		
Total Drum Weight	18,435	kg
Transportation	8,387.84	tkm
Output		
Total Drum Weight	18,435	kg