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Evaluation of Waste Management Performance in Pariaman City Using Life Cycle Assessment (LCA)

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ABSTRACT

Pariaman City's waste generation in 2022 is 38.26 tons/day. Waste management in Pariaman City is still not optimal, resulting in waste piling up in TPA South Tungkal. The waste reduction value at the research location after processing with BSF larvae can reduce 0.005 tons/day or 0.02% of the total waste generation in Pariaman City. The environmental impacts in waste management studied are Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP). Reducing the environmental impact of processing organic waste has been carried out, the smallest impact reduction results were obtained, namely in scenario 1, namely processing organic waste with BSF larvae in waste banks and TPS 3R. The results obtained were the impact characterization value from comparing several impact categories. GWP value 32,060,838.136 10^3 kg CO_2-eq, AP 0.00246 $x10^3$ SO_2-eq, and EP 0.00134 $x10^3$ kg PO_4^{-3}. So it can be concluded that scenario 1 has a smaller GWP, AP, and EP impact on the environment compared to scenario 0 and is used as the best alternative scenario for waste management in Pariaman City.

Keywords: *Black Soldier Fly (BSF) Larvae; Environmental Impact; Life Cycle Assessment (LCA); Organic Waste Management.*

INTRODUCTION

The generation of waste continues to increase every year, resulting in the volume of waste at the Final Processing Site (TPA) becoming high. One of the landfills that exceeds its capacity is TPA Tungkal Selatan which is located in North Pariaman District, Pariaman City, West Sumatra Province. Based on data from the Pariaman City Strategic Plan prepared by the Pariaman City PerkimLH Service in 2020, the conditions for handling and managing waste in Pariaman City are still not optimal, resulting in waste piling up in TPA Tungkal Selatan.

Waste management in Pariaman City currently is regional scale waste management, where waste is processed at the reduce, reuse, recycle waste processing site better known as TPS 3R, then the residue is disposed of in the landfill, and city scale management is carried out from the source and then disposed of in the landfill (Lubis, 2018). Waste management carried out at the source using the 3R system can reduce the area of waste in the landfill [2]. One form of recycling in organic waste management is composting. One method that is often used and continues to be developed is composting using Black Soldier Fly (BSF) larvae. The use of BSF larvae can be used as a solution for reducing urban organic waste [3].The use of BSF larvae is used as a better decomposer of organic material compared to other organisms [4] and the use of BSF larvae can reduce organic waste by 82.87% [5].

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Based on the description above, it is necessary to evaluate the waste management performance of Pariaman City using the LCA method, so that it can improve waste management performance which is still less than optimal. Evaluation of the performance of Pariaman City's waste management is carried out on an existing or ongoing basis using the proposed scenario with the application of the BSF larvae bioconversion method carried out at the waste bank.

MATERIALS AND METHODS

Data Collection

Primary data was obtained from the results of direct measurements of waste reduction and organic waste processing activities using BSF larvae at the Sahabat Alam Waste Bank. Field research was carried out by reviewing organic waste handling activities in the Kampung Apar Village environment. This research was conducted at the Sahabat Alam Waste Bank which is located in Kampung Apar Village, South Pariaman District, Pariaman City. This waste bank has carried out waste bioconversion by utilizing the larvae of the Black Soldier Fly (BSF) or known as the Black Soldier Fly. The results obtained from the Sahabat Alam Waste Bank activities are in the form of solid compost, liquid fertilizer, and dry larvae.

Secondary data was obtained from related agencies and other sources relevant to the thesis such as waste generation and composition data, planning data, materials and equipment involved (energy and fuel requirements) SimaPro database, and related research.

As for the steps in evaluating the waste management system, several scenarios are prepared, including:

a. Scenario 0 for existing waste management,

b. Scenario 1 for organic waste management with BSF larvae.

LCA Analysis of Organic Waste Management Scenarios

The LCA research procedure consists of four stages including:

a. Definition of Goals and Scope

   The aim of this LCA study is to assess the reduction of environmental impacts from processing organic waste with BSF larvae. Meanwhile, the scope or limitations of LCA use include waste generation, collection and transportation, and final processing at TPA Tungkal.

b. Inventory Analysis input stage

   At this stage, it identifies and qualifies the flow of materials, energy, and emissions released into the environment. At this stage, data is collected that can support LCA analysis. Collecting data that can support LCA analysis, such as the amount of waste generated, and energy required over distance, as well as creating scenarios to be planned. For reference to LCA data, see Appendix A. The inventory data that will be needed is explained in Table 1 below.

Table 1. Data Inventory

Parameter	Unit
Reduction of BSF larvae organic waste	Study
Waste generation	Interview DLH
Waste Transport Route	Interview DLH
Types of Waste Transport Vehicles	Interview DLH
Transport route distance	*Google Map*
Emission Data	Simapro database, related journals

c. Impact Assessment Stage
   At this stage, an evaluation of the environmental impact is carried out using the results of the LCI and providing information for interpretation in the final phase. Next, grouping and assessment of impacts on the environment are carried out based on the data obtained at the LCI stage.
d. Interpretation Stage
   Interpretation aims to identify and evaluate information from LCI and LCIA results from four waste management system scenarios in accordance with the specified objectives and scope.

RESULTS AND DISCUSSION

Organic Waste Processing with BSF Larvae

Waste processing using BSF larvae can reduce the generation of organic waste entering the South Tungkal landfill. Organic waste in the form of fruit waste is transported by motorbike rickshaw from the source to the waste bank. After that, organic waste is sorted first, then waste that cannot be processed is thrown into the nearest container. Then the waste is chopped to reduce the size of the organic waste to make it easier for BSF larvae to degrade the waste. The life cycle of BSF can be seen in Figure 2 below.

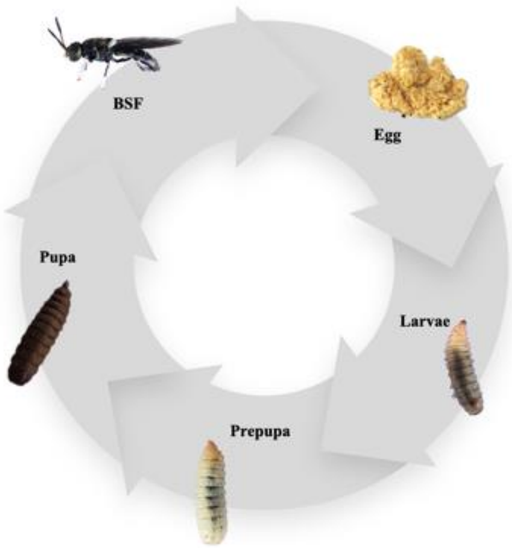

Figure 2: Life Cycle of the Black Soldier Fly

Processing organic waste into compost takes 23 days depending on the amount of waste and the number of BSF larvae because the amount of waste affects waste reduction [6]. The amount of organic waste processed at the Sahabat Alam Waste Bank is 35.91 kg or 0,036 tons. From processed organic waste, there is a reduction of around 31.45 kg of organic waste, or 87.58% of processed waste. The waste that has been converted into organic fertilizer can be reused [7].

Next, to determine the level of waste reduction / Waste Reduction Index (WRI) by BSF larvae. The level of waste reduction obtained was 0.876, while the WRI value obtained was 3.86%/day. Next, calculations were carried out for repetitions 2 and 3 for the WRI value of

BSF larvae. The calculation of the WRI value for BSF larvae during the research is explained in Table 2 below.

Table 2: WRI Value of BSF Larvae

Experiment	Initial Dry Mass (g)	Final Dry Mass (g)	Reduced Mass (g)	Degradation Value	Degradation Percentage (%)	WRI (%/day)
1	37,250	5,200	32,050	0,860	86	3,59
2	35,250	4,080	31,170	0,884	88	4,02
3	35,250	4,120	31,130	0,883	88	4,01
Average ± SE	**35,917**	**4,467**	**31,450**	**0.876± 0.008**	**87.59±0.777**	**3.86±0,144**

Waste reduction by BSF larvae in the table above shows a high average reduction percentage value. Of the total waste processed, this reduction percentage shows that BSF larvae are able to reduce organic waste by 87.59 ± 0.777%. Meanwhile, the WRI value is 3.86 ± 0.144%, indicating the ability of BSF larvae to reduce organic waste. A high WRI value indicates good reduction efficiency (Diener, Zurbrügg, and Tockner 2009).The WRI value shows the ability of BSF larvae to reduce organic waste, whereas the higher the WRI value, the higher the ability of BSF larvae to reduce organic waste [9]. Waste consumption by BSF larvae is influenced by the nutrient content of the substrate, the water content of the substrate, and the texture of the feed [10].

Waste that has been converted will become organic fertilizer that can be reused [7]. Composting time in the BSF larvae composting process until it becomes mature compost. Compost maturity indicators based on SNI 19-7030-2004 are seen in terms of texture, color, and smell which is similar to the smell of soil. The quality of the compost is seen based on changes in color, structure, and smell of the compost produced from the start of the research to the end until the compost is mature. The results of the quality of compost or residual residue from unprocessed waste are carried out by compost tests at the Solid Waste Laboratory of the Unand Engineering Department. The parameters that will be tested for compost fertilizer are Water Content, Carbon, Nitrogen, Phosphorus, Potassium, and C/N Ratio. The results of measuring the quality of solid fertilizer can be detailed in Table 3 below.

Table 3: Quality of Solid Fertilizer Experiment I, II and III

No	Parameter	Satuan	I	II	III	KepMentan No 261 Tahun 2019	SNI 19-7030-2004	
							Min	Maks
1	Kadar Air	%	28.04	25	27.26	8-20	-	50
2	Karbon	%	24.47	27.35	24.69	Minimum 15	9.8	32
3	Nitrogen	%	1.33	1.51	1.33	-	0.40	-
4	Fospor	%	0.42	0.60	0.55	-	0,10	-
5	Kalium	%	0.83	1.02	0.95	-	0,20	*
6	C/N Rasio	%	18.40	18.11	18.56	$\leq$ 25	10	20

Note: * = value greater than the minimum or smaller than the maximum

Based on the table above, physically the compost meets the SNI 19-7030-2004 quality standards, where the resulting compost is blackish in color has a smooth texture, and smells like earth. Judging from the regulations of the Minister of Agriculture Decree Number 261 of 2019 concerning Minimum Technical Requirements for Organic Fertilizers, Biological Fertilizers and Soil Improvers and SNI 19-7030-2004 concerning Specifications for Compost

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from Domestic Organic Waste, the quality value of the compost does not exceed the quality standard limit of the regulation so that the results from waste that is not processed by BSF larvae can be used as compost. After processing with BSF larvae, unprocessed waste can be used as compost [11].

In this research, we assess and compare the planned organic waste management scenarios using the LCA method. This impact analysis was carried out using SimaPro software. Based on ISO 14040, the LCA method consists of 4 stages, including the definition of objectives and scope, input analysis inventory (LCI) stage, impact assessment stage, and interpretation stage. The following are details of the stages for LCA analysis.

a. Goal and Scope Definition

The aim of this research is to analyze the environmental impacts resulting from waste management activities in several proposed scenarios and produce recommendations for a waste management system. The assessment is carried out by comparing the emissions produced by each system.

b. Life Cycle Inventory

This waste generation data is used as input for each alternative that will be prepared. Input from waste generation. Input to waste generation for each scenario can be seen in the table.

Table 4: Energy Requirements Inventory Data for Waste Management Scenario 0 and Scenario 1

Input	Unit	
	Scenario 0	**Scenario 1**
Collection and Transport		
Waste generation (ton)	38.26	38.26
Collection and Transport		
Waste generation (ton)	27.01	26.96
Energy Requirements (tkm)	3,297.9	3,291.8
Landfill		
Waste generation (ton)	27.01	26,96
Energy (MJ)	4,674.88	4,657.57

The inventory analysis stage produces a network in the form of a process diagram that occurs in each scenario. On the SimaPro 9.0 display, the network is displayed according to the inventory data that was previously input. The red line in the diagram shows the relationship between each process. The network in each scenario can be seen in the following picture

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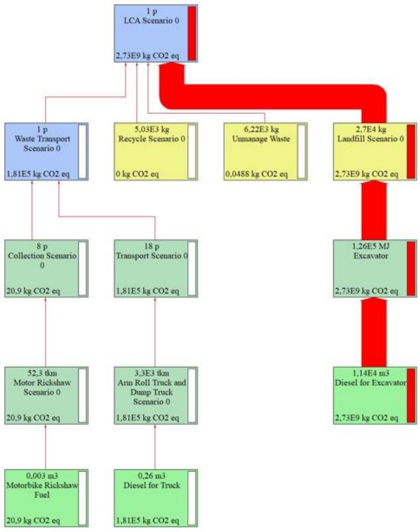

Figure 3: Network Scenario 0

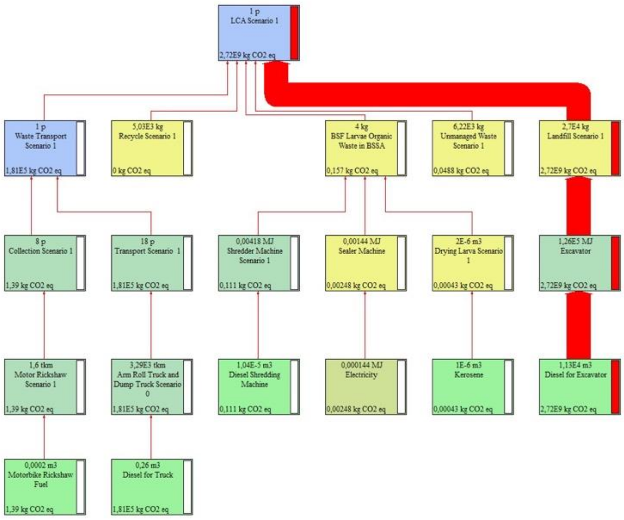

Figure 4: Network Scenario 1

Based on the network, scenario 0 has a thick red line in the landfill process, because it has a thick red line in the process. The thicker the red line, the greater the emissions produced. This process uses heavy equipment in the form of an excavator that uses diesel fuel. Diesel fuel produces CO_2 compounds and has a high greenhouse gas impact [12]. Therefore, it is necessary to pay attention to the fuel used to reduce the impact on the environment.

Life Cycle Impact Assessment

The impact assessment method used is CML-IA (baseline). This method is used because it can assess the impact on midpoint indicators well and uses the ISO 14040 standard. The impact criteria contained in the CML-IA (baseline) method are Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP). Then, grouping and assessment of the impacts on the environment are carried out in the form of classification, characterization, and normalization.

1) Impact Classification

Acidification Potential (AP), and Eutrophication Potential (EP). The GWP value, which is the main greenhouse gas that causes global warming, is CO_2 and CH_4, expressed in units of kg CO_2 equivalent, AP value, the impact of which can cause potential acidification in the environment. The compounds that contribute to AP are SO_x, NO_x, HF, and HCL which are expressed in units of kg SO_2. The EP value is the impact that causes the potential for eutrophication, namely nitrogen and phosphorus in units of kg PO_4^{3-}. Other compounds that are not PO_4^{3-}but contribute to eutrophication are equivalent to PO_4^{3-} units.

2) Impact Characterization

Impact Characterization by comparing the results of inventory analysis in each impact category and determining the magnitude of the impacts that have been classified. The impact characterization value can be explained as follows.

- Global Warming Potential (GWP)
  Scenario 0 has the highest GWP level value, namely 2,732,175,181 x 10^3 kg CO_2-eq. This is due to the failure to process organic waste, resulting in high levels of organic waste generation. Processing of exhaust gas at TPA Tungkal is not carried out so the pollutants contribute to being released into the air. Furthermore, the GWP value after scenario 1 is 2,717,020,181 x 10^3 kg CO_2-eq.

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- Acidification Potential (AP)
  In Scenario 0, the AP value has a higher AP value than the other scenarios, namely 68.192 x 103 kg SO_2 eq. After that, the AP value in scenario 1 is 67.815 x 10^3 kg SO_2 eq. The AP value in each scenario is dominated by air emissions that are exposed to the landfill process. Scenario 0 is bigger than the other scenarios because in scenario 0 the waste transported is not processed before being disposed of in the landfill.

- Eutrophication Potential (EP)
  The largest EP value is in scenario 0, namely 17.701 x 103 kg PO_4^{3-}eq, while the smallest EP value is next in scenario 1, namely 17.631 x 103 kg PO_4^{3-}eq, namely waste management with BSF larvae carried out in waste banks. Scenario 0 is the highest value for EP. This high EP value comes from waste that is dumped in landfills, resulting in large air pollutants [13].

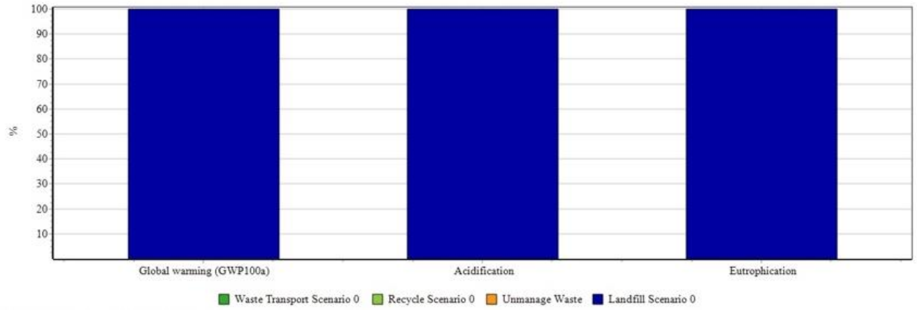

Figure 5: Impact Assesment Scenario 0

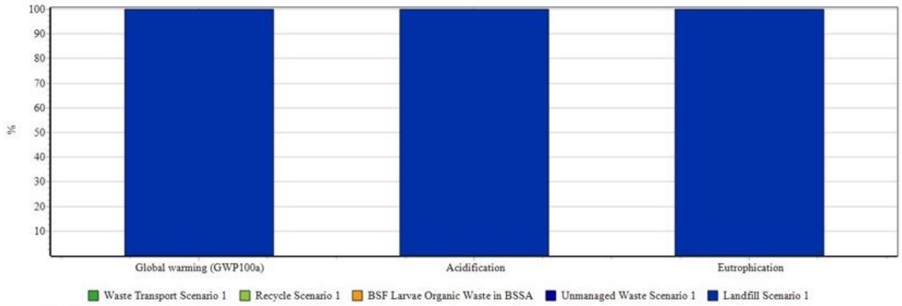

Figure 6: Impact Assesment Scenario 1

Interpretation

The interpretation stage is the final stage in LCA, with the aim of identifying, evaluating, and concluding the environmental impact analysis of the existing organic waste management system and planning scenarios for Pariaman City. Interpretation of the calculation results is used to assess the relationship between inventory data and impact assessment. Impact contribution to each alternative, then analysis is carried out to determine the alternatives.
The impact contribution consists of GWP, AP, and EP, more fully can be detailed as follows.

- Global Warming Potential
  The impact contribution value for the GWP category can be seen in Table 4.12 and Figure 4.11. The results of the impact contribution for the GWP value of the four alternatives have the largest GWP value caused by landfill activities at the landfill. The landfill process produces a greater environmental impact on global warming [14]. Apart from the landfill process, the waste transportation process also has a GWP impact, namely in scenario 0. The highest contribution of the GWP value is in scenario 0, while the lowest GWP value is in scenario 1. The emissions that really influence the high GWP value are CH_4, and CO_2. The impact contribution values and images for the GWP categories can be seen in Table 5 below.

Table 5: Impact Contribution for GWP Category

Processs	**Skenario 0**	**Skenario 1**
	($x10^3$)	
Garbage transport	181	181
Recycle	0	0
Unmanaged Waste	0.000049	0.000049
Landfill	2,732,175.67	2,717,020.07
BSF larvae organic waste management	0	0
Total	2,732,356.67	2,717,201.23

- Acidification Potential
  The results of the impact contribution to the AP value of the three alternatives have the largest AP value caused by landfill activities at the TPA. Meanwhile, other recycling processes and unmanaged waste have an AP value of scenario 0 or you could say they don't exist. In landfilling activities, the AP value for scenario 1 is lower than the AP value for scenario 0. The impact contribution value for the AP category can be seen in Table 6 below.

Table 6: Impact Contribution for AP Category

Processs	**Skenario 0**	**Skenario 1**
	($x10^{-1}$)	
Garbage transport	46.805	46.714
Recycle	0	0
Unmanaged Waste	0	0
Landfill	681,886.19	678,104
BSF larvae organic waste management	0	0.0000000083
Total	**681,932.99**	**678,150.423**

- Euthrophication Potential
  The highest EP value is for the landfill process in scenario 0. The EP value for the landfilling process in scenario 1 is a smaller value, this means that the EP value for scenario 1 is a value that has a smaller impact on the environment. The impact contribution value for the EP category can be seen in Table 7 below.

Table 7: Impact Contribution for EP Category

Processs	**Skenario 0**	**Skenario 1**
	($x10^{-1}$)	
Garbage transport	12.17	12.14557
Recycle	0	0
Unmanaged Waste	0	0
Landfill	177,290.409	176,306.964
BSF larvae organic waste management	0	0.000000000002162
Total	**177,302.58**	**176,319.11**

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Analysis of Waste Management System Improvements

Based on the impact characterization results, scenario 1 is the best alternative because it has the smallest impact value. In scenario q, organic waste is managed at a waste bank. The organic waste management carried out is processing organic waste with BSF larvae. After carrying out the LCA analysis, the planned processing process can reduce environmental impacts, in fact, there are still impacts, namely processes that use equipment that produces energy. So, it is necessary to make improvements and recommendations to reduce the impact on the environment. The recommendations for improvement proposed for this selected alternative are:

1. Waste Collection and Transport Process
   In the process of collecting and transporting waste that has an impact on the environment is the fuel used by the waste transportation equipment. The type of fuel greatly influences the emissions it produces. In addition, the distance between transportation locations results in greater emissions being released. Therefore, it is recommended to choose a closer transportation route, so that the emissions produced are also reduced. Apart from that, it is also recommended to use fuel from Arm Roll Trucks and Dump Trucks which is more environmentally friendly, such as replacing diesel with Pertamina Dex fuel. Pertamina Dex fuel has lower emissions and less fuel consumption than biodiesel and dexlite [15]. In terms of volume, Pertamina Dex is used less than diesel fuel and the usage time is found to be more time efficient compared to diesel fuel [16].
2. Waste Processing Process at the Waste Bank
   In the process of processing organic waste with larvae, a chopping machine is used which produces emissions because it is fueled by diesel. The same goes for the collection and transportation process. It is also recommended to replace the fuel for this chopping machine with fuel that is more environmentally friendly.

CONCLUSION

Processing with BSF larvae can reduce waste entering the landfill by 0.005 tons/day or 0.02% of the total waste generation in Pariaman City which is 38.26 tons/day. The amount of waste disposed of in the landfill is 27.01 tons/day without processing, causing an impact on the environment. There are 2 scenarios in Pariaman City waste management, namely scenario 0 is waste management in existing conditions, and scenario 1 is an organic waste management system using BSF larvae in the Waste Bank. Reducing the environmental impact of processing organic waste has been carried out, the smallest impact reduction results were obtained, namely in scenario 1, namely processing organic waste with BSF larvae in waste banks and TPS 3R. The results obtained were the impact characterization value from comparing several impact categories. GWP value 32,060,838.136 10^3 kg CO_2-eq, AP 0.00246 x10^3 SO_2-eq, and EP 0.00134 x10^3 kg PO4-3. So it can be concluded that scenario 1 has a smaller GWP, AP, and EP impact on the environment compared to scenario 0 and is used as the best alternative scenario for waste management in Pariaman City.

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