Life Cycle Assessment (LCA) of Refused Derived Fuel and Biogas Production as an Option of Sleman Regency Municipal Solid Waste Management

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Abstract

Sustainable municipal waste management is a big challenge for cities in Indonesia such as Sleman Regency, in D.I.Yogyakarta. Waste to Energy (WtE) is one of the methods in municipal solid waste (MSW) management. Energy recovery from municipal waste is expected to produce electricity and/or thermal energy and thereby may reduce the amount of waste transferred to landfill.This study aims to evaluate the environmental impact of two energy recovery scenarios of municipal solid waste management in Sleman Regency. Here, we investigated 3 options for MSW management: direct combustion of once sorted waste to produce energy(O-1) , an integrated combustion of inorganic waste through the formation of densified Refuse Derived Fuel (dRDF) followed by energy production (O-2) and scenario which are including dRDF and biogas followed by energy production (O-3). The environmental impacts from both scenarios were computed with Life Cycle Assessment (LCA) simulation by using OpenLCA 1.10.3 software. The impact assessment include global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and human toxicity potential (HTP). The LCA simulation results showed that the GWP value of O-1; O-2; and O-3 were 0.674kg CO_2eq / kWh, 0. 659 kg CO_2eq / kWh, and 0.574 kg CO_2eq/kWh, respectively. The AP, EP and HTP values for O-3 are consistently lower than that of O-2 and O-1. Thus, the LCA simulation results showed that MSW conversion into dRDF and biogas as a part of WtE technology is more environmentally friendly than direct combustion of MSW to energy.

Keywords: LCA, OpenLCA, Sleman, MSW, dRDF

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1. INTRODUCTION

Creating a healthy environment is the first step that every city must take in order to improve public health. One sector that can be improved and become an indicator of a sustainable city is waste management. To date, waste is still one of the biggest problems that cannot be completely resolved for many cities in developing world, including Indonesia.

A problem that is often become a concern in municipal waste management in Indonesia is the limited capacityof the final disposal site. Many cities in Indonesia still use landfilling and also open dumping. In addition, the growth of urban area will make it difficult to find a new landfill location and hence new disposal sites will be further away from the city[1,2]. This problem is also experienced by Sleman Regency. Rapid population growth causes the expansion of residential areas. As aresult, it is increasingly difficult to find new landfilllocations [3].

Waste to Energy (WtE) is one of the better options than landfilling in Municipal Solid Waste (MSW) Management. There has been raising interest to produce refuse derived fuel (RDF) from MSW as a part of WtE effort. It is often considered as an economical WtE technology through the formation of waste pellets from inorganic materials. For RDF production, size reduction and magnetic separation are carried out toobtain fluff. Fluff RDF (fRDF) is an optional fuelwhich is obtained by separating metals, glass and other dangerous materials from waste. Then, to increase the calorific value, fRDF can also be converted into densified RDF (dRDF) by adding calcium dihydroxide[4]. In addition, another method is mechanical-biological treatment (MBT). MBT is a method that can minimize waste pollution. Waste pollution which is mentioned as an effect on the environment from landfilling due to odor, self-heating, automatic biogas production, and pathogen growth. The product of the MBT process is biogas. Biogas can be interpreted as a combustible gas which is resulted from the anaerobic decomposition of organic material[5].

The environmental impact assessment for the conversion of MSW into energy through theformation of dRDF and biogas can be evaluated with a Life Cycle Assessment (LCA). LCA is a method of measuring the environmental impact of a product during the product's life cycle[6]. The LCA simulation follows ISO 14040 and ISO 14044 standards and has been widely used as an effective tool to plan a waste management system. LCA allows us to assess the environmental impact of various option solutions and able to identify the main areas that require comprehensive improvement by impact assessment simulation including acidification potential, greenhouse gas emissions, toxicity, photochemical oxidation, and others. Conversion of waste to energy can also cause emissions to the atmosphere as air pollutants[7,8].

This study aims to calculate the environmental impact through LCA simulations as well as the potential for energy recovery that can be generated from 3 options of municipal waste management in Sleman Regency which covers 3 options of single-sorted waste and incineration; production of Densified Refuse Derived Fuel (dRDF) and incineration; and Densified Refuse Derived Fuel (dRDF) and biogas followed by incineration[9].

2. METHODS

The research methodology refers to ISO 14040 of 2006 concerning Life Cycle Assessment (LCA) analysis. The stages of this research broadly consist of: (1) Goal and scope definition; (2) Life cycle inventory; (3) Life cycle impact assessment, and (4) interpretation and result. All simulations were conducted using OpenLCA software.

2.1. Goal And Scope Definition

The scope of this study uses a "gate to grave" scope, which means that the LCA analysis is limited to the process being reviewed. What is not covered inthis study is transportation (fueled transportation) to the waste processing site into dRDF and biogas. Eachflow that is reviewed in this simulation consists of mass, energy, and emission as input and output which is described in the reference flow. In this study, the functional unit (FU) is 3.6 MJ of energy generated from the incineration process. In this study, the current value in the reference flow is determined based on field studies and literature. The detail of reference flow includes in the form of waste mass balance (tons MSW), electricity demand (kWh electricity), and volumetric flow of fuel and water.

2.2. Literature Study and Data Collection

This study uses real data (primary) in the form of waste generation data followed by an analysis of the proximate and ultimate content of the samples obtained. For RDF production such as equipment inventory, electricity, and fuel for making fluff RDF (fRDF) were obtained from direct observation at PT. Narpati Agung in Semarang and reference for making dRDF.

The inventory data for making biogas were obtained from the Gamping Biogas power plant which is a collaborative project between the Waste Refinery Center (WRC) UGM and Koperasi Gemah Ripah (KGR). Data were obtained in the form of a series of processing equipment, electricity needs, water needs, and fuel needs for biogas[10]. In addition, some data that were not available from direct observations were taken from the ecoinvent database, such as the emission of each type of waste when it enters the system. Proximate analysis in Table 1 was carried out on organic samples and inorganic samples consisting of plastics, wood, textiles, paper, plastic bottles, and rubber. The results of the analysis of organic samples showed the calorific value of 1,642.6 cal/gr, moisture 77.62 %w/w, and ash 8.88 %w/w. While for inorganic samples the analysis results showed the calorific value of 6,298.17 cal/gr, moisture 13.73 %w/w, and ash 8.94 %w/w. Other primary data were obtained by ultimate analysis of organic samples, wood, textiles, plastic, plastic bottle and paper. While the ultimate data of some other types of waste were secondary data[11].

Table 1. Ultimate Composition of Sleman Regency MSW

Type	Composition (%Wt)	Ultimate (%Adb)				
		C	H	O	N	S
Organic	16.97	37.4	5.78	35.8	2.01	0.27
Wood	1.61	43.88	6.27	45.15	1.97	0.16
Textile	2.04	60.93	6.36	28.76	0.45	0.2
Paper	8.85	42.25	6.36	40.62	0.25	0.1
Plastic Bottle	3.82	72	17	0	3	0
Plastic	15.88	56	6	26	0	0
Rubber	1.16	78	10	0	2	0
Others	43.79	26.3	3	2	0.5	0.2

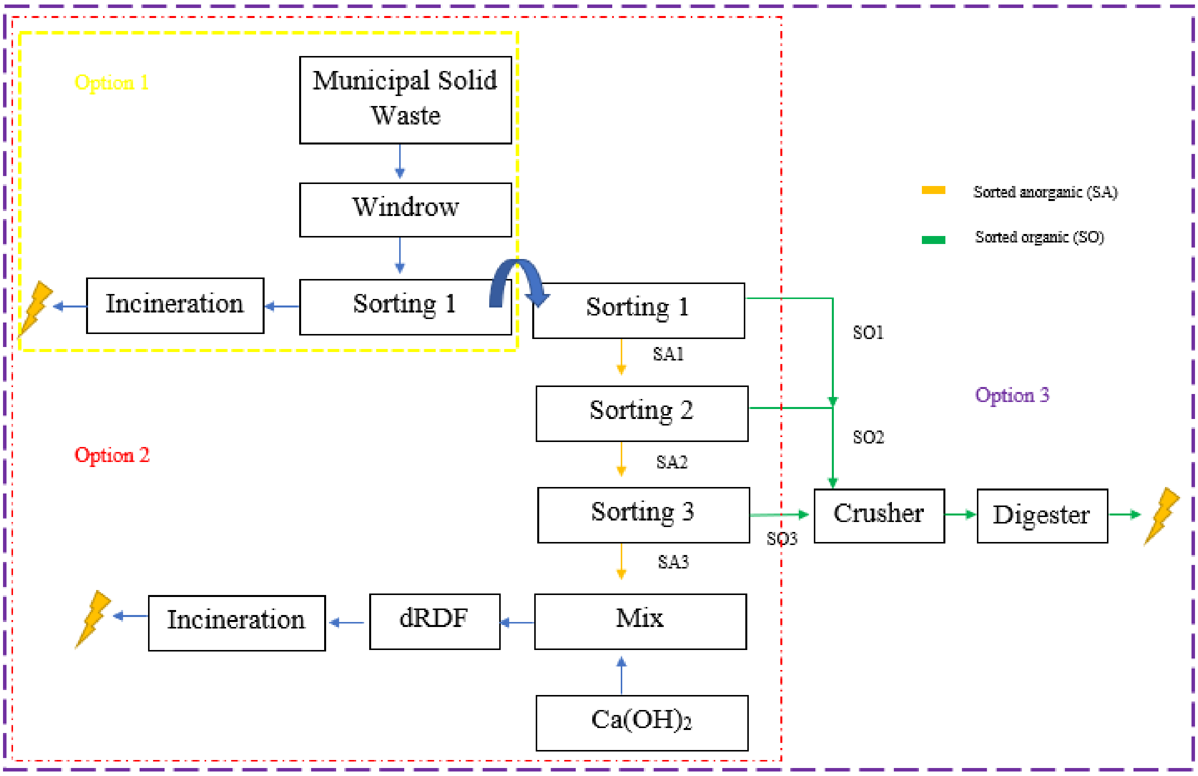

Fig 1. Scheme of dRDF and biogas as waste management altenative

HHV and LHV values were obtained by entering the data in Table 1 into the formula[12]. The amount of waste used in the simulation is calculated over 30 days for 1,231.86 tons/day. There were 5.87 %Wt hazardous and toxic materials,glass waste, and metal waste of weight composition. The composition of Sleman's waste was obtained based on field observations at 5 TPS in Sleman Regency which shown in Table 1.

Figure 1 shows the 3 scenarios of LCA for the present study. To begin with, option 1 is called as one sorted waste (OSW). Before being converted into energy, MSW is processed through the raw material pretreatment which consists of windrow and sorting 1. In the raw material pretreatment process as shown in Figure 1, the waste loses moisture content which is mostly processed in the windrow unit. The amount ofmoisture content that has been reduced is 14% of the mass ofwaste input. Furthermore, the waste is separated into inorganic, organic, and some other waste consisting of hazardous and toxic materials, glass waste, and metal waste. Inorganic waste is continued to the incineration unit. Then, the processed waste is burned in an incinerator.

For option 2, the inlet feed of MSW was further processed into dRDF which consists of various MSW pretreatment processes which are consisting of windrow, sorting1, sorting 2, sorting 3, and pelletizing. Sorting 1 is a size reduction and organic separation (SO1 flow) process using a shredder, inorganic press, conveyor 1, and conveyor 2. At this stage, SA1 flow will be obtained with a size of ±60 mm. Sorting 2 will separate organics (SO2 flow) of SA1 that are still included. So that the result of accumulation is called SA2 flow. This process involves a conveyor sorting machine and a conveyor feeding sorting. Furthermore, the SA2 stream enters sorting 3, which aims to separate inorganic and organic (SO3 flow). The tools used are magnetic separator and product conveyor. Then SA3 is converted into dRDF. This process is requiring an additional 8% by weight of calcium dihydroxide. Mixing process is using a hopper (calcium dihydroxide) and screw conveyor. Then the mixture enters the pelletizer to produce dRDF and to be incinerated.

Furthermore, the process in option 3 is an inclusion of biogas technology followed by incineration. The series of tools used are same as in option 2 The result of sorting in the form of organic is processed to become biogas. This process will produce methane, hydrogen and carbon dioxide. The process begins by reducing the size of the waste by crusher. The process requires a total of 48% water from the total inlet waste. Then the slurry is fed into the digester. In the digester, waste will be accumulated into gas. The gas will be transferred to a power plant to beconverted into electricity.

2.3. Life Cycle Inventory

Data collection is carried out in the form of primary data and secondary data. Data collection is based on LCA ISO 14040 method. Data is collected for each process unit in the system. Data required to provide input and output calculations in the system. Emissions are aggregated based on the units within the boundary and the processes that occur. Emission data is obtained based on secondary data. Emission data is adjusted to the inventory of the equipment used with the intention that the emissions are valid for use.

Emission factor is adjusted to the impact assessment that has been determined for fresh waste, dRDF and biogas[13-15]. Emission data in the form of flue gas produced by the incineration process, use of diesel fuel, use of gasoline, electricity consumption, and waste final disposal. Secondary data are used for solar fuel emission factor in form of CH_4, CO_2, and N_2O. Also for gasoline fuel in form of CO, CO_2 , and HC[16].

2.4. Life Cycle Impact Assessment (LCIA)

Life Cycle Impact Assessment (LCIA) is the stage of calculating environmental impacts. At this stage the data and emission resources that have been collected are used to support calculations. Different and varied emissions will be difficult to determine which has the lower impact among the alternatives. Then the LCIA will link inventory results to more general impacts. The selection of impact categories should reflect a comprehensive set of environmental concerns related to the product system under study, by condisering goal and scope.

Impact indicators are selected and processed in the OpenLCA 1.10.3 Software with the impact assessment category CML-IA (baseline) and the cumulative energy demand method. Normalization and Weighting using World 2000 standards. Impact calculation using Ecoinvent standard system quality dataset. In this study, the impact analysis using the characterization impact assessment method is calculated using the OpenLCA software Some of the environmental impacts are analyzed in this study include global warming, acidification, eutrophication, and human toxicity. The impact category was chosen because of environmental issues that need to be considered in Indonesia from the results of combustion and represent the simulation results to be applied.

3. RESULT AND DICUSSION

The data described in Table 2 at this stage are in the form of mass balance, electricity demand, fuel demand, and air requirements needed in the incineration process and RDF production. The highest calorific value is produced from option processing 3. This is due to the addition of energy from the combustion of dRDF and biogas. In other words, more waste is utilized in the process.

Table 2. Inventory data

Option	Product	Input (ton)	Potential (month)			Consumption (month)	
			LHV (MJ/kg)	Energy (TJ)	Product (ton)	Fuel (liter/month)	Electricity (MWh)
Option 1	OSW	36,955.80	9.56	72.64	15,194.16	3,798,540.34	581.78
Option 2	dRDF	15,194.16	20.39	79.71	7,818.74	1,954,684.17	432.28
Option 3	dRDF	15,194.16	20.39	79.71	7,818.74	2,599,193.25	432.28
	Biogas		18.36	31.24	3,404.17	2,943.58	27.81

From Table 2, it can be seen that option 2 requires the least amount of raw material to produce 1 kWh. Alternative 3 requires more waste than alternative 2. From the simulation results, functional biogas produces 1.01 MJ compared to dRDF with 2.59 MJ from the specified 3.6 MJ unit. The energy from combustion shows that option 3 has the potential to produce the most energy compared to other options. This is because more waste is utilized in option 3. The calorific value that can be used for option 3 is also the largest compared to the others.

Global warming is calculated based on greenhouse gases that are radiative to the atmosphere. The impact of the Global warming potential (GWP) category is the equivalent of kg CO_2 into the air. From the results of calculations using OpenLCA, CO_2 is a gas that contributes to each unit process. Figure 2 shows that the largest equivalent kg CO_2 value is shown in option 1 with GWP impact of of 0.674, 0.658 and 0.574 kg CO_2eq/kWh, for Option 1,2 and 3, resepctively. The largest contribution of CO2 lies in the final disposal,especially paper waste and in the incineration unit with a total of 0.13326 Kg. The research results is obtained from this study can be compared with the other study which reported that the emissions produced reached 478 kg CO_2/ton RDF from combustion[17]. Carbon dioxide can be caused by incomplete combustion which allows large quantities of unburned hydrocarbons and also generated from the use of diesel fuel (derived from fossil sources)[18].

Pollutants that contribute to the environmental impact of acidification potential (AP) include SO_2, NOx, HCl, and NH_3. The impact of this category is expressed in unitsof kg SO_2 equivalent to the air. The calculation resultsshows that nitrogen monoxide and sulfur dioxide gas contribute the most to the impact of each process. Figure 3 shows simulation results in this study indicate that the combustion process (incineration) contributes greatly to the impact of acidification. The number of emissions for option 3 is 2.6 $.10^{-4}$ kg SO_2/kWh eq, while option 2 is 3.6 $.10^{-4}$ kg SO_2 eq /kWh and option 1 is 3.7 $.10^{-4}$ kg SO_2 eq/kWh. Acidification will have an impact on the disruption of lake and forest biota because of air pollution. As shown in the figure that incineration has a major effect on the impact of acidification, this is related to air emissions from thermal energy facilities (NOx , SO_2) will effect on acidification[19] .

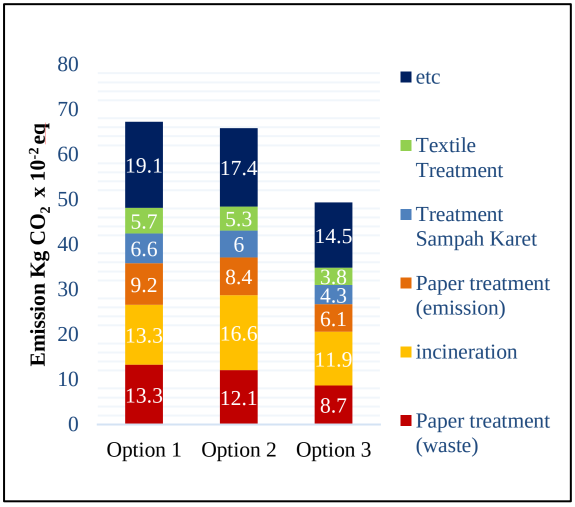

Fig 2 Global warming potential impact categories

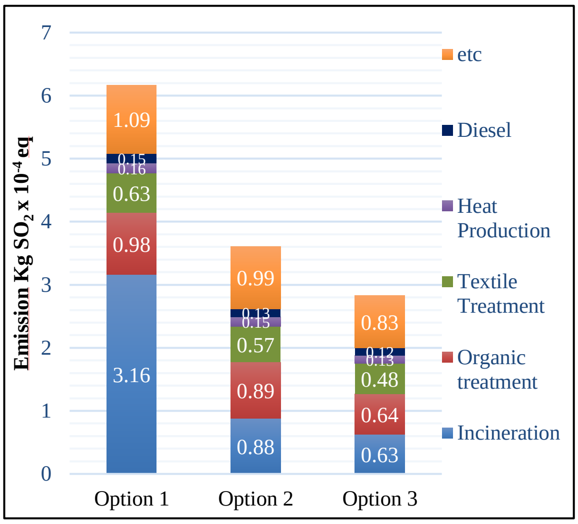

Fig. 3 Acidification impact categories

Measurement of human toxicity potential (HTP) is obtained based on pollutant emissions of PM, SOx, NOx, and heavy metals. Figure 4 presents the results of measuring the impact of human toxicity. From the results of the study, the emission values were 0.2856 kg 1,4-dichlorobenzene eq/kWh for option 1, 0.262 kg 1,4-dichlorobenzene eq/kWh for option 2 and 0.2194 kg 1,4-dichlorobenzene eq/kWh for option 3. It can be said that option 3 is better than option 1 and 2. The results for the category of human toxicity impact are broadly influenced by the heavy metals contained in the input material[20]. Waste management options using incineration will have less impact than landfilling[21].

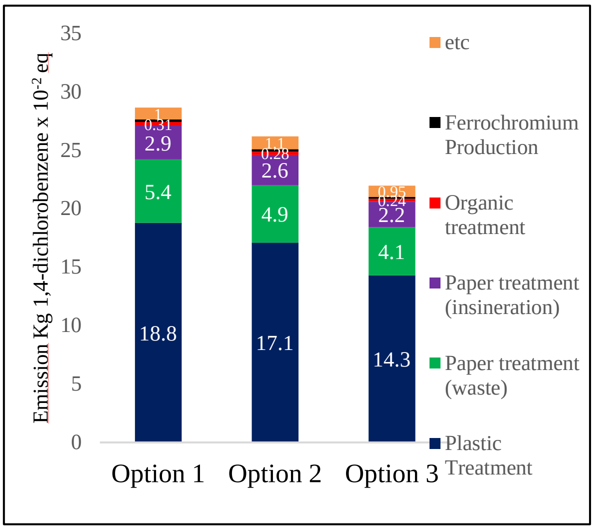

Fig.4 Human toxicity potential (HTP) impact categories

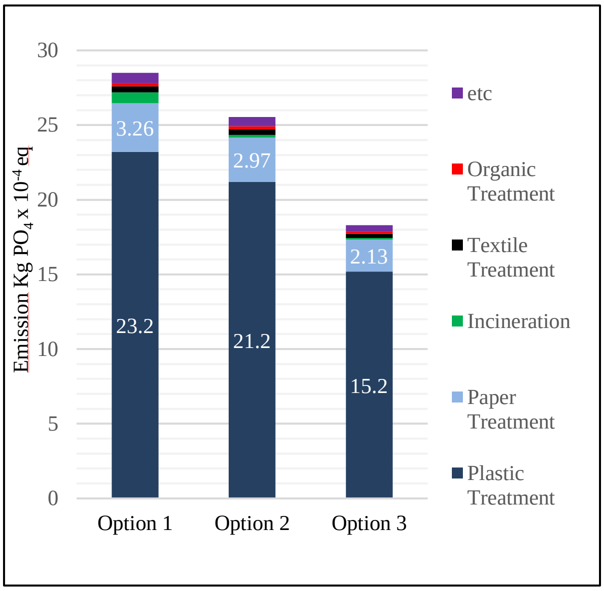

Fig.5 Eutrophication Potential (EP) impact categories

Changing in water conditions that result an imbalance of organisms and water quality can be caused by too much nutrient composition in the water.

Figure 5 shows the results of measuring the impact of eutrophication. From the results of the study, it was found that plastic waste had the greatest impact with a percentage of 81.61% through chemical oxygen demand (COD) and nitrogen emissions. The emission rate from eutrophication potential (EP) for option 1 was 2.85 $.10^{-3}$ kg PO_4 eq/kWh and it was higher than the emissions for option 2 and 3 with values of 2.55 $.10^{-3}$ kg PO_4 eq/kWh and 2.13 $.10^{-3}$ kg PO_4 eq/kWh, respectively.

To reduce the environmental impact from combustion, it is necessary to have a control device such as electrostatic precipitator unit as an effort to filter emissions to the air. In addition, the sorting process contributes greatly to the environmental impact. Sorting includes the use of fueland electricity. The sorting process causes the composition of the waste to enter the incineration stage. Result of contribution analysis shows that the value of sorting process is 75.77% compared to 24.23%on incineration for global warming potential. Hence, it is necessary to optimize waste sorting so that the composition of the incineration input is better.

4. CONCLUSIONS

An LCA study to investigate 3 scenarios of MSW management in Sleman Regency, Indonesia has been presented by proposing 3 scenarios: fRDF production (O-1), dRDF production (O-2) and dRDF+Biogas (O-3). The LCA simulation shows that most of environmental impact from O-3 were consistently lower than waste management in O-1 and O-2. For option 3, the global warming potential value reaches 0.574 kg CO2 eq/kWh. The acidification potential was 0.00026 kg SO4 eq/kWh and eutrophication potential was 0.00213 kg PO4 eq/kWh. The potential impact of human toxicity was 0.2194 kg 1,4-dichlorobenzene eq./kWh. For emissions from combustion, it is necessary to have a control device to minimize air pollution. In addition, this study also reveals the importance of waste sorting step. It is critical to improve the sorting step to obtain higher quality of RDF and better combustion.

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