

## Life cycle assessment (LCA) refuse derived fuel (RDF) waste in pusat inovasi agro teknologi (PIAT) Universitas Gadjah Mada as alternative waste management for energy

Titi Tiara Anasstasia<sup>a</sup>, Muhammad Mufti Azis<sup>b</sup>, Iman Haryanto<sup>c</sup>, Rio Aryapratama<sup>d</sup>,

<sup>a</sup>Environmental Science, Graduate School, Universitas Gadjah Mada, Teknika Utara Street, Pogung, Yogyakarta, Indonesia

<sup>b</sup>Department of Chemical Engineering, Faculty of Engineering, Universitas Gadjah Mada, Grafika 2 Street, Yogyakarta, Indonesia

<sup>c</sup>Department of Civil Engineering, Vocational Collage, Universitas Gadjah Mada, Gedung SV UGM, Sekip Unit 1, Catur Tunggal, Yogyakarta, Indonesia

<sup>d</sup>Industry Ecology, University of Freiburg, Germany

*First submission : 21<sup>th</sup> September 2017, Revised submission : 21<sup>th</sup> November 2017, Acceptance 10<sup>th</sup> December 2017*

©IjoLCAS 2018

### Abstract

Pusat Inovasi Agroteknologi (PIAT) handles institutional waste generated from Universitas Gadjah Mada (UGM). Waste from UGM is called Institutional Solid Waste (ISW) reaches 1,427.27 kg/week. In this study, Life Cycle Assessment (LCA) analysis was used as a tool to calculate and evaluate the environmental impact of potential ISW conversion to densified Refused Derived Fuel (dRDF) with gate to gate framework system. For simulation, OpenLCA software equipped with the Ecoinvent database was used in this work. The results showed that conversion of combustible inorganic waste into densified Refuse Derived Fuel (dRDF) along with conversion of organic waste into compost gave following environmental impacts: global warming potential of 1.3E+00 kg CO<sub>2</sub> eq, acidification 3.9E-03 kg SO<sub>4</sub> eq., eutrophication 7.1E-01 kg P eq., human toxicity 1.2E+00 kg; 1,4-dichlorobenzene and terrestrial ecotoxicity 6.1E-02 kg; 1,4-dichlorobenzene. By separating combustible from non-combustible inorganic waste may significantly improve the quality of dRDF as well as the quantity of compost. The substitution of coal using dRDF combined with the selling of compost is a feasible option. In addition, our results also showed that the installation of exhaust gas emission control could further reduce the environmental impact of dRDF production. An economic evaluation was also conducted to evaluate the scenario of converting ISW into dRDF and compost. This option appeared to be profitable, provided that no restrictions to the processed waste, steady flow of dRDF product to the end-users, and the presence of standard price for dRDF.

**Keyword:** LCA; densified RDF; waste to energy; OpenLCA

---

\* Corresponding author. Tel.: +6285730117293; Fax: +62 274 544975,  
E-mail address. tiara.anasstasia@gmail.com

## 1. INTRODUCTION

Pusat Inovasi Agroteknologi (PIAT) currently manages institutional solid waste within Universitas Gadjah Mada (UGM). The current solid waste management system is limited only for the processing of organic waste. The inorganic waste treatment is still restricted where some portion of inorganic Institutional Solid Waste (ISW) has been treated in Piyungan landfill. As a result, there has been considerable interest to implement an efficient and cost-effective inorganic waste management system in PIAT. One of the processing methods that can be used is the energy recovery-based solid waste processing.

The advantages of energy recovery-based solid waste processing methods do not only reduce the amount of solid waste but also as a generation of renewable energy sources that is competitive with fossil energy [3]. An incineration is a form of energy recovery processing that has been widely applied by several countries in the world [1]. Waste incineration in the United States is capable of producing electricity up to 600 kWh / ton, while China could produce electricity up to 264.13 kWh / ton [20,23]. Implementation of waste to energy technology through waste incineration in Indonesia is relatively low (5%) when compared to landfilling (80%) and composting (10%) [13].

In general, there are 2 types of solid waste incineration: direct and indirect incineration methods. Refuse Derived Fuel (RDF) is a form of indirect incineration which is preceded by a waste treatment process to produce solid fuel with high heating values [10,14]. As a result, the production of RDF offers flexibility on usage, and it can be sold for off-site processing [15,11]. It has also been reported that RDF can also be used as a substitution fuel for cement industry kilns to reduce the use of coal. Indocement is one of the cement industries that has successfully produced and utilized RDF with RDF heating value of 3,883 KCal/kg [11].

Meanwhile, in other countries such as Thailand, RDF has also been developed as the energy source for electricity production. The use of RDF can produce potential low environmental impacts [21]. In America, there are 65 waste incinerators with feeds of more than 20 million tons/year and 15 RDF incinerators with feeds of more than 5 million tons/year. This incinerator is capable of producing electricity up to 600 kWh / ton [20].

The feasibility of the energy recovery method that is proposed to be implemented at PIAT should also be assessed from an environmental point of view. LCA has been used by several studies to evaluate waste management systems, including the implementation of energy recovery and optimization

steps [16,17,10]. Regarding the location, characteristics, and analytical methods in this study is specifically used OpenLCA software and ecoinvent database which has never been done in Indonesia before so that it will be authenticity of this study.

The LCA study in this paper is conducted to calculate and determine the environmental impact of RDF production as an alternative inorganic solid waste processing in PIAT UGM. The quality of RDF that has been targeted here is fluff RDF (fRDF) and densified RDF (dRDF). The fRDF is obtained after the separation of glass, metal, and some inorganic waste, which is then shredded to obtain particle size passed through a 2-In — square mesh screen (about 95% by weight) [5]. The dRDF is the result of compaction of 600 kg / m<sup>3</sup> of combustible waste fraction (in the form of pellets, slugs, cubettes, briquettes, etc.) in order to facilitate storage and transport [5,19]. The dRDF potential calorific value is equivalent to subbituminous coal (20 MJ / kg) [18].

It is a significant thing to do to find out the potential environmental impacts that might be generated, before the processing method can be implemented. The result of this study is important to guide the technology development and implementation of RDF. Moreover, it can offer improvements to the environment.

### 1.1. Case Study Description: PIAT UGM

Institutional Solid Waste (ISW) collected at the PIAT UGM comes from in-road trash, internal UGM area, and around the campus. ISW transport facilities are dump trucks and carts with erratic transport periods. Waste transport period is adjusted to the quantity of waste produced. The more activities carried out on campus, the quantity of waste produced is higher [6]. The characteristic of ISW in the PIAT is still mixed, due to the absence of upstream separation as well as during transportation. The PIAT waste management system could be described as in Figure 1 below.

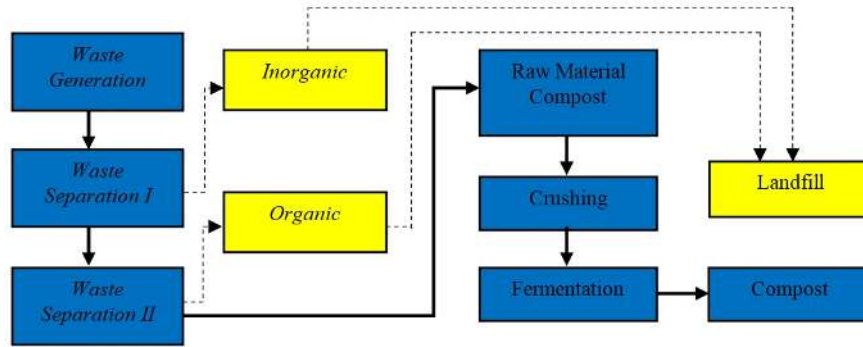
### 1.2. ISW PIAT UGM as A Potential Source for Densified RDF Production

The main quality index of fuel is heating value [7]. Ash content illustrates waste fuel efficiency related to the formation of fly ash. Moisture content is also closely related to the heating value. High water content values can reduce the heating value produced. The characteristic of ISW in PIAT UGM according to their heating value, ash content, and moisture content is presented in Table 1.

**Table 1.** Estimation of generation and composition of ISW

Time	Heating Value (Cal/gram)	Wt (%)	Ash (%)
Week 1	5,731.11	3.43	7.06
Week 2	4,571.27	7.75	6.73
Week 3	5,941.05	4.90	7.05
Week 4	6,343.03	4.83	8.24
<b>Average</b>	<b>5,646.62</b>	<b>5.23</b>	<b>7.27</b>

Some inorganic waste components are solid combustible waste with high heating values, such as plastic, paper, wood, and rubber [8]. Although the UGM PIAT is dominated by organic waste, if the waste management system only relies on composting, the unused energy could reach as high as 585.42 GJ, equivalent to 162.62 MWh.



**Figure 1.** The waste management system in PIAT UGM.

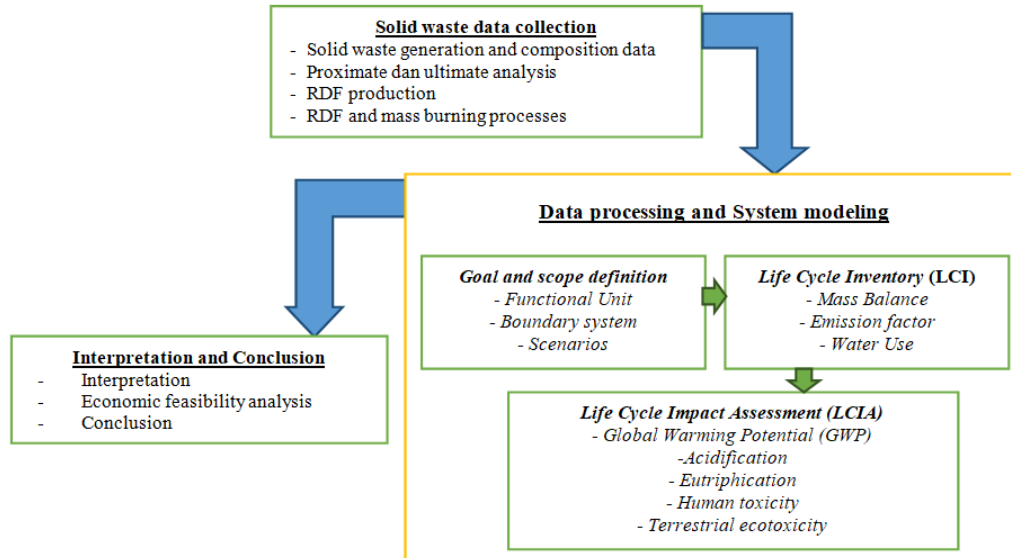
**2. METHODS**

The research framework consists of several stages (Figure 2), namely: (1) data and literature collection; (2) data analysis; (3) conclusions. The LCA analysis is carried out based on ISO 14041.

analysis method (Table 2). The types of measured waste are: organic, inorganic (plastic, paper, rubber/textile, and wood), residues, and other waste (B3, glass, and metal). The results of this stage were the data on the solid waste generation (kg/week), waste composition(%), and heat potential of waste components. The Calculation of energy potential is based on [22].

**2.1. Data Collection**

Waste generation and composition data are estimated based on SNI 19-3964-1994 by Load-count



**Figure 2.** Research framework

## 2.2. Data Analysis

The LCA analysis consists of: (1) Goal and scope definition; (2) Inventory analysis; (3) Impact assessment; and (4) Interpretation. The LCA computation that has been performed in this study was conducted on OpenLCA software equipped with ecoinvent standard database.

### 2.2.1. Study Goal and Scope Definition

The purpose of this study was to calculate and evaluate the environmental impact of ISW conversion to densified RDF as an effort to minimize the rate of inorganic waste generation at the PIAT UGM. The scope of this study is gate to gate, where the object used in the research is only limited to the process of solid waste processing into densified RDF started from when ISW reaches the PIAT UGM to produce densified RDF. The functional unit used is the potential of 1 kWh of energy generated from densified RDF. Variations in quantity and components of waste that are processed to reach 1 kWh of energy are reference flow in this study.

### 2.2.2. Inventory analysis

The second phase of the LCA analysis involves the process of collecting and calculating field data. Field data used is based on primary and secondary data. Inventory results are then used to build a solid waste management system model into RDF. The output in the form of heat potential generated is calculated based on Equations 1 and 2 [22]:

$$HHV = (1-M) HHVd \quad (1)$$

$$LHV = HHV (1-M) - 2.44M \quad (2)$$

HHVd = High Heating Value Default (MJ/kg)

LHV = Low Heating Value (MJ/kg)

M = Moisture Content (%).

### 2.2.3. Impact assessment

The OpenLCA software calculates the potential environmental impact of each scenario with the CML baseline characterization. Assessment of potential impacts is specific to Global Warming Potential (GWP), Acidification, Eutrophication, Human toxicity, and Terrestrial ecotoxicity. The reason for choosing potential impacts is based on the emission characteristics that are dominated by emissions that cause of these impacts.

### 2.2.4. Interpretation

The final stage of LCA analysis before decision making and action plan. The interpretation method uses a contribution analysis [2]. The aim is the identification of data that has the most dominant contribution to environmental impact indicators. Therefore, after knowing the dominant causes of environmental impacts, to improve the densified RDF manufacturing process at the PIAT UGM which is more environmentally friendly can be recommended.

Table 2. Waste generation, composition, and energy potential

Parameter	Value
<b>Waste generation</b>	<b>1,427.27 kg/week</b>
Composition:	
Organic	63.45%
Plastic	16.42%
Paper	7.67%
Wood	7.89%
Rubber/Leather/Textile	0.92%
Residues	1.30%
Others	2.35%
<b>Energy potential</b>	<b>585 GJ/yr</b>

The data related to ISW processing into densified RDF are in Tables 3 and 4 as follow.

Table 3. Inventory data

Parameter	Value
<b>Electricity (kWh):</b>	
<b>a. Pretreatment</b>	0
<b>b. Secondary treatment</b> (1 crusher, 2 belt conveyor, 1 screener)	95.22
<b>c. Tertiary treatment</b> (1 shredder, 4 belt conveyor, 2 crusher)	210.42
<b>d. Downstream process</b>	27
<b>e. Incineration</b>	18.48
Diesel (liter/week)	123.19
Water (liter/week)	136,003.76

Table 4. Emission factor

Parameter	Value
PM	7.04E-02
As	6.00E-06
Cd	8.83E-06
Cr	1.41E-05
Hg	5.66E-06
Ni	4.41E-06
Pb	2.02E-04
SO <sub>2</sub>	3.94E-03
HCl	7.06E-03
NO <sub>x</sub>	5.07E-03
CO	1.94E-03
CO <sub>2</sub>	2.71E+00
CDD/CDF	9.56E-09

EPA, 1996 and IPCC, 2007

**Table 5.** Mass balance for ISW PIAT UGM

Process	Stage I		Stage II		Stage III	
	Input	Output	Input	Output	Input	Output
Pretreatment	1,427.27 kg	741.31 kg	-	-	-	-
Secondary treatment	-	-	296.52 kg	165.47 kg	-	-
Tertiary treatment	-	-	165.47 kg (a) +444.79 kg (b)	469.49 kg	-	-
Downstream process	-	-	-	-	469.49 kg +23.48 kg (c) +7.51 kg (d) -7.59 kg (d)	492.77 kg
Incineration	741.31 kg	4,866.70 MJ	469.49 kg	5,969.57 MJ	492.77 kg	6,371.52 MJ

a : paper                      c : binder                      e : weight loss  
b : hard waste                d : calcium hydroxide

**Table 6.** Mass balance of organic and residue

Process	Stage I		Stage II		Stage III	
	Input	Output	Input	Output	Input	Output
Pretreatment	1,427.27 kg	652.35 kg (f) 33.54 kg (g)	-	-	-	-
Secondary treatment	-	-	296.52 kg	126.62 kg (f) 4.43 kg (g)	-	-
Tertiary treatment	-	-	165.47 kg (a) +444.79 kg (b)	126.62 kg (f) 14.15 kg (g)	-	-
Downstream process	-	-	-	-	469.49 kg +23.48 kg (c) +7.51 kg (d) -7.59 kg (d)	0.2 kg
Incineration	741.31 kg	0 kg	469.49 kg	0 kg	492.77 kg	0 kg

f : organic                      g : residue                      h : water

### 3. RESULTS AND DISCUSSION

The scenario of waste processing into a densified RDF consists of 5 stages according to Fig. 3. The output of this process is the potential energy expressed in heat values (MJ). During the processing, ISW mass balance patterns are in accordance with Table 5 and 6. Based on the simulation results in

OpenLCA, it can be seen that the potential impacts resulting from the ISW processing become RDF densified according to Figure 3. In general, it can be seen that the main contributors of all environmental impact are from the use of fossil fuel in the incineration stage.



**Figure 3.** ISW processing flow diagram

### 3.1. Contribution of potential environmental impacts

Global warming potential (GWP) refers to the warming (relative to CO<sub>2</sub> eq.) when chemicals are contributing to this effect by trapping the Earth's heat. The GWP equivalent emission factor calculates the impact value for global warming effects (global climate change) in OpenLCA. Based on the results of the calculation presented in Table 8, it can be seen that the parameters that have the potential to cause GWP are the number of carbon dioxide in the air generally.

Acidification is expressed in units of kg SO<sub>2</sub> equivalent to air. This impact occurs due to SO<sub>x</sub> and NO<sub>x</sub> emissions from burning fossil fuels in the air. Acidification is an indirect effect of acid rain. Acid rain occurs due to rainwater, dew, and snow has low acidity, usually expressed in pH. Emissions such as SO<sub>x</sub> and dissolved NO<sub>x</sub> can cause acidification. Based on Figure 4 it can be seen that the most significant impact of acidification is caused by Nitrogen monoxide.

Eutrophication is expressed in kg equivalents PO<sub>4</sub><sup>3-</sup> into water (kg PO<sub>4</sub><sup>3-</sup>eq.). This impact causes excessive plant growth in the waters due to increased nutrients. The types of nutrients that cause eutrophication are nitrogen and phosphorus. The presence of these nutrients is increase the primary productivity of water. The presence of water algae will absorb nutrients that will be needed by animals and aquatic plants. When dead, the algae will sink and decomposed by bacteria. The decomposition process will require a large amount of oxygen. As a result, the amount of oxygen in the waters decreased and kill a number of water organisms such as fish and other aquatic plants.

The characteristic of eutrophication which can be seen is when the water color turns into green, yellow, brown, even red and cloudy. This impact causing a decrease in metabolism, aesthetics, and economy of water. Based on Table 7, the biggest impact of eutrophication produced by Nitrogen oxide parameters is 0.728 kg PO<sub>4</sub><sup>3-</sup>eq. The forming of Nitrogen oxide is caused by the oxidation of nitrogen compounds contained in waste and nitrogen fixation

in the atmosphere. The conversion process of nitrogen content in waste occurred at relatively low temperatures (<1,090 °C), while nitrogen fixation in the atmosphere occurred when it reaches a higher temperature. In general, incinerators work at relatively lower temperatures, so according to [9] around 70-80% of the nitrogen oxide formed is influenced by the Nitrogen content in the waste.

Emissions of several substances (such as heavy metals) can have an impact on human health. The specific factors are expressed as Potential Human Toxicity. The impact of this category is expressed in units of kg 1.4 dichlorobenzene equivalent to air and water (kg 1.4 DB eq.). Some parameters released into the air are: Nickel, Arsenic, Cadmium, Lead, and Particulates Matter (PM). The parameter was released into water such as: vanadium ion, antimony, selenium, barium, and so on, giving a global impact, which states human toxicity. Based on Table 8, it can be seen that Cadmium and Arsenic most dominantly produces the impact of Human toxicity. According to [9] the amount of these emissions, especially for PM parameters is influenced by the characteristics of the waste, the design, and operation of incinerators. The combustion of non-combustible waste was released as flue gas during combustion. Combustible waste that is burned produces solid fly ash particles.

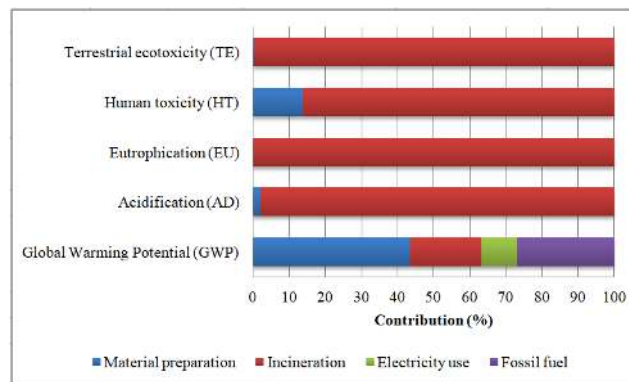
Toxicity measures for mammals (especially rodents) were used to represent potential side effects for organisms living in terrestrial environments from exposure to toxic chemicals. Impact values are based on the identity and amount of toxic chemicals such as its output into air and surface water. Impact characterization is based on the danger value of chronic poisoning combined with the amount of inventory. This category is expressed in units of kg 1.4 dichlorobenzene equivalent (kg 1.4 DB eq.). Based on Table 8, it can be seen that the parameter which has the most potential to cause this impact was Mercury. Some metals that contribute to this impact came from the sources of waste used such as paper, newspapers, wood, metal debris and so on. According to EPA 1996, several types of metals such as Arsenic, Cadmium, Chromium, and Lead are usually associated with particulate matter (PM), while Mercury is in steam.

**Table 7.** The results of the analysis of potential impact values with the OpenLCA software and the Ecoinvent database

GWP (kg CO <sub>2</sub> eq.)	AD (kg SO <sub>4</sub> eq.)	EU (kg PO <sub>4</sub> <sup>3-</sup> eq.)	HT (kg 1,4-dichlorobenzene)	TE (kg 1,4-dichlorobenzene)
1.3E+00	3.9E-03	7.1E-01	1.2E+00	6.1E-02

**Table 8.** Value of potential impact categories

Potential Impact	Category	Value	Unit
Global Warming Potential (GWP)	Carbon dioxide	6.7E-01	kg CO <sub>2eq</sub>
	Carbon dioxide, fossil	4.1E-01	
	Carbon dioxide, biogenic	8.9E-02	
Acidification	Nitrogen monoxide	2.1E-03	kg SO <sub>4eq</sub>
	Sulfur dioxide	1.0E-03	
	Nitrogen oxide	7.1E-04	
Eutrophication	Nitrogen oxide	7.2E-01	kg PO <sub>4</sub> <sup>3-</sup> <sub>eq</sub>
	Others	1.4E-03	
Human toxicity	Arsenic	5.1E-01	kg 1,4-dichlorobenzene
	Cadmium	3.6E-01	
	Nickel	4.3E-02	
Terrestrial Ecotoxicity	Mercury	4.5E-02	kg 1,4-dichlorobenzene
	Chromium	1.2E-02	
	Arsenic	2.7E-03	



**Figure 3.** The contribution of the environmental impact in ISW processing becomes densified RDF

### 3.1. Alternative handling of impacts

Based on the previous analysis, it has been known that the contributors to the environmental impact of densified RDF are the process of controlling flue gas incineration. Some alternatives that can be used to reduce the number of emissions produced during the incineration process are: Electrostatic Precipitator (ESP) and Spray dryer / Electrostatic precipitator (SD / ESP) (Table 9).

**Table 9.** Sensitivity analysis

Parameter	ESP	SD/ESP
GWP	99.7%	99.8%
Acidification	88%	88%
Eutrophication	29.9%	29.9%
Human toxicity	87.6%	89.2%
Terrestrial ecotoxicity	94.8%	94.3%

Indications for improvement through SD / ESP are recommended by [9] where the flue gas handling technology is most commonly used in the United States. This technology is able to produce dry products, to avoid the production of new wastewater. The ash from this handling can be reused, and one of them was reused as RDF. This indication of improvement was still not able to prevent the potential for eutrophication, so further handling is needed to minimize these impacts.

According to the potential calorific value produced by densified RDF, when adjusted to the Tanner diagram [24], it can be burned without using additional fuel. The choice of using biofuels needs to be considered because the price is still relatively expensive. An indication of the handling of the impact of eutrophication that already exists is through the control of aquatic sediments and the use of green belts in waters. Offering indications of improvement still require more in-depth studies to find out more detail of the emission reductions can be achieved.

### 3.3 Economic Evaluation

RDF technology for waste processing also has problems in terms of costs. The application of RDF technology has a high investment cost compared to other biomass conversion technologies such as pyrolysis and gasification. Economic analysis that will be taken into account in this discussion are initial investment costs, operational costs, and benefit costs. This waste treatment system is expected to be able to operate for 25 years. Transportation costs are not taken into account because the waste treatment unit is assumed to be in the location of PIAT UGM. , The assumption of interest rate, used 12%.

#### a. Investment cost

The planned investment period will be charged in the first five years of installation. The initial investment costs include the cost of procuring dRDF processing equipment, installation costs, and the value of the land needed to build a waste treatment plant. The value of these costs is generally obtained from the data of PT. Indocement Cirebon and several other supporting data (Table 10).

#### b. Cost benefits

This shows all the positive benefits that will be felt by the general public with the renewal of municipal solid waste processing with dRDF technology (Table 11). These benefits include:

1. Saving Cost from the substitution of coal into RDF alternative fuel. The current coal price (with moderate to high calorie) is IDR. 1.260.000 per ton and the price of RDF alternative fuel is adjusted to the European RDF price standard of IDR. 1.333.300 per ton, so there is a saving cost of IDR. 73.300 per ton.
2. Increasing the quantity and quality of RDF production through renewing waste processing into dRDF is expected to be able to produce alternative fuels to replace coal with a ratio of 0,669 (calculated from PT Indocement RDF 3.883 kCal/kg compared to 5.800 kCal/kg coal).
3. Saving costs from the addition of landfill needs, amounting to 0,4 ha per year (assuming 6 ha of land is full within 15 years). The price of land around the landfill area is assumed to be IDR 4.000.000.000/ha.
4. Reducing groundwater pollutants arising from waste.
5. Revenues are obtained from the sale of RDF alternative fuels and fertilizers. Fertilizer prices are adjusted to the highest retail price of subsidized fertilizers based on Permentan No. 60 / Permentan / SR.310 / 12/2015, IDR5000 per kg.

In reality, the benefits that arise may not only be that but also in the rising of risk reduction because the waste in this study has not been taken into account.

**Table 10.** Investment cost

Material	Quantity	Price of Material (IDR)
RDF equipment	1 set	1,382,012,852
Incinerator	1 unit	400,000,000
Water pump	1 unit	14,000,000
Water tank	1 unit	6,700,000
Pipe instalation	10 m	13,341,000
Drying Equipment (Greenhouse)	120 m <sup>2</sup>	159,576,000
Civil Installations (28 m x 40 m)	1 unit	560,000,000
Land Value (28 m x 40 m)	m <sup>2</sup>	2,240,000,000
<b>Total</b>		<b>6,157,642,704</b>

**Table 11.** Cost benefit

Parameter	Unit	Unit price	Total benefit (yr)
<b>Output</b>		IDR	IDR
RDF (ton/yr)	492,77 48 day	1,333,300/ton	31,536,492
Fertilizer (ton/yr)	905,59x48 day	5,000/kg	217,341,600
<b>Cost benefit</b>			
Saving cost (ton/yr)	330x 48day	1,260,000/ton	19,860,751
Land (landfill) (ha/yr)	0.4	4,000,000,000/ha	1,600,000,000
<b>Total Benefit</b>			<b>1,868,738,843</b>

#### c. Operations and Maintenance Costs (OM)

These operational and maintenance costs are all costs needed for the operation and maintenance of the RDF technology project. The project operation is carried out for two shifts, 8 hours per day, and 300 work days per year. Details of OM costs are in accordance with Table 12 below.

**Table 12.** Operations and Maintenance Costs

Parameter	Quantity	Unit Cost (IDR)	Total (IDR)
Maintanance	twice/ yr	50,000,000	200,000,000
Labor cost	12 month		178,392,000
Electricity cost	500 kW/hr	1,700	40,800,000
Fuel	123,19	10,000	59,131,200
Starch	23,47 kg/w	20,000	22,531,200
Calcium Hydroxide	7,51 kg/w	290,000	104,539,200
Material	12 month		31,862,100
Operational	12 month		10,750,000
<b>TOTAL</b>			<b>648,005,700</b>



The results of economic analysis can be seen in Table 13.

**Table 13.** Results of economic analysis

Parameter	Value
BCR	1.21
NPV	2,523,752,167
IRR	21.62%
Discount factor	<20%
BEP unit:	
dRDF (tons)	3.78
Fertilizer (tons)	6.95
BEP (IDR)	25,781,328.59
BEP profit (IDR)	586,869,448.7

The B / C value can be interpreted that for every 1 rupiah invested in a project, it will receive a net savings of IDR 1.21. The allowable interest rate is <20%. If the interest rate is lower, then the ISW processing becomes densified RDF will be more feasible to run. The NPV calculation results showed a

#### 4. CONCLUSIONS

An LCA study of ISW treatment to produce densified RDF in PIAT UGM has been conducted in the present study. The energy potential that could be generated from inorganic waste is around 162,62 MWh / year. The implementation of WtE in PIAT UGM by producing densified RDF lead the highest thermal energy, which is around 6,371.52 MJ. It was also found that the composition of waste affects the potential of thermal energy can be generated.

LCA simulation was used to evaluate the environmental impact of ISW processing to produce densified RDF. The global warming potential value reaches 1,3 kg CO<sub>2</sub> eq. Acidification potential 3.9E-03 kg SO<sub>4</sub> eq., and eutrophication of 7.1E-01 kg PO<sub>4</sub> eq. On the potential impact of human toxicity and terrestrial ecotoxicity, each of them is 1.2E+00 kg 1,4-dichlorobenzene eq., and 6.1E-02 kg 1,4-dichlorobenzene eq., respectively. The potential for environmental impacts is predominantly caused by densified RDF incineration which is needed to convert the RDF to energy. One of the efforts that can be conducted in order to reduce the environmental impacts of densified RDF production is by installing a spray dryer/electrostatic precipitator in the exhaust line of the incinerator.

The densified implementation of RDF in the UGM PIAT is economically feasible. The results of BCR analysis produce BCR values of 1.21 (more than 1) with an interest rate of <20%. The results of the NPV analysis are valued at IDR. 2.523.752.167 (NPV> 0 and positive) for the 25-year analysis period. IRR value was obtained 21,62%, the balance of income and expenditure was achieved when dRDF

positive value and more than zero (NPV> 0), it can be concluded that ISW processing investment into dRDF is feasible to run. To be able to operate under BEP (zero profit), PIAT UGM must be able to produce 3,78 tons of dRDF / week at a price of IDR. 1.333.300 per ton and 6,95 tons of compost/week at a price of IDR. 5.000.000 per ton.

Real conditions in the field indicate that the amount of waste collected in UGM PIAT is still much lower than that (1427,27 kg). The limitation of garbage collection in the PIAT UGM related to the composition of waste received is one of the obstacles to be able to achieve BEP production and profit. So far the composition of waste that can be received by UGM PIAT is more dominant in organic waste. If not achieved, the waste will be immediately disposed of into landfills. BCR, NPV, IRR and BEP values can be achieved when consumers from RDF are clear. In this study, the consumer target is assumed to be a cement factory, as in the PT Indocement Cirebon BUMDES.

production reached 3,78 tons and compost 6,95 tons per week with a total income of IDR. 39.803.403.71.

#### ACKNOWLEDGMENT

This study was funded by "Dana Hibah" Graduate School Universitas Gadjah Mada. The authors would also like to thank Pusat Inovasi Agroteknologi (PIAT) UGM, PT Indocement Cirebon for their valuable inputs to this study. We would also like to acknowledge funding support from UGM PDUPT research grant with contract no. 128/UN1/DITLIT/DIT-LIT/LT/2018.

#### REFERENCE

- [1] Balogun B. Energy Recovery Possibilities From Municipal Solid Waste, In Lagos, Southwest Nigeria. Thesis. Lappeenranta University of Technology. 2017.
- [2] Baumann H, and Tillman AM. The Hitch Hiker's Guide to LCA, Student Literatur, Poland:Dimograf; 2014.
- [3] Branchini L. Waste to Energy, Municipal Waste Overview. DOI 10.1007/978-3-319-13608-0\_2. 2015.
- [4] IPCC. Emissions from waste incineration, [www.ipcc-nggip.iges.or.jp/.../5\\_3\\_Waste\\_Incineration.pdf](http://www.ipcc-nggip.iges.or.jp/.../5_3_Waste_Incineration.pdf) . 2007.

- [5] Caputto AC, dan Pelagagge PM. RDF Production Plants: I Design and Cost. Applied Thermal Engineering, 2002;22:423-437.
- [6] Daskalopoulos E, Badr O, Probert, SD. Municipal Solid Waste: A prediction methodology for the generation rate and composition in the European Union countries and the United States of America: Resources. Conservation, and Recycling. 1998;24:155-166.
- [7] Demirbas A, and Sahin A. Evaluation of Biomass Residue 1. Briquetting Waste Paper and Wheat Straw Mixture. Fuel Processing Technology. 1998;55:175-183.
- [8] EPA. Waste Management Hierarchy and Homeland Security Incidents, <<https://www.epa.gov/homeland-security-waste/waste-management-hierarchy-and-homeland-security-incidents>>. 2016. (Accessed 30 Maret 2017. Pkl. 23.30 WIB).
- [9] EPA. Fifth Edition, Volume I Chapter 2: Solid Waste Disposal. <<https://www3.epa.gov/ttn/chief/ap42/ch02/index.html>>. 1996. (Accessed 10 Oktober 2017).
- [10] Feo GD and Malvano, C. The Use of LCA in Selecting the Best MSW Management System. Waste Management. 2009;29:1901-1915.
- [11] Gendebien A, Leavens A, BlackmoremK, Godley A, Lewin K, Whiting KJ, and Davis R. Refuse Derived Fuel, Current Practice And Perspectives. Final Report. 2003. Juli 2003.
- [12] Indocement. Laporan Pemanfaatan RDF di Indocement. PT Indocement Tunggal Prakarsa Tbk., Bogor. 2015.
- [13] IPCC. *Emissions from waste incineration*, [www.ipcc-nggip.iges.or.jp/.../5\\_3\\_Waste\\_Incineration.pdf](http://www.ipcc-nggip.iges.or.jp/.../5_3_Waste_Incineration.pdf) 2007.
- [14] Kiss I, and Alexa V. *Short Introspection regarding The Sawdust Briquetting As Sustainable Solution For The Environment*. Analecta. 2010; 8(2): 2064-7964.
- [15] Kilgroe JD, Finkelstein A, Sommerlad RE, dan Seeker WR. Environmental Characterization Of Refuse Derived Fuel Incinerator Technology, <<http://www.seas.columbia.edu/earth/wtert/sofos/nawtec/1988-National-Waste-Processing-Conference/1988-National-Waste-Processing-Conference-38.pdf>> 1988. (Accessed 28 Februari 2017).
- [16] Kourkoumpas DS, Karellas S, Kouloumoundras S, Koufodimos G, Grammelis P, dan Kakaras E. Comparison of Waste-to-Energy Processes by Means of Life Cycle Analysis Principles regarding the Global Warming Potential Impact: Applied case Studies in Greece, France and Germany. Waste Biomass Valor. 2015; 6:605-621.
- [17] Khoo HH. *Life Cycle Impact Assessment of Various Waste Conversion Technologies*’, Waste Management. 2009; 29:1892-1900.
- [18] Li Y, Liu H, and Zhang O. High-pressure compaction of municipal solid waste to form densified fuel. Fuel Processing Technology.2001;74:81-91.
- [19] Nithikul J. *Potential of Refuse Derived Fuel Production from Bangkok Municipal Waste*, Thesis, School of Environment Resource and Development Asian Institute Of Technology.2007;3: 43.
- [20] Psomopoulos CS, Bourka A, Themelis NJ. Waste-to-energy: a review of the status and benefits in USA. Waste Manage. 2009; 29:1718–1724.
- [21] Sedpho S, Sampattagul S, Chaiyat N, and Gheewala SH. Conventional and exergetic life cycle assessment of organic rankine cycle implementation to municipal waste management: the case study of Mae Hong Son (Thailand), Int. J. Life Cycle Assess. 2017;22:1773-1784.
- [22] Sokhansanj S. The effect of moisture on heating values. Biomass Energy Data Book.2011.
- [23] Song Q, Wang Z, Li J, Duan H, Yu D, and Liu G. Comparative life cycle GHG emissions from local electricity generation. Renewable and Sustainable Energy Reviews. 2018;81:2450-2459.
- [24] Tanner VR. Die Entwicklung der Von-Roll-MÄ1=4llverbrennungsanlagen (The development of the Von-Roll incinerators), Schweiz Bauzeitung.1965; 83: 251–260. <<http://dx.doi.org/10.5169/seals-68135>>.