Life Cycle Assessment of Refuse Derived Fuel (RDF) for Municipal Solid Waste (MSW) Management: Case Study Area Around Cement Industry, Cirebon, Indonesia

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Abstract. Life Cycle Assessment (LCA) is a useful tool to evaluate the environmental impact of Municipal Solid Waste (MSW) processing. Here, a BUMDES (village owned enterprise) converted MSW to Refuse Derived Fuel (RDF) in the area around a cement plant in Cirebon, Indonesia. The RDF that is produced is used as a partial substitute fuels for the kiln in the cement industry. The purpose of present study was to evaluate the environmental impacts of RDF production through an attributional LCA study. The results were compared with the current practice of MSW treatment system. The waste management system that will be compared includes RDF and direct combustion. LCA simulation was conducted in the OpenLCA software, which is equipped with ecoinvent database as well as primary data from the field. The company treated about 2,259.96 kg of waste day. The results showed that the production rate of RDF is about 966 kg / day. The analysis shows that the conversion of combustible municipal solid waste into RDF is more environmentally friendly than direct combustion with environmental impacts as follows: GWP 8.40E-01 kg CO₂ eq., Acidification 4.36E-04 kg SO₂ eq., Eutrophication 7.18E-04 kg PO₄ eq., ODP 3.59E-09 kg CFC-11 eq., And Human toxicity 2.27E-01 kg 1.4 dichlorobenzene eq. The use of RDF as a substitute fuel for the cement industry is economically advantageous if: there are no restrictions on processed waste, the RDF product sales to the cement industry is ensured, and the RDF product price should be economically viable. The initial investment costs and high operating as well as the maintenance costs could be a challenging issue when dealing with MSW processing to RDF.

Keywords: LCA, RDF, Municipal Solid Waste.

1. Introduction

It is generally accepted that waste management in Indonesia is still a problematic issue as most of the cities only rely on final disposal method. There has been huge controversy on the current practice of waste management system due to limited capacity of existing landfills. Open dumping system is implemented as a result of poor practice of 3R (Reduce, Reuse and Recycle) and the absent of large scale WtE in Indonesia. The situation becomes more complex due to inadequate public funding as well as the unqualified human resources. Based on the hierarchy of waste management, the open dumping system such as landfills should be placed as the last option for waste handling below 3R (reduce, reuse and recycle) and waste to energy (WtE) technology. At least there are 5 waste management systems that are better than open dumping, i.e.: Recovery, Recycle, Reuse, Reduce, and Prevention. One form of material recovery systems is waste conversion which can be used as fuel, better known as Waste to Energy (WtE) that includes waste incineration and Refuse Derived Fuel (RDF).

The implementation of WtE usually utilizes waste with high potential heating value, such as inorganic waste (plastic, paper, wood, rubber, and textiles) with several processing. Cement industry is an industry that has the potential to receive benefit from waste management. It may utilize waste as a substitute for fossil fuels as the main energy source in the kiln. Based on the Climate Change initiative in Indonesia (known as RAN-GRK), cement industry is one of the priority sectors involved in planning...
and implementing GHG emission reductions along with metal industry. Based on Olivier et al., 86% of the CO₂ emissions of the cement industry in China are generated from burning fossil fuels during the production process. In producing 1 ton of cement, the process yields around 0.83 tons of CO₂ with 80% clinker factor. The emission is 0.45 tons CO₂ from calcination; 0.28 tons from coal burning, and 0.1 tons from power plants for operational purposes [2]. Based on the European Commission in 2010, cement industry is recorded as the industry with a huge amount of fuel needs. CEMBUREAU (1999) stated that 40% of the total operational costs of the cement plant were spent on energy procurement. The increase in global CO₂ emissions indicates that the using of fossil fuel is increasing. Whereas, the main environmental problem associated with cement production is emissions.

Cirebon Regency is one of the growing municipals in Indonesia which struggles to find a new land for new landfill since 2006. Since 2002, the cement industry in Cirebon is committed to reduce emissions and control the environmental impacts caused by cement production process through ISO 14001. One of the focuses in the implementation of ISO 14001 is through substitution of fossil fuels with Refuse Derived Fuel (RDF) as well as the embodiment of the recovery material system in the triangle of waste management hierarchy. The potential of waste in Cirebon Regency is around 1,426 tons / day with the target of RDF consumption is reaching 360 tons / day. For the time being, the actual consumption of RDF at PT Indocement is still limited which is obtained from village owned enterprise who processed waste to RDF from the surrounding village, i.e.: Ciwaringin, Kedung Bunder, Gempol, Palimanan Barat, Cikeusal, and Cupang. The use of RDF as a substitute for fossil fuels in kilns is incorporated with Program Kampung Iklim (ProKlim) as stated in the The Ministerial Decree of Environment and Forestry Year 2012 Number 19.

The purpose of this study was to compare the WTE-based waste conversion process based on 3 treatment system choices (open dumping, direct incineration, and Fluff RDF). Open dumping is a waste management system that has been applied for long time in Cirebon Regency. A number of villages also started to build a number of direct incineration facilities as a way to manage their waste. Fluff RDF is a scenario that is carried out by the cement industry to utilize MSW as a substitute fuel in cement production. The Life Cycle Assessment (LCA) is used to calculate and compare the environmental impacts of the three waste management systems to obtain the most appropriate and environmentally friendly system. LCA studies are carried out using the OpenLCA software and the Ecoinvent standard database.

2. Case Study Description: The Areas Around Cement Industry, Cirebon, Indonesia

Municipal Solid Waste (MSW) comes from external (customer/community) and internal (factory) activities, then processed in the form of RDF, biomass, and compost. RDF and biomass were used by the cement industry as fuel in the process of cement making, while compost is used as fertilizer for plants in the factory area. Previously, there were two waste treatment systems that had been implemented namely: open dumping, and direct incineration. Meanwhile, MSW incineration is carried out conventionally without emission control, because the incinerator used does not have an operational standard. Cement industry in Cirebon through the use of MSW is expected to reduce the quantity of MSW that is directly disposed into final disposal and use it as the substitution for fossil fuels (such as coal in kilns).

In 2008, the cement industry in Cirebon is committed to participate in improving public health by establishing a waste management unit (called BUMDES) in one of the assisted villages to produce RDF. The objectives of waste management include: addressing environmental problems caused by waste, as a role model for the community to get familiar with healthy living behavior, processing waste into useful products (compost, alternative fuels), and creating new jobs for surrounding communities. It is evident that the MSW conversion program to RDF and compost has contributed to the reduction of untreated MSW in the area around cement industry in Palimanan, Cirebon. Based on Figure 1, it could be seen that the implementation of the program has facilitated an increasing trend of RDF-compost production from 2009-2016 with the peak at 2016.
2.1. Refuse Derived Fuel

Based on Gendebien et al., (2003), RDF refers to the separation of fractions with high calorific values from the MSW separation process. RDF is produced from mechanical separation of the combustible fraction and the non-combustible fraction of solid waste, in which the combustible fraction is then chopped and granulated [9]. The type of RDF produced and used by PT. Indocement Cirebon is called fluff RDF. Fluff RDF is an alternative fuel from waste processing by separating metals, glass, and other inorganic materials. The material is processed in such a way that passes through a 2 inch square sieve screen [1] [11]. Fluff RDF production begins with separation of waste from heavy metals, glass, and other organic materials. Inorganic waste was then chopped up to 80 mm. Enumeration process done repeatedly to obtain the product size of 25 mm [5]. Fluff RDF production in BUMDES consists of 3 main stages: manual separation, secondary treatment, and tertiary treatment as described as follows:

a. Manual separation
The feed which consists of mixed MSW were manually separated to a number of groups as: organic waste, wood, and other wastes. Other wastes consist of: toxic hazardous material, glass, cans, and metals. Organic waste is further processed into compost. Other wastes are stored in typical storage. Combustible MSW such as plastic waste, paper waste, rubber waste, and textile were sent to the next step.

b. Secondary treatment
The hard combustible garbage such as plastic bottles, pipes, and the likes goes through the process of crushing and screening in stage 1. The processing at this stage involves several machines such as conveyor, screen 1, and crusher. The output of this stage is combustible solid waste in the size of ± 30 mm which has been separated from some organic waste (compost material).

c. Tertiary treatment
The final processing unit includes shredding and crushing to obtain combustible MSW with size of ± (5-10) mm. This stage involves several machines such as: shredder, screen 2, crushing 2, and crushing 3. Multilevel MSW destruction serves to destroy and flatten the size of the MSW, especially for hard waste to obtain ± 5 mm size.

3. Methods
The LCA study that we demonstrate here follows the ISO 14040 and ISO 14044 standard.

3.1. Goal and Scope
The purpose of this study is to calculate and compare the potential environmental impacts of final disposal, incineration, and conversion of MSW into RDF. The details of the goal and scope are more specifically explained in boundary system, functional unit, and assumption.

a. System boundary
The system limits used are gate to gate (Fig.2) which means that the research object used only includes:

- Scenario I: All MSW is transferred to the Kopi Luhur final disposal. This scenario takes the cost of transporting MSW into account as well as landfill emission.
Scenario 2: Burning MSW with conventional incinerators that are already in surrounding area around cement industry. Here, the waste is incinerated without any flue gas treatment process.

Scenario 3: The MSW processed into a fluff RDF with a size of 0.8 cm. The remaining organic waste is processed into compost, biomass waste will be used as alternative fuel, the remaining inert waste and paper are disposed to final disposal.

b. Functional unit
The functional unit serves as the base reference for calculations that are adjusted to the goal and scope definition. The function unit (FU) used is 1 kg of MSW feed that has been processed. Variation in quantity of waste treated, energy, and distance are considered as a part of reference flow.

c. Assumptions
Assumptions that have been taken to support this research consists of:
- The distance between the MSW collection point to the waste treatment unit is used as the basis for determining the environmental costs to be paid from the scenario 1. The distance of MSW collecting point to final disposal is about 24.8 km. The standard fare for transporting MSW is IDR 10,000 / m³.
- Electricity composition used which adjusted to Ministry of Energy and Mineral Resources National Electricity Data year 2016.
- The combustion efficiency is 50% for the incinerator.
- Mass flow and composition of treated waste based on the average MSW generation data per day (BUMDES Waste Data year 2016).
- Potential leachate resulting from waste decomposition at final disposal is not taken into account.

Figure 2. Boundary System

3.2. Inventory analysis
The inventory analysis is the second phase of LCA analysis. This stage involves the process of collecting and calculating field data. Primary data consists of MSW production and composition, while secondary data consists of data on electricity needs, water requirements, and emission factors. The field data obtained then used as a basis in building the system model of each process. System modeling is conducted using OpenLCA software and the Ecoinvent database. The basis for calculating LCI analysis is based on reference and flow units.

3.2.1. The MSW generation, composition, and characteristic.
External waste is the type of waste which come from outside of the factory (area around cement industry: ex. Palimanan Barat Village). Internal waste is the type of waste which comes from office activities and cement paper waste. Measurement of the amount and composition of MSW is carried out in accordance with SNI 19-3964-1994. The amount of MSW produced from around Cirebon industrial cement is 2,259.96 kg / day which consists of 46.32% internal waste and 53.68% external waste. The composition value is almost balanced because 26.27% of internal waste comes from cement paper waste. The composition of MSW from all sources of waste is presented in Figure 3. The potential emissions resulting from Scenario 1 were obtained from Kustiasi, et al. (2014) with the resulting emission factor of final disposal as shown in Table 1. For scenario 2, the output in the form of heat and emission potential generated from scenario 2 is calculated based on Chang Equation (Eq. 1) with emission factor as presented in Table 2.
HHV= 15410+32350H-11500S-20010O-16200Cl-12050N  \hspace{1cm} (1)

Where  \(HHV\) = Higher Heating Value in Btu/lb (Conversion of 1 Btu/lb = 2.326E-03 MJ/kg)
\(H, S, O, Cl, N\) = Percentage of representative proximate and ultimate composition of MSW (Rugg et al., 1999).

Table 1. Emission factor of final disposal

| Parameter | Value (kg CH₄) |
|-----------|----------------|
| MSW       | 0.150          |
| Organic   | 0.42-0.47      |
| Wood      | 0.013          |
| Biomass   | 0.005          |
| Foods     | 0.074          |

Table 2. Emission factor for incinerator unit in scenario 2

| 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 |
| SO₂       | 3.94E-03 |
| HCl       | 7.06E-03 |
| NOₓ       | 5.07E-03 |
| CO        | 1.94E-03 |
| CO₂       | 2.71E+00 |
| CDD/CDF   | 9.56E-09 |

Source: EPA, 1996 and IPCC, 2007

The incinerator that we used in scenario 2 is not a standardized model as it is merely a concrete building without any instrument to control the emission. As the approach in this study, we have modeled the incinerator in scenario 2 as a Horja Double Burner incinerator. The amount of fluff RDF, biomass, and compost produced in the Cirebon cement industry are calculated based on mass balance data (Table 4 and 5). The amount of electricity, fuel, water, and hauling distance for each scenario is presented in Table 3. The electricity demand for waste processing is supplied by State Electricity Co. (PLN), which comes from 59.61% of coal; 23.35% natural gas, and 17.06% of oil (Kementrian Energi dan Sumber Daya Mineral (KESDM), 2016) as shown in Table 3. The emission factors are obtained from Ministry of Energy and Mineral Resources of Republic Indonesia, 2016. Fuels are required during the combustion process of MSW (SC2). Water is needed during the direct combustion process for incinerator cooling. Standard water requirement for Horja Double Burner incinerator is ± 92 liter/min.
Table 3. Electricity, water, and hauling distance

| Process               | Scenario 1 | Scenario 2 | Scenario 3 |
|-----------------------|------------|------------|------------|
| Electricity (kWh)     |            |            |            |
| Manual separation     | -          | -          | -          |
| Secondary treatment   | -          | -          | 52.88      |
| Tertiary treatment    | -          | -          | 273.34     |
| Incineration          | -          | -          | 28         |
| Distance (km)         |            |            |            |
| Source-collecting point (km) | 2         | 2          | 2          |
| Collecting point-final disposal (km) | 24.8     | -          | 24.8       |
| Collecting point-incinerator | -      | 2          | -          |
| Fuel (l)              | -          | 564.99     |            |
| Water (l)             | -          | 623749.75  |            |

Table 4. Mass balance of fluff RDF production

| Process               | Scenario 1 | Scenario 2 | Scenario 3 |
|-----------------------|------------|------------|------------|
| Input (kg)            | Output (kg) | Input (kg) | Output (kg) | Input (kg) | Output (kg) |
| Collection point      | IW: 453.08 | 2,259.96   | EW: 1,213.15 | 2,259.96   | IW: 453.08  | 2,259.96   |
|                       | PW: 593.73 |            |             |            |             |            |
| Incineration          | -          | 2,259.96   | HHV = 24.21 MJ/kg | -          | -          | -          |
| Transport to final disposal | 2,259.96 | -          | -            | -          | -          | -          |
| Manual separation     | 2,259.96   |            | B: 644.10   | C: 156.16  | IW: 2.27   | PW: 120.21 |
| Secondary treatment   | 1,337.22   |            | C: 93.70    |           | C: 62.47   |
| Tertiary treatment    | 1,028.82   |            | B: 214.70   |           |            |

Mass balance shows the mass flow of MSW started from the input of MSW into Material Recovery Facility (MRF) to produce fuel which then transported to the kiln of Indocement Cirebon Ltd., West Java. MSW mass flow will refer to the stages: pretreatment, secondary treatment, tertiary treatment, to produce fluff RDF. The mass balance result comes from the field observation of MRF UPS BUMDES.

Table 4. Mass balance of Compost (C), Biomass (B), Inert Waste (IW), and Paper Waste (PW)

| Process               | Scenario 3 |
|-----------------------|------------|
| Input (kg)            | Output (kg) |
| Collection point      | IW: 453.08 | 2,259.96   |
|                       | EW: 1,213.15 |            |
|                       | PW: 593.73 |            |
| Manual separation     | 2,259.96   | B: 644.10  |
|                       |           | C: 156.16  |
|                       |           | IW: 2.27   |
|                       |           | PW: 120.21 |
| Secondary treatment   | 1,337.22   | C: 93.70   |
|                       |           | B: 214.70  |
| Tertiary treatment    | 1,028.82   | C: 62.47   |

The impact categories that have been investigated in this study are: Climate Change caused by CO2, CH4, N2O etc; Acidification caused by SO2, NOx, HCl, and NH3; Ozone layer depletion caused by Ozone-Depleting Substances (ODS); Human toxicity potential caused by several emissions such as heavy metals; Freshwater aquatic ecotoxicity potential caused by a number of particulates such as PM10 released into fresh waters. The selection of these environmental impacts is based on the needs of the analysis as well as the dominance of the emissions included in the impact category. The method for evaluating the impact of this study uses the Center for Environmental Studies (CML) baseline from the Institute of Environmental Sciences, Leiden University. The baseline CML method is one of many databases containing characterization factors for life cycle impact assessment (LCIA). CML baseline method is one of many databases containing characterization factors for life cycle impact assessment (LCIA). Normalization and weighting processes uses the World 2000 standard. The calculation of the impact involves Ecoinvent standard database system quality. The aim of this stages is to classify and assess significant environmental impacts. Impact categories are selected based on the chosen focus of
study. In this study, the impact analysis consists of characterization impact assessment and single score impact assessment.

4. Result and Discussion

4.1. Life Cycle Impact Assessment (LCIA)

The OpenLCA software and Ecoinvent databases are used to calculate and determine environmental impacts. The methods offered in this software are complete, including: characterization, normalization, and weighting. The results of the potential environmental impact analysis of open dumping, incineration, and the implementation of fluff RDF for MSW in UPS BUMDES are shown in Table 5.

In general, fluff RDF produces lower impact potential than open dumping and direct incineration. Converting MSW to RDF Fluff resulted in lower potential impacts and better quality of solid waste fuel (in terms of HHV). In other words, Fluff RDF scenario is better than open dumping and incineration. It is important to note that scenario 3 produces the main product of Fluff RDF and side products such as compost and biomass. Processing organic waste into compost can reduce the rate of waste output that is discharged to final disposal, as well as the rate of waste decomposition which resulted in the increasing of CH4 emissions as a result of organic matter decomposition. These results are in accordance with Kustiasi et al. (2014) and Suprihatin et al. (2008) who stated that compost production per ton can reduce 0.21-0.29 tons CH4 emissions. The side product of biomass is also useful as auxiliary fuel by Cirebon cement factory. The type of biomass obtained is mostly in the form of rice hulls. Comparison of heat potential from coal, RDF and biomass fluffs is in accordance with Figure 4. Coal has the highest energy potential than alternative fuels (Fluff RDF and rice husk). Fluff RDF and biomass can substitute fuel requirements of Plant 9-10 up to 382 tons/day (53% of target). Heating value of fluff RDF is about 3883 kcal/kg (67% of coal), whereas the total substitution of heat consumption is about 7%.

![Figure 4. Coal, RDF and Rice Hull Comparative](image)

Table 5. Life Cycle Impact Assessment

| Scenario     | GWP   | EU    | AD    | HT    | ODP   |
|--------------|-------|-------|-------|-------|-------|
| Open dumping | 8.36E+00 | 7.36E-04 | 5.75E-04 | 2.32E-01 | 1.92E-08 |
| Incineration  | 1.84E+00 | 1.13E-03 | 4.84E-03 | 2.03E+00 | 1.75E-07 |
| Fluff RDF    | 8.40E+01 | 7.18E-04 | 4.36E-04 | 2.27E-01 | 3.59E-09 |

Global Warming Potential (GWP) is caused by gases of CO2, CH4, N2O and others, which commonly expressed in the unit of kg CO2 eq. Converting MSW to RDF, biomass, and compost can reduce the rate of waste output at final disposal. In addition, this process may also reduce land use for final disposal. In MSW management system, the gases are obtained from the decomposition. The lowest GWP value is from the Fluff RDF scenario in comparison to scenarios 1 and 2. It could be inferred that the open dumping scenario produces the highest GWP value.

The open dumping system only puts waste in the final disposal openly. The open dumping system is implemented as a result of the low level of MSW collecting and funding, in addition to the limited qualified human resources. The disadvantages of the open dumping system include: triggering the increasing of greenhouse gases such as CH4, becoming a hotbed of disease, and producing leachate that can pollute the surrounding water and soil. Meanwhile in scenario 2, emissions arise due to the absence of emission control system in the incinerator. Eutrophication potential (EU) is an indirect impact that caused by PO43-, P, N, H2PO4, so on. This is stated in the impact category with equivalence kg PO43- eq. in water (kg PO43- eq.). The characteristics of eutrophic waters are green, yellow, brown, even red, and turbid. This impact can cause the decreasing in water metabolism, aesthetics, and economical. Scenario 3 produces the lowest eutrophication potential than Scenarios 1 and 2. Burning MSW with a
conventional incinerator that does not have an air control system can disperse emissions into the air, up to a certain time when these emissions settled, for example at raining time. Sediment of emission then will cause the increase of nutrients which further can enhance the primary productivity of waters. The presence of water algae will absorb nutrients needed by aquatic animals and plants. Furthermore, algae will sink when it die, then being decomposed by bacteria. The decomposition process requires oxygen in large quantities. As a result, the amount of oxygen in the water will decrease and kill aquatic organisms such as fish and aquatic plants.

Acidification potential is caused by SO₂, NOₓ, HCl, and NH₃ and is an indirect effect of acid rain. This impact category is expressed in units of kg SO₂ equivalent to air (kg SO₂ eq.). Scenario 3 produces the lowest acidification potential while scenario 2 still produces the highest potential impact. The concentration of Nitrogen monoxide and Sulfur dioxide compounds is related to the content of N and S elements in burned MSW. Obviously the contents will vary according to the variation of burned MSW. Emissions from heavy metals can cause adverse effects on human health. This potential impact is expressed in units of kg 1.4 dichlorobenzene equivalent to air and water (kg 1.4 DB eq.) It can be caused by several emissions such as: Nickel, Arsenic, Cadmium, Lead, and Particulates Matter (PM) released into the air. In Scenario 2 which produces the highest emissions, it can be caused by MSW which still in mixed conditions which allows some metal-containing waste to be burned, because this scenario is not preceded by a stage of separation. Ozone depletion potential is caused by CFC, HCFC, Halon, CCl₄, CH₃Br, CH₃Cl, and others. This effect can damage ozone layer, reduce the ability of ozone to absorb ultraviolet (UV) rays that enter the atmosphere, so that increasing the amount of carcinogenic UVB that reach the earth's surface. This potential impact is relatively very small for each scenario.

4.2. Interpretation

Interpretation of the result is the final stage in LCA study before making any decisions and planned activities. Systematically, the process of converting MSW into RDF Fluff is analyzed based on inventory data and the results of impact analysis. The results will draw conclusions and recommendations for improvement according to the desired objectives in accordance with ISO Standard 14040. The analysis of data interpretation in this study uses the method of contribution analysis and results improvement methods. The advantage of contribution analysis method is to characterize the supply chain process, so that the most significant contributor is acquired to the potential impact of the cycle (EPA, 2011). Contribution analysis can also be used to determine energy usage that contributes to the impact indicator (Mery et al., 2013). In this study, the contribution analysis aims to find out the process that provide the greatest contribution in potential impact accompanied by an analysis of improvements, so that it is able to provide recommendations for improvement in the process of converting MSW into fluff RDF in the end.

4.2.1. Hotspot identification

In general, the impact contributors if being ranked from the most dominant are coming from external waste, internal waste, waste paper cement, electricity usage, and transportation to final disposal. Figure 5 shows the contributors to each potential impact. The sensitivity simulation results show that at distances up to 200 km, the potential impact value does not significantly increasing. When the distance is 24.8 km (the same distance as final disposal), the potential impact is also far from the potential impact value of Scenario 1 (Table 5). From these values, it indicates that with the same distance as final disposal, processing MSW into Fluff RDF is more environmentally friendly than open dumping. It is also possible to use MSW from areas far from BUMDES.
Figure 5. Hotspot identification: a) Global Warming Potential; b) Acidification Potential; c) Eutrophication Potential; and d) Human Toxicity and e) Ozone Depletion Potential.

Table 6. Sensitivity analysis of distance.

| Distance (km) | GWP (kg CO\textsubscript{2} eq.) | EU (kg PO\textsubscript{4}--eq.) | AD (kg SO\textsubscript{2}--eq.) | HT (kg 1.4-dichlorobenzene eq.) | ODP (kg CFC-11 eq.) |
|--------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|---------------------|
| 2            | 8.40E-01                      | 7.18E-04                      | 4.36E-04                      | 2.27E-01                      | 3.59E-09            |
| 24.8         | 8.41E-01                      | 7.20E-04                      | 4.50E-04                      | 2.28E-01                      | 3.90E-09            |
| 200          | 8.54E-01                      | 7.40E-04                      | 5.10E-04                      | 2.33E-01                      | 6.30E-09            |
| 500          | 8.75E-01                      | 7.60E-04                      | 6.20E-04                      | 2.41E-01                      | 1.04E-08            |

4.2.2. Economic Analysis.

Fluff RDF technology for waste processing usually has constraints in terms of high investment costs. The application of RDF technology requires high investment cost compared to other biomass conversion technologies such as pyrolysis and gasification. Economic analysis that needs to be taken into account in this discussion are: initial investment costs, operational costs, and benefits costs. Benefits to be gained from RDF are biomass, compost products, as well as the saving of land use for open dumping. The planned investment period is for the life span of the machines for 20 years at an interest rate of 15%. Benefits that arise in this initial investment include equipment costs and installation costs. The value of these costs is obtained from cement industry data.

Production of fluff RDF is beneficial if we evaluate from following factors: income generation for the community, saving costs, the need for additional land if the waste is not processed, and the opportunity cost of substituting coal with RDF alternative fuels. In reality, the benefits might be more than that, such as in the form of reducing risks arising from the presence of MSW, i.e. groundwater pollution and so on, which have not been taken into account in this study. The operational and maintenance costs are the costs that is related to the operation and maintenance of RDF processing technology. The project's operations are carried out for 2 shifts, 16 hours per day, and 300 working days per year.

Table 6 shows the economic evaluation of fluff RDF scenario. Calculation of benefits and costs incurred is calculated in the Annual Value. Based on the results obtained by a B / C ratio greater than 1, the planned MSW processing into RDF is economically feasible. The BCR value can be achieved when consumers from RDF, biomass, and compost can be guaranteed with a long-term contract. In this study, the consumer target is assumed to be a cement plant, as in BUMDES. To attract the economic aspects, there is a need to find potential suitable consumers other than the cement industry. An example of potential consumer of RDF utilization is perhaps the national electricity company PLN to produce the electricity. However, further evaluation should be conducted to evaluate the cost and incentives policy to implement this plan.

Table 6. Sensitivity analysis of distance.

| Cost             | Value             |
|------------------|-------------------|
| Investment cost  | IDR 13,245,8998.932 |
| O & M (5%)       | IDR 3,068,117.397    |
| Benefit cost     | IDR 6,137,228.800   |
| n                | 20 yr              |
| A/P              | 0.1598             |
| BCR              | 1.45               |
5. Conclusions

An LCA study to evaluate the MSW processing scenarios has been conducted by considering 3 scenarios: open dumping in the final disposal (scenario 1), direct incineration (scenario 2) and production of fluff RDF (scenario 3). It can be concluded that from the three scenarios of waste processing in the vicinity of Cirebon cement plant, processing waste into Fluff RDF is more environmentally friendly than open dumping and incineration. The analysis shows the environmental impacts of scenario 3 are as follows: GWP 8.40E-01 kg CO2 eq., Acidification 4.36E-04 kg SO2 eq., Eutrophication 7.18E-04 kg PO4 eq., ODP 3.59E-09 kg CFC-11 eq., And Human toxicity 2.27E-01 kg 1,4 dichlorobenzene eq. The use of RDF as a substitute fuel for the cement industry is economically advantageous if: there are no restrictions on processed waste, the RDF product sales to the cement industry is ensured, and the RDF product price should be economically viable.

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7. References

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