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Research Paper

Comparative Life Cycle Assessment for Improvement of Solid Waste Management System of Pariaman Coastal Tourism Area

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Abstract
Sustainable tourism should provide environmentally friendly solid waste management. This study aims to assess the environmental impact of the waste management system applied to the Pariaman Coastal Tourism Area using the Life Cycle Assessment (LCA) method and provide recommendations for improving an environmentally friendly waste management system. The aspects studied are limited to waste handling, waste, energy required and generated in the system's operation. The study compared two scenarios of solid waste management; the existing (scenario 1) and the proposed one (scenario 2). The study was conducted on solid waste management of 170.51 kg/day. The impact assessment method used is CML-IA. The results of impact characterization showed that the impact of scenario 1 is higher than scenario 2 on Global Warming Potential (GWP) 7.5 times and Eutrophication Potential (EP) 90.6 times, while on Acidification Potential (AP) was lower 1.6 times. Activities at landfill sites contribute the most significant impact of GWP, AP, and EP. It is recommended to choose shorter collection and transportation routes, substitute the solid waste vehicles fuel, change the power plant source for composting machine, and apply the sanitary landfill with leachate treatment and gas processing.

Keywords
Environmental Impact, Life Cycle Assessment, Pariaman Coastal Tourism Area, Solid Waste Management System

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1. INTRODUCTION

Solid waste is defined as the residues of daily human activities and natural processes in solid forms (Pariatamby et al., 2014), by increasing the population, more waste will generate. It is necessary to manage or process the solid waste into materials with economic value, so waste has not harmful to the environment (Zaman and Lehmann, 2011). One of the activities that generate solid waste is tourism. Tourism relates to various activities supported by various facilities and services the community, business people, central government, and local governments provide. Tourism development is needed to encourage equal opportunity to do business, get benefits, and face the challenges of changing local, national, and global life (Wiratini and Utama, 2020).

Pariaman City is included in the tourism potential area of West Sumatra Province, and Pariaman City Government develops tourism areas as a strategic city development (Arlym and Hermon, 2019). The tourism area included Kata Beach, Cermin Beach, Gandoriah Beach, and Angso Duo Island, covering 3.92 km^2. Aziz and Mira (2019) reported that solid waste generation of the Pariaman Coastal Tourism Area was 170.51 kg/day. The composition of solid waste is classified into organic and inorganic waste. The most significant component is organic waste, with 90.79%, while the rest is inorganic waste. The recycling potential of solid waste in the tourism area of Pariaman City consists of 95.072% non-ferrous metals, 93.359% plastic, 64.505% glass, 36.787% food waste, 19.231% paper, and 16.408% wood.

Moreover, Aziz et al. (2020) observed that the existing condition of waste management in the Pariaman Coastal Tourism Area uses a City scale. The container system uses individual and communal storage systems. The compartment and sorting applied in the Coastal Tourism Area consists of three types of wastes, namely organic, inorganic and hazardous waste for communal containers. However, waste does not comply with the sorting provided it is still mixed. Waste collected using an individual pattern goes directly to the landfill site at South Tungkal. Garden waste and paper waste are burned around the beach area. The only waste processing at Integrated Solid Waste Treatment Plant (ISWTP) South Tungkal is composting. Inorganic waste collection from Angso Duo Island is carried out once a month and brought to the collector agent.

Aziz et al. (2020) recommended a waste management scenario with a service level of waste management system for the Pariaman Coastal Tourism Area, is planned 100% for each stage of service. The scale of waste management that is planned is the scale of area management. The planned storage patterns are individual and communal. Communal storage consists of three types of waste, green containers for compostable waste, yellow for reusable and recyclable waste, and red for other waste, including hazardous waste and residue. The solid waste collection uses indirect communal patterns. Waste processing at recycling center applies to compost and recycling of waste planned to be located near Kata Beach. The transportation of residual waste and other waste from the recycling center uses the Hauled Container System (HCS) transportation pattern to the landfill site at South Tungkal Pariaman City.

The Life Cycle Assessment (LCA) method has been used to assess the environmental impact of solid waste management systems. Colón et al. (2010) applied on the environmental assessment of home composting, Abduli et al. (2011) applied on the management of municipal solid waste in Tehran, Saheri et al. (2012) applied on the assessment of waste disposal options in Malaysia, while Aziz et al. (2016) evaluate the environmental impact of community composting using LCA. LCA also assesses alternatives in improving the solid waste management system, such as improving the community composting system (Aziz et al., 2018), improving alternatives on combination of solid waste treatment technologies in combining with landfilling (Hadzic et al., 2018), improving of the recycling rate in municipal solid waste (Ferronato et al., 2021), and improving processing technology options on the market waste sources (Aziz et al., 2022). Nurunnisa (2020) have reported the environmental performance evaluation of the existing solid waste management system of Pariaman Coastal Tourism Area and recommended some improvement spots to be applied to practice the environmentally friendly system. Therefore, it is necessary to see the impact of the better solid waste management system promoted by (Aziz et al., 2020). It focuses on solid waste reduction practice in the tourism area through the 3R (reduce-reuse-recycle) approach at the recycle centre. Recommendations can be proposed for a better waste management system in the Pariman Coastal Tourism Area.

The objectives of this study were to compare the environmental impact of the existing solid waste management system and the proposed solid waste management system using the LCA method and deliver a recommendation to improve the better management system for Pariaman Coastal Tourism Area.

2. EXPERIMENTAL SECTION

The research was conducted to analyze the potential environmental impact on the solid waste management system of the Pariaman Coastal Tourism Area. Then the deficiencies in waste management are identified. Alternatives for tourism waste management will be recommended and analyzed for their environmental feasibility using the LCA method to obtain the best waste management system applied in the Pariaman Coast Tourism Area.

This study consists of a literature review, data collection, and LCA analysis. The literature study aims to learn the theoretical basis that is related and directly related to the implementation of this study. Literature studies are conducted by collecting data from related agencies and studying theories from various sources in textbooks, journals, and related regulations.

Data collection consists of secondary data and primary data collection. Secondary data indirectly provide information to data collectors. Secondary data collected consists of : (a) data from Aziz and Mira (2019) about solid waste generation, composition, recycling potential, and characteristics of solid waste in the tourism area of Pariaman City; (b) data from Aziz et al. (2020) regarding the planning of the solid waste management system for the Pariaman Coastal Tourism Area; (c) materials and equipment needed during the management and processing that takes place in the Pariaman Coastal Tourism Area and Integrated Solid Waste Treatment Plant (ISWTP) at South Tungkal; and (d) data refer to the SimaPro database Cirotha et al. (2019) and related research data.

Meanwhile, primary data is obtained from observing existing waste management conditions in the Pariaman Coast Area. It related to technical and operational aspects consisting of solid waste generator, container, collection, processing (composting and recycling), transportation and landfills, field observations, or interviews to complete the data collected that is still incomplete.

The alternatives that have been prepared must be analyzed for their environmental feasibility using the LCA method. LCA consists of four stages Krishna et al. (2017) they are (1) goal and scope definition to determine the study objectives, functional units, and system boundaries; (2) Life Cycle Inventory (LCI) aims to identify and quantify the flow of materials, energy, and emissions released into the environment; (3) Life Cycle Impact Assessment (LCIA) to classify the category of impacts arising from each system; and (4) interpretation, aims to identify and evaluate information on the results of the LCI and LCIA following the stated objectives and scope.

Goal and scope definition is the guide that can help the consistency of an LCA study, and the objective should indicate the reasons for the research being carried out and the goal of the research. If there are a lot of data available, LCA restrictions must be carried out for the study to be more focused and on target. If the available data is minimal, then the purpose of the LCA needs to be redefined according to the available data. The limitations of using LCA in this study are the generation, composition, and potential for recycling. The limit made for each alternative uses the same function unit, namely 170.51 kg of waste generated. This functional unit is used as the standard of all processes in this analysis.

The inventory analysis stage collects data that can support LCA analysis, then called inventory data. Some inventory data is available in the SimaPro software. However, if additional other available processes are needed, the inventory data described in the literature review can be used. The life cycle inventory is based on waste management and functional units, namely 170.51 kg/day. This stage is also modeled as a process diagram consisting of several alternatives, each of which has its process diagram. So, the necessary inventory data can be entered in the subsequent impact analysis.

The impact assessment stage evaluates the potential impact on the environment using the results from the LCI. Moreover, it provides information to interpret the final phase. At this stage, grouping and assessing the impact on the environment will be carried out based on the data obtained at the LCI stage. The impact assessment method used in this study is the CML-IA (baseline) method developed by the Institute of Environmental Sciences, Leiden University, Netherlands (Rydh and Sun, 2005). This method was chosen because it is applied to many LCA studies on solid waste management (Yay, 2015; Rajcoomar and Ramjeawon, 2017; Liu et al., 2021; Özer and Yay, 2021). At least the impact assessment phase consists of a classification of impact and impact characterization.

Classification of impact requires all incoming resource data and the resulting environmental emissions for the various impact categories. Environmental impacts that were studied include Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP). These three impact categories were chosen because they were mostly related to solid waste management's impact on the environment and researchers.

Global warming potential analyzes the impact that could lead to global warming potential. The compounds that most contribute to this global warming potential are CO_2 (carbon dioxide) and CH_4 (methane). This global warming potential is expressed in units of kg of CO_2 so that other compounds that are not CO_2 but have a contribution to global warming are equivalent to the weight of CO_2. Acidification potential analyzes the impact of potential acidification on the environment. The compounds that most contribute to this acidification potential are acidic compounds such as SOx, NOx, HF, and HCl. Acidification potential is expressed in units of kg SO_2. Other compounds that are not SO_2 but have contributed to the acidification are equivalent to the mass units of SO_2. Eutrophication potential analyzes the impacts that can lead to eutrophication potential. The compounds that most contribute to this eutrophication potential are nitrogen and phosphorus. This eutrophication potential is expressed in units of PO_4^{3-} kg. Other compounds that are not PO_4^{3-} but contribute to eutrophication are equivalent to PO_4^{3-} weight. Inventory data are grouped based on similar environmental impact estimates (Rydh and Sun, 2005).

Impact characterization provides a way to directly compare LCI results in each impact category. The characterization factors translate different inventory inputs into indicators of direct comparable impact. Impact characterization also determines the magnitude of the classified impacts, both quantitatively and qualitatively. As an optional step, weighting stages are carried out to select the best alternative. The weighting stage is carried out to determine the magnitude of each impact on the overall impact category magnitude.

Interpretation aims to identify, evaluate and conclude the environmental impact analysis of the waste management system in the Pariaman Coastal Tourism Area assessed in the previous stage. Interpretation is carried out based on the analysis results of SimaPro software. Analyze the feasibility of environmental and potential aspects of each of the waste management systems starting from the collection system until the waste reaches the landfill site. The analysis assesses which stages of the waste management system have a significant impact on all scenarios and compares several scenarios to determine the best scenario. Contribution analysis to determine the contributors to the significant impacts at a system stage and improvement analysis contains recommendations for improvements to the existing system to become a more environmentally sound system.

This LCA analysis uses SimaPro 9.0 software. SimaPro software is used because of its ease of operation and is the popular software used by many researchers and industries worldwide.

3. RESULTS AND DISCUSSION

3.1 Waste Generation, Composition, and Recycling Potency

Data on waste generation is taken from Aziz and Mira (2019) it was found that the waste generation of the Pariaman Coastal Tourism Area was generated every day. The calculation of waste generation results for the Pariaman Beach Tourism Area is based on the unit weight of 170.51 kg/day or the unit volume of 5,166.92 liter/day. The difference in the maximum and minimum value obtained from each facility used as sample points is due to differences in the number of visitors who come and the types of waste.

Based on Aziz and Mira (2019) the composition of waste in the Pariaman Coastal Tourism Area shows that the most significant component is organic waste with a percentage of 90.79%. In comparison, the percentage for inorganic waste is 9.21%. The waste composition in the Pariaman Coastal Tourism Area is dominated by food waste, namely 30.86%. Meanwhile, another waste that contributed less to the composition of the waste was plastic 26.31%, paper 18.29%, yard waste 11.01%, miscellaneous waste 6.92%, wood, non-ferrous metals 1.27%, glass 1.02%, textiles 0.90%, and rubber 0.85%. Meanwhile, for recycling potency, waste

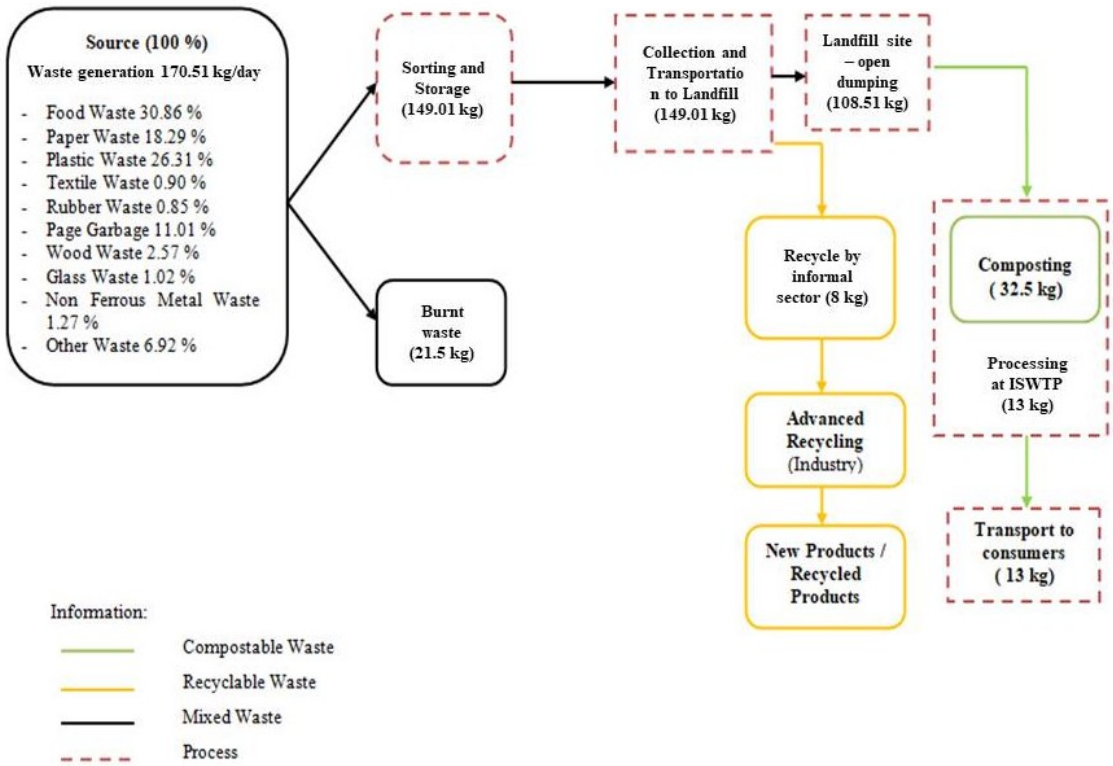

Figure 1. Scenario 1

components with higher recycling potency are plastic 93.23%, non-ferrous metal 95.07%, and glass 64.51%.

3.2 Solid Waste Management Scenarios for Pariaman Coastal Tourism Area

3.2.1 Waste Management Scenario 1

Scenario 1 is the condition of the existing waste management system implemented in the Pariaman Coast Tourism Area (Nurunnisa, 2020). Pariaman City has implemented a new paradigm in waste management. The collected waste is processed first at Integrated Solid Waste Treatment Plant (ISWTP) South Tungkal before landfilling is carried out. The existing waste management system of the Coastal Tourism Area is a city scale. In scenario 1, there is no waste reuse activity applied and recycling activity only composting food waste at the ISWTP.

The percentage of compostable waste processed at the ISWTP is 32.5%, of 170.51 kg. The compost that has been finished is transported to consumers 13 kg, 8 kg of recyclable waste originating from Angso Duo Island was collected by the informal sector (cleaning workers) and delivered to the collector agent or third parties. Compostable waste processing at ISWTP South Tungkal, the processed waste is still a tiny portion. The residual waste that is disposed of in the landfill is 108.51 kg. Scenario 1 diagram can be seen in Figure 1.

3.2.2 Waste Management Scenario 2

Scenario 2, developed based on Aziz et al. (2020) is a waste management system design in the Pariaman Coast Area carried out on the Pariaman Coastal Tourism Area, consisting of Kata Beach, Cermin Beach, Gandoriah Beach, Angso Duo Island, and Tangah Island. The general design in managing solid waste in the Pariaman Coastal Tourism Area aims to reduce waste from sources and increase community participation in 3R-based waste management. The waste management plan that will be carried out is area-scale waste management. This study aims to minimize the volume of waste entering the landfill. The planned area-scale waste management in the Pariaman Coastal Tourism Area is to build a recycling center.

In this scenario, the waste is collected in a condition divided into three types of waste, namely compost-worthy waste, recycled waste, and other waste. This collection process is structured to facilitate further waste management. This collection means that motorized pedicabs directly take the waste generated by the Pariaman Coastal Tourism Area to the recycling center near Kata Beach for compost-worthy waste processing using the takakura stacking method and waste recycling. In alternative scenario 2, the waste generation is the same as scenario 1, which is 170.51 kg, compostable waste is 49.937 kg to 19.97 kg. Waste that was composted was food waste and yard waste. The recyclable waste is 63.019 kg which is processed to reduce the waste

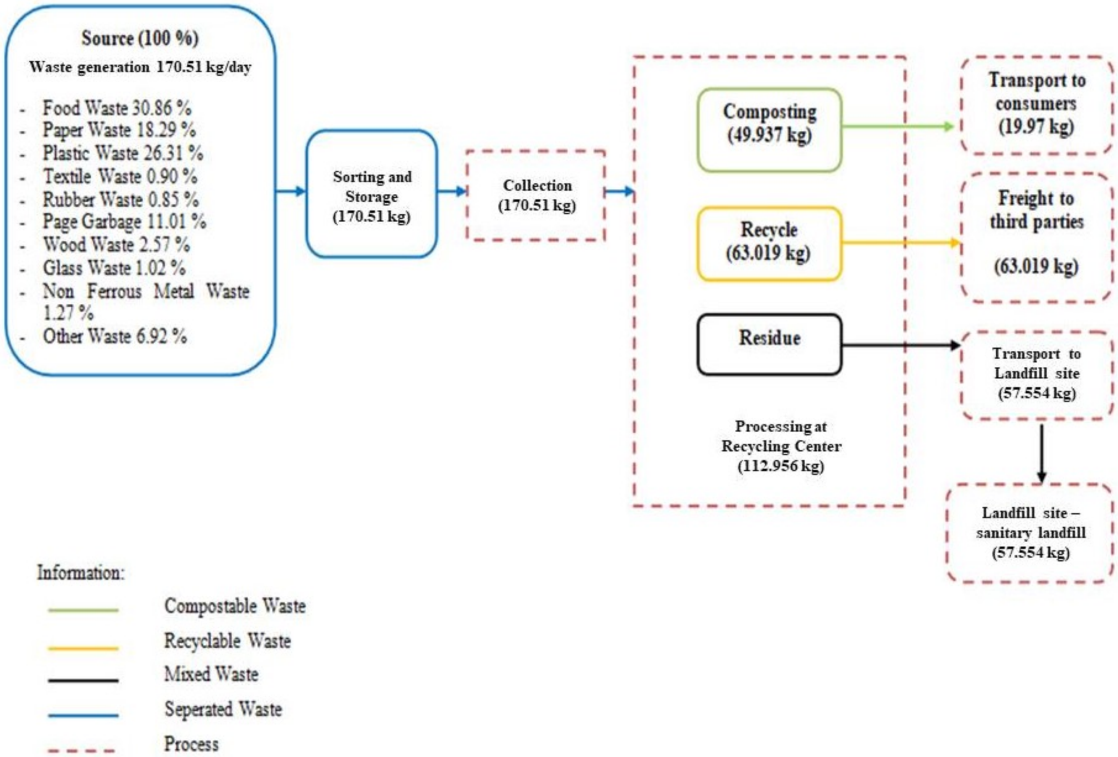

Figure 2. Scenario 2

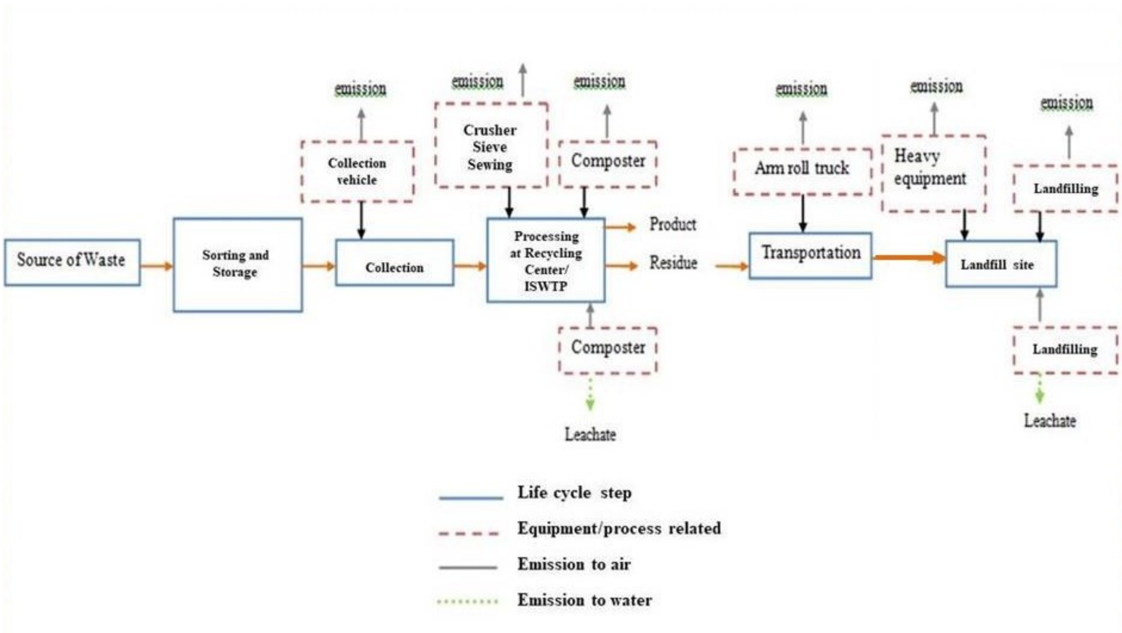

Figure 3. System Boundary

brought to the landfill using an arm roll truck. The others waste disposed of to the landfill is 64.55 kg. The waste that is poured into the landfill in alternative scenario 2 is smaller than the alternative scenario 1 to reduce the impact on the landfill. Scenario diagram 2 can be seen in Figure 2.

Table 1. Material Input and Output of Solid Waste Management Scenario

Items	Scenario 1 Input (kg)	Scenario 1 Output (kg)	Scenario 2 Input (kg)	Scenario 2 Output (kg)
Sorting and storage	170.51	170.51	170.5	170.51
Burnt waste	21.5	21.5	-	-
Collection	149.01	149.01	170.5	170.51
Transfer	149.01	149.01	-	-
Transport	149.01	149.01	-	-
Compostable to recycle center	32.5	32.5	49.94	49.94
Compostable to consumer	13	13	19.97	19.97
Recyclable to recycle center	8	8	63.02	63.02
Recyclable to consumer	8	8	63.02	63.02
Landfill process	108.51		57.55	
Total	170.51		170.51	

Table 2. Scenario 1 Inventory Data Input

Items	Scenario 1
Functional unit: Waste generated 1 ton	
Waste handling	Mixed
Waste generation	0.170 ton
Waste generation served	0.149 ton
Burned waste	0.0215 ton
Collection routes distance (Route: Island-dock)	15 km
Transportation routes distance (Route: Beach-ISWTP)	11.8 km
Compostable waste	
Waste generation to be compost	0.032 ton
Waste generation from composting process	0.013 ton
Transportation routes distance (Route: ISWTP-consumer)	13 km
Recyclable waste	
Waste generation to be recycled (by informal sector, local officer)	0.008 ton
Transportation routes distance (Route: Beach-collector)	2.3 km
Residue	
Waste generation to be landfilled	0.10851 ton
Transportation routes distance (Rute: Beach-landfill)	11.8 km

3.3 LCA Analysis of Waste Management Scenarios

3.3.1 Goal and Scope Definition

The definition of objectives and coverage aims to select a better scenario in the existing and proposed waste management system using the Life Cycle Assessment (LCA) method and provide recommendations for a better waste management system for the Pariaman Coastal Tourism Area alternative solutions in minimizing environmental impacts. This alternative is structured from source to final processing by incorporating processes and flows in each management system based on the waste journey from source to landfill.

This alternative analysis is limited from collecting sources and recycling center, transportation from sources to landfill and ISWTP, processing at ISWTP/recycling center (composting and recycling), transportation from ISWTP/recycling center to collector agent, transportation from ISWTP/recycl

Table 3. Inventory Data of Waste Management Energy Demand Scenario 1

Items	Energy	Unit
Collection and transportation from the beach to landfill	1.758	Tkm
Collection from island to dock	0.12	Tkm
Transportation from the beach to the collector	0.018	Tkm
Transportation from ISWTP to consumers	0.169	Tkm
Compost crusher	0.029	MJ
Compost siever	0.011	MJ
Excavator operation (MJ)	1.17	MJ

Table 4. Scenario 2 Inventory Data Used in SimaPro Software

Items	Scenario 2
Functional unit: Waste generation 1 ton	
Waste handling	Separated into compostable waste, recyclable waste, and others
Waste generation of Pariaman Beach	0.170 ton
Waste served	0.170 ton
Collection routes distance (Route: Sources to recycling center)	4.8 km
Collection routes distance (Route: Island to harbor)	15 km
Compostable waste	
Waste generation to be compost	0.049 ton
Waste generation of the composting process	0.019 ton
Transportation distance (Route: Recycling center to consumer)	4 km
Recyclable waste	
Waste generation to be recycled	0.063 ton
Transportation distance (Route: Recycling center to collector agent)	2.8 km
Others waste	
Waste generation to be landfilled	0.057 ton
Transportation distance (Rute: Recycling center to landfill)	11.3 km

ing center to consumers until final processing at the landfill.

This study did not analyze the informal sector's waste processing system (scavengers). The functional unit used follows the amount of waste generation and the limitations of each alternative using the same functional unit. The assessment is carried out by comparing the emissions produced in each system. Reducing the generated waste generation by applying to process, namely composting and recycling, is then analyzed to minimize the total generation that is filled in the landfill. System limitations for LCA analysis on waste management in the Pariaman Coastal Tourism Area can be seen in Figure 3.

3.3.2 Inventory Analysis (Life Cycle Inventory)

The functional unit used at this stage is 170.51 kg of waste generation. This waste generation becomes an input in each of the alternatives prepared. Input and output of waste generation based on the composition of the Pariaman Coastal Tourism Area can be seen in Table 1.

The fundamental inventory data needed for alternative scenario 1 can be seen in Table 2 and Table 3.

The primary inventory data required for alternative scenario 2 can be seen in Table 4 and Table 5.

3.3.3 Impact Assessment

The characterization will compare the inventory analysis results in each impact category. Impact characterization also determines the magnitude of the classified impacts. The

Table 5. Waste Management Energy Demand Inventory Data Scenario 2

Items	Energy	Unit
Collection from sources to recycling center	0.682	Tkm
Collection from island to the harbor of Gandoriah Beach	0.0184	Tkm
Collection from Gandoriah Beach harbor to recycling center	0.024	Tkm
Transportation from recycling center to landfill	0.6504	Tkm
Transportation from recycling center to consumer	0.0798	Tkm
Transportation from recycling center to collector agent	0.1764	Tkm
Compost crusher	0.4126	MJ
Coconut peeling machine	0.0006	MJ
Sewing machine	0.27	kWh
Excavator (MJ)	1.251	MJ

Table 6. Characterization of The Impact of Each Alternative

Process	Scenario 1			Scenario 2		
	GWP	AP	EP	GWP	AP	EP
Waste burning	92.1	-	-	-	-	-
Collection	-	-	-	15	17 x 10^{-4}	7.92 x 10^{-4}
Transportation	4.2	1.6 x 10^{-2}	3.88 x 10^{-3}	4	1.53 x 10^{-2}	3.7 x 10^{-3}
Composting	2	13 x 10^{-3}	20.4 x 10^{-3}	9.2	67.3 x 10^{-3}	23.8 x 10^{-3}
Recycling	0.04 x 10^{-5}	0.52 x 10^{-9}	0.13 x 10^{-9}	1.40 x 10^{-5}	5.08 x 10^{-9}	1.34 x 10^{-9}
Landfilling	1.08 x 10^{5}	20.4	2.45 x 10^{3}	1.44 x 10^{4}	33.1	27
Total	108,098.30	20.4173	2,450.01	14,428.20	33.18284	27.02763

Table 7. Weighting Results

Process	Scenario 1			Scenario 2		
	GWP	AP	EP	GWP	AP	EP
Waste burning	1.51 x 10^{-20}	-	-	-	-	-
Collection	-	-	-	4.21 x 10^{-21}	6.45 x 10^{-23}	1.75 x 10^{-22}
Transportation	1.17 x 10^{-21}	6.10 x 10^{-21}	8.55 x 10^{-21}	1.12 x 10^{-21}	5.82 x 10^{-21}	8.16 x 10^{-21}
Composting	5.58 x 10^{-22}	4.95 x 10^{-22}	4.50 x 10^{-21}	25.6 x 10^{-21}	256 x 10^{-22}	52.6 x 10^{-21}
Recycling	0.11 x 10^{-27}	0.20 x 10^{-27}	0.30 x 10^{-27}	3.93 x 10^{-27}	1.93 x 10^{-27}	2.96 x 10^{-27}
Landfilling	3.02 x 10^{-17}	7.75 x 10^{-18}	5.41 x 10^{-15}	4.03 x 10^{-18}	2.69 x 10^{-17}	5.96 x 10^{-17}
Total per category	3.02 x 10^{-17}	7.76 x 10^{-18}	5.41 x 10^{-15}	4.04 x 10^{-18}	2.69 x 10^{-17}	5.96 x 10^{-17}
Total		1.81 x 10^{-15}			3.02 x 10^{-17}	

results of the impact characterization assessment can be seen in Table 6.

This weighting provides a score for each scenario by multiplying the normalization results with the factors obtained from the SimaPro 9.0 database. The weighting results can be seen in Table 7.

3.3.4 Interpretation

Based on the weighted impact assessment results, several impact categories can be compared in Table 7 For GWP, based on the comparison, scenario 1 has a value of 3.02 x 10^{-17}, which is higher than in scenario 2 because there is much waste in the landfill and only processes less waste. Scenario 2 has the lowest value of 4.04 x 10^{-18} because it

Table 8. Contribution of Impact for The GWP Category

Process	Scenario 1	Scenario 2
Waste burning	3.65 x 10^{-24}	-
Collection	-	5.97 x 10^{-25}
Transportation	1.66 x 10^{-25}	1.59 x 10^{-25}
Composting	7.92 x 10^{-26}	3.63 x 10^{-26}
Recycling	0.16 x 10^{-31}	5.57 x 10^{-31}
Landfilling	4.28 x 10^{-21}	0.57 x 10^{-21}
Total	4.28 x 10^{-21}	0.57 x 10^{-21}

processes more waste at the source than scenario l. For AP, the value in scenario 1 is 7.76 x 10^{-18}. Scenario 2 with the highest AP value as 2.69 x 10^{-17} because it processes the most waste. Moreover, for EP, the value in scenario 1 is 5.41 x 10^{-15}, and for scenario 2, it is 5.96 x 10^{-17}. Scenario 1 has a higher EP value because there is much waste in the landfill site.

The impact contribution for the GWP categories can be seen in Table 8. Based on the results of the impact contribution to the GWP value, the scenarios have an immense GWP value due to landfill activities in the landfill site. Emissions that significantly affect the high GWP value are CH_4, CO_2, NOx, and VOC. This condition is because processing in leachate and gas landfills does not cause significant exhaust gas emissions. In Scenario 1, there is only composting for recycling carried out by the informal sector, and the amount of processed waste is small so that more waste is dumped in the landfill site. Whereas in scenario 2, the impact or GWP value is smaller than the other alternative because more processing has been done at the source so that the waste generated in the landfill sites reduced.

The impact contribution for the AP category can be seen in Table 9. The most significant AP impact was on the transportation and landfill process at the landfill site based on the contribution results. NOx and SO_2 emissions produced in landfills and transportation processes are the leading causes of the increase in the AP value. Transport has a much more significant acidification impact than landfills. However, landfills have a significant impact. Besides that, the composting and recycling collection processes also contribute to AP.

The impact contribution for the EP category can be seen in Table 10. Based on the contribution of the impact that occurred on EP, the average value of EP in each scenario, the most significant value occurred in the landfill process in the landfill site. Scenario 1 has the most considerable EP value because there is a lot of garbage in the landfill, which results in significant air pollutants. The resulting gas emissions such as CH_4, N_2O, NH_3, and VOC cause an increase in the EP value. In addition, the collection process also contributes to the occurrence of EP, and the energy needs of using tools for waste processing also contribute to the EP value in a small percentage.

3.3.5 Improvement Analysis

From the weighting results in the previous stage, scenario 2 is better than scenario 1 because it has a smaller weight value as 3.02 x 10^{-17} than 1.81 x 10^{-15}. In scenario 2, processing has been carried out at the source at recycling center by composting and recycling. However, after being analyzed using the LCA method, the processing, which was initially expected to reduce environmental impact, still has an impact, especially on any process that uses energy-generating equipment. So it is necessary to improve and have alternative solutions in minimizing the impact on the environment. The following are some of the recommendations put forward for the selected alternatives.

On collection and transportation process, the contributor of impacts on the environment comes from consuming fuel. Longer distances also cause higher emissions. Therefore, it is recommended to choose a transportation route closer to the distance, so the impact caused by emissions is more negligible. Waste transportation uses arm roll trucks to replace the truck fuel with a more environmentally friendly one. Pertamina dex fuel is a diesel fuel that has a CN (Cetane Number) 53 value with a sulfur content below 300 ppm. According to the EURO 3 International Standard, which is better than consumption, dexlite has CN 51 with a sulfur content of 1,200 ppm bio solar has CN 48 with a sulfur content of 3,500 ppm (Dobrzyńska et al., 2020). The higher the CN value, the better the exhaust emissions from diesel-engined fuels.

Alternative processing carried out at recycling center is composting and recycling for recyclable waste. The processing process uses tools such as a trash chopper and a coconut chopper. According to **?** the energy generated by the engine has an impact on the environment because it uses diesel-fueled propulsion, which contains sulfur dioxide (SO_2), which triggers the high impact of the AP (Acidification Potential) value. The more waste generation is processed, the greater the emission produced. Therefore, using electricity with solar power plant technology, solar energy is one of the environmentally friendly energy sources because no pollution is produced during the energy and source conversion

Table 9. Impact Contribution for AP Category

Process	Scenario 1	Scenario 2
Waste burning	-	-
Collection	-	2.14 x 10^{-25}
Transportation	2.02 x 10^{-23}	1.93 x 10^{-23}
Composting	1.64 x 10^{-24}	84.9 x 10^{-24}
Recycling	0.66 x 10^{-30}	6.40 x 10^{-30}
Landfilling	2.57 x 10^{-20}	8.91 x 10^{-20}
Total	2.57 x 10^{-20}	8.91 x 10^{-20}

Table 10. Impact Contribution for EP Category

Process	Scenario 1	Scenario 2
Waste burning	-	-
Collection	-	4.56 x 10^{-25}
Transportation	2.23 x 10^{-23}	2.13 x 10^{-23}
Composting	1.17 x 10^{-23}	13.7 x 10^{-23}
Recycling	0.79 x 10^{-30}	7.73 x 10^{-30}
Landfilling	1.41 x 10^{-17}	0.015 x 10^{-17}
Total	1.41 x 10^{-17}	0.015 x 10^{-17}

process. Energy is widely available in nature (Guangul and Chala, 2019).

On landfilling process, reducing the generation of waste into the landfill can be done by optimizing waste processing at recycling center so that the waste generation that is carried and dumped to the landfill site is reduced. The application of the sanitary landfill processing method in which the waste cells are closed or covered with soil, which this year will increase the land by 2 Ha for landfills at South Tungkal. Sanitary landfills contribute to eutrophication, global warming, and the impact of photochemical oxidation. In contrast, open dumping has the highest potential impact in the categories of global warming, ozone layer depletion, photochemical ozone formation, and human toxicity through the soil because it does not apply techniques to control gas emissions and leachate (Saheri et al., 2012). At the base of the dumpsite, pipes are made to drain leachate, which is then processed into energy and methane-catching pipes that are now not functioning and then processed into energy.

4. CONCLUSIONS

The potential environmental impact of the current waste management system has a huge impact compared to other scenarios. Based on the weighting results from the normalization of the impact assessment using the CML-IA method from the SimaPro software, scenario 1 is at least environmentally feasible because it has the highest weight value as 1.81 x 10^{-15}. The resulting impact classifications are GWP (Global Warming Potential), AP (Acidification Potential), and EP (Eutrophication Potential). The resulting impact characterization for the GWP value was 108,098.3 kg CO_2-eq, the AP value was 20.4173 kg SO_2-eq, and the EP value was 2,450.0059 kg PO_4^{3-}. Scenario 2 is the chosen alternative because it is environmentally feasible to have the lowest weight value, namely 3.02 x 10^{-17}. The resulting impact classifications are GWP (Global Warming Potential), AP (Acidification Potential), and EP (Eutrophication Potential). The resulting characterization of the impact for the GWP value is 14,422.11 kg CO_2-eq, the AP value is 33.11756 kg SO_2-eq, and the EP value is 27.00693 kg PO_4^{3-}.

Some recommendations for waste management systems that can be given to be implemented in the Pariaman Coast Tourism Area are the collection and transportation process choosing a transportation route closer to the distance, the less impact it will produce, and replacing truck fuel with truck fuel Pertamina dex. Processing processes such as recycling recycled waste using a chopper should use electricity with solar power plant technology because it produces a minor impact. Lastly, the landfill applies the sanitary landfill processing method where the waste cells are closed or covered with soil. It is necessary to develop waste management in the landfill with leachate treatment and gas processing to minimize the processes that are the leading cause of the significant impact category levels.

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