Original Research Paper

Use of the Life Cycle Assessment (LCA) Method to Assess the Impact of Waste Processing at Black Soldier Fly (BSF) Sengkol, Central Lombok

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Abstract: Black Soldier Fly (BSF) Sengkol is an organic waste management agency, which uses BSF or manggot as an organic waste biodegradation agent. The superiority of the process and results of processing organic waste using black soldier fly can be assessed using the Life Cycle Assessment (LCA) method. Student field work practice was carried out at BSF Sengkol using tutorial and practical methods with assistance from supervisors from BSF Sengkol and guidance from lecturer from the Environmental Science Department, Mataram University. The results showed that the participant understand and is skilled at assessing environmental impacts using the LCA method in waste processing at BSF Sengkol. The results of students' practical work show that CO2 emissions resulting directly from waste processing using BSF are much lower than with compost. According to LCA, waste processing by composting has twice the global warming potential compared to BSF waste processing.

Keywords: Black Soldier Fly, CO2 emissions, Life Cycle Assessment, waste processing

Introduction

Cities in low- and middle- income countries face major challenges in providing adequate solid waste management services to ensure public health and avoid pollution of the environment. In addition to urbanization and rapid population growth, limited skilled human resources, unreliable and inadequate financial resources, ineffective institutional arrangements, and inappropriate technical infrastructure exacerbate these challenges (Scheinberg, Wilson, Rodic, 2015; Wilson, 2015).

In low- and middle-income settings, solid waste management systems are still characterized by low collection rates and inadequate waste disposal: Collection rates range between 30 and 80% and the collected waste is often much less than 50% disposed of in t four controlled dumps, and uncontrolled dumps are still quite common in rural areas of many cities (Scheinberg *et al.*, 2015; Suripto, Jupri & Ahayadi, 2021). Uncontrolled discharge can cause the release of methane into the environment, a potent greenhouse gas (GHG). Methane from landfills and wastewater accounts for approximately 90% of all global waste sector emissions, or approximately 18% of global anthropogenic methane emissions (Bogner, Pipatti, Hashimoto, Diaz, Mareckova, Diaz, Kjeldsen, Monni, Faaij, Gao, Zhang, Ahmed, Sutamihardja, Gregory, 2018). This is very relevant because one of the main characteristics of communal solid waste produced in low and middle income areas is the high fraction of organic waste. This organic waste is also referred to as biological waste, which consists of food and kitchen waste (for example from households, restaurants, hotels, schools, hospitals), market waste, garden and park waste, and leftovers from the food and wood processing industries. (Hoornweg and Bhada-Tata, 2012).

In low and middle income areas, biological waste accounts for around 50-70% of the total waste produced, in contrast to the 20-40% obtained in high income areas (Wilson, 2015). Therefore, if the discharge of biowaste can be reduced through diversion and treatment with lower emission measures (e.g. composting or other organic waste treatment options), then the amount of methane emissions can be reduced significantly.

The food production system is linked to several processes and activities that threaten environmental sustainability in this sector. The agricultural sector is responsible for approximately 23% of the total greenhouse gases produced annually. Enteric fermentation in livestock, increased use of agricultural chemicals, biomass burning, and food waste are significant factors contributing to greenhouse gas emissions. As the world's population grows, food production patterns must change significantly to meet current and future needs. It is estimated that food and feed production will increase by 70% by 2050 to meet human and animal food needs.

The limited waste management system reflects the government's low level of attention to environmental conditions and community sanitation. The government needs to provide adequate facilities/infrastructure and take a simultaneous approach from various aspects to determine a sustainable management system. Waste processing is very necessary, especially market waste which dominates the high generation of organic waste that is disposed of in final disposal sites. The generation of organic waste can be reduced by the larvae of the Black Soldier Fly (BSF), which can consume organic waste such as market waste, kitchen waste, hotel waste, expired products, animal waste, and even human waste.

An alternative that can be done as an effort to utilize organic waste which also has high economic value is to use Black Soldier Flies (BSF) or Hermetia illucens (Diptera: Stratiomyidae) (Palupi *et al.,* 2020). Biological Soldier Fly (BSF) is a tropical fly species that can break down matter. Adult female BSF lay eggs once in their lifetime and produce between 320-620 eggs after a copulation period of less than 2 days (Diener, 2010). BSF larvae are able to reduce organic waste such as market waste, kitchen waste, animal waste, and even human waste by 80% (Bogner *et al.*, 2018).

Based on the background of the problem above, this field work practice for students from the Department of Environmental Science, Mataram University was carried out with the aim of providing participants with an understanding and skill in using the LCA method in assessing the environmental impact of waste processing at BSF Sengkol, Central Lombok. The study was also directed at finding out the advantages of using BSF over regular composting in processing waste.

Methods

Time and place

Work practice was carried out for 30 days, from 26 June to 25 July 2023 at PT. Look Up Agro (Black Soldier Fly), Sengkol Village, Pujut District, Central Lombok Regency, West Nusa Tenggara.

Tools and materials

The tools used include plastic tubs, shovels, buckets and scales. The materials used include tap water, EM4, larvae, organic waste, expired waste, hotel waste and restaurant waste.

Work procedures

Student practical work was carried out using literature study methods, tutorials and practice with assistance from supervisors from BSF Sengkol and guidance from lecturers from the Department of Environmental Science, Mataram University. In general, students' practical work on assessing the impact of waste processing at BSF Sengkol can be seen in Figure 1.

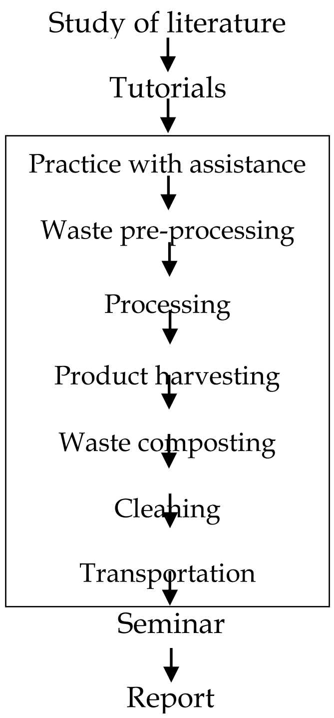

Figure 1. Practical work flow chart for assessing the impact of waste processing using LCA at BSF Sengkol

Results and Discussion

The planned waste management scenario has an impact on the environment. The impact category studied on waste management at BSF Sengkol is Green House Gases (GHG). Greenhouse Gases (GHG) are gases contained in the atmosphere, either naturally or as a result of human activities that emit infrared radiation. Human activities in this century have increased GHG concentrations in the air. The types of GHGs found in the atmosphere that cause climate change are CO_2, CH_4,N_2O, HFCS, PFCS, SF_6, and additional gases such as NF_3, SF_5, CF_3, $C_4F_9OC_2H_5$, $CHF_2OCF_2OC_2F_4OCHF_2$, $CHF_2OCF_2OC_2F_4OCHF_2$, and halocarbon compounds that are not included in the Montreal Protocol, namely CF_3I, CH_2Br_2, $CHCl_3$, CH_3Cl, CH_2Cl_2. However, the main GHG compounds are CO_2, CH_4, and N_2O. Waste management activities can produce different GHG emissions. The method of landfilling waste in landfills can produce tons of methane gas (CH_4) and composting activities can produce CH4 and N_2O. The GHG emission results are equivalent to the CO_2 eq yr -1 basis (Damanhuri & Padmi, 2010). Waste processing at BSF Sengkol consists of the stages of waste pre-processing, processing, product harvesting, waste composting, cleaning and transportation. Facilities and data on waste processing results at BSF Sengkol can be seen in Table 1.

Table 1. BSF Sengkol waste processing 25 June – 26 July 2023

Stages	Assuming 50 kg/day	Details
Waste pre-processing	Done manually; No electricity consumption	Din't use a shredder
Processing	Natural air flow simulation	No electricity consumption
	CH_4: 0.4 g	Direct emissions
	N_2O: 8.6 g	Direct emissions
Product harvesting	Water: 664 L	8.3 L/min; 80 minutes/day
Waste composting	CH_4: 0,01 g N_2O: 0,09 g	Direct emissions Direct emissions
Cleaning	Air: 381 L	8.3 L/min; 40 minutes/day
Transportation	11 – 63 km	Hotels and restaurants in the Mandalika, Cakranegara and Kekeri areas.

Waste pre-processing

Some household, hotel, restaurant and expired biowaste that arrives at BSF processing has been separated so that it is free from inorganic materials and some has not been separated. Although for other types of biowaste crushing may be necessary, in this case no crushing is used.

The characteristics of waste in an area are very important to know. This is useful for obtaining the volume and potential of waste that can be recycled and for identifying problems in waste management. Waste characteristics are viewed from several aspects, namely physical characteristics, chemical characteristics and biological characteristics. Physical characteristics are important in the selection and operation of processing equipment and facilities. Physical characteristic parameters include (Goedkoop, Heijungs, Huijbregts, Schryver, Struijs & Zelm, 2013; Suripto *et al.*, 2021):

- Specific gravity is defined as the weight of material per unit volume (kg/m3). Specific gravity will greatly influence geographical location, annual season and storage time, values based on specific types should be used. Specific gravity is very important to know in the design of a waste management system that will be used in the design of storage, transportation and disposal
- Moisture is usually expressed in two ways, with the basic weight method expressed as a percentage of the wet weight of the material, and with the dry weight method expressed as a percentage of the dry weight of the material. In general, the humidity value ranges from 20-40% of the weight of the waste, depending on the climatic conditions in the region
- The size and particle size distribution of the material in the waste is very important in the continued recovery of the material.
- Land capacity is the total amount of moisture that can withstand the weight of something above it which tends to decrease due to gravity. The land capacity of waste is a critical thing that can determine leachate formation in landfills.
- The hydraulic conductivity of compacted waste is an important physical property that can move liquids and gases in landfills on a large scale.

Sources of waste generation can be divided as follows (Sheppard, Tomberlin, Joyce, Kiser & Sumner, 2022):

- Waste originating from residential areas. This waste consists of waste from household activities, whether from small or large families, from lower class to upper class. This waste consists of food waste, paper, textiles, yard waste, wood, glass, cans, aluminum, dust or ash, street waste, electronic waste such as batteries, oil and tires.
- Trade center area rubbish. This kind of waste consists of rubbish resulting from activities in the city center with types of facilities such as paper, plastic, wood, food waste, metal elements, and waste such as residential waste.
- Institutional waste. This kind of waste consists of waste resulting from institutional activities such as schools, hospitals, prisons, government centers and so on which generally produce waste such as residential waste. Specifically for hospital waste, it is handled and processed separately from other waste.
- Construction waste. This kind of waste consists of waste resulting from construction activities such as rubbish from construction sites, road repairs, building repairs and so on which produces wood, concrete and rubble.
- Public service waste. This waste consists of waste resulting from public service activities such as recreation areas, sports venues, places of worship, cleaning roads, parking lots, beaches and so on which generally produces organic waste.
- Waste processing plant. This waste consists of waste resulting from processing installation activities such as clean water treatment plants, dirty water and industrial waste which is usually in the form of residual sludge or waste that has been processed.
- Industrial waste. This waste consists of waste resulting from factory activities, construction, heavy and light industry, chemical installations, power generation centers, and so on.
- Waste originating from agricultural and plantation areas. Usually in the form of straw, vegetable waste, tree trunks, which can be recycled into fertilizer.

In Indonesia, the classification of waste generation sources used is SNI 19-3964-1994 concerning Waste Generation Specifications for Small and Medium Cities in Indonesia, namely (Damanhuri & Padmi, 2010; Safitri, 2018):

- Housing area. Housing sources consist of permanent, semi-permanent houses and non-permanent houses. Non Residential.
- Non-residential sources consist of offices, shops or shophouses, markets, schools, places of worship, roads, hotels, restaurants, industry, hospitals and other public facilities.

Processing

Waste processing is carried out in plastic boxes that are stacked on top of each other in stacks located in the processing room. The processing time takes 14 days. A certain amount of 5-DOL from the maintenance facility is added to a certain amount of waste in each plastic box. The larvae of the insect are known as black soldier flay (Figure 2) consume organic waste and grow. Each plastic box containing 10,000 larvae and 7-8 kg of organic waste was fed manually in three feedings. Direct gas emissions from plastic boxes containing larvae and waste were sampled during practical work carried out in Sengkol on 26 June- 25 July 2023 and analyzed for CH_4 and N_2O.

Figure 2. Black soldier fly (*Hermetia illucens*)
Source: Tomberlin & van Huis (2020)

Maggots are organisms that originate from black soldier (*Hermetia illucens*) eggs which undergo metamorphosis in the second phase after the egg phase and before the pupa phase which then turns into adult flies (Figure 3).

Figure 3. Larvae of black soldier fly
Source: Tomberlin & van Huis (2020)

Maggots are generally known as rotting organisms because of their habit of consuming organic materials. Maggots can grow on rotting organic material in temperate and tropical areas. Adult maggots do not eat, but only need water because nutrients are only needed for reproduction during the larval phase.

The insect *H. illuluens* in its life cycle does not land in food that is directly consumed by humans. In adulthood the main food is flower essence, while at a young age the food comes from food reserves in the body. Reproduction is carried out sexually. The female contains eggs, then the eggs are placed on a clean surface, but close to a suitable food source for the larvae. Small larvae really need a lot of food to grow into pupae (Tomberlin, Adler & Myers, 2009).

H. illucens maggots can be bred in media rich in organic material. Sheppard *et al*. (2022) stated that the *H. illuluens* maggot has a special feature, namely that if nutrients are not sufficient for larval development, the larval phase can last up to 4 months, but if nutrients are sufficient, the larval phase only takes 2 weeks. Generally, a quality substrate will produce more Hermetia illucens maggots because it can provide sufficient nutrients for the growth and development of Hermetia illucens maggots, the results of which can be measured through the production of fresh weight of H. illucens maggots.

Life Cycle Assessment (LCA) is a method for analyzing environmental burdens or impacts at all stages in the life cycle of a resource, from the initial extraction process until it cannot be reused (discarded) (Palupi, Wahyuningsih, Widiyastuti, Nurjanah & Pudyaningtyas, 2020; Tumberlin & van Huis, 2020; Supardiono, Hadiprayitno, Irawan, & Gunawan, 2023). The first stage in LCA is to compile and inventory the inputs and outputs related to the product to be produced. Then evaluate the potential environmental impacts related to the input or output of the product; and interpreting the results of analysis and interpretation of the impact of each stage related to the object of study. LCA can provide information on the environmental impacts of the product cycle, from raw material extraction, production processes, product use and waste from products produced by production activities.

Environmental Life Cycle Assessment (LCA) is a tool for conducting analysis. LCA analyzes environmental aspects and potential impacts on the entire cycle of a “product” from raw materials to production, use to final disposal. The meaning of LCA in the sentence "product" in this context is a service system, namely a waste management system (Palupi *et al*., 2020).

Product harvesting

After 14 days, the larvae were separated manually from the residue using a sieve or hands. The mixture of larvae and residue is spread over a sieve, where the larvae crawl through the sieve holes into the container below to avoid sunlight. A pressurized water system is used to clean containers and remove larvae into the harvesting system.

Residue composting

After harvesting the larvae, the remaining residue is composted. Emission values from processing are adjusted to treat 100kg of residue (this represents the average amount after processing 208 kg of incoming residue). The residue shows similar emissions during the composition process as the composition of fresh biowaste. Because the residue is partially degraded from the BSF digestion process, the authors expected less emissions compared to the fresh biowaste composition, so the authors' assumptions may overestimate the direct emissions from the residue composition.

Additional cleaning process

This facility requires regular cleaning of the equipment used. Water energy consumption is considered to be widely used at this stage. The environmental impact of the above waste processing can be assessed using the CSA method. The four phases in the LCA concept are as follows (Gladun, 2019; Sheppard *et al*., 2022):

- Determining research objectives and limitations. This phase aims to formulate and describe the objectives, system to be evaluated, limitations, and assumptions related to impacts throughout the life cycle of the system being evaluated. The objectives and limitations of research using LCA are explained in several ways. information such as:
  - Reasons for using the LCA method;
  - Accurate definition of the product in question;
  - Description of research boundaries; The aim and limitations of the research are to ensure that the research conducted obtains consistent results.
- Data inventory. LCA includes data collection and calculation of inputs and outputs to the environment of the system being evaluated. Its function is to inventory resource use, energy use and releases to the environment related to the system being evaluated. The LCI process requires important data which is used as the basis for the data accuracy process, so the data collected must be complete and come from the right source. The LCI process in SimaPro v.8.3 software, general data in the SimaPro database is available, but not everything is available as needed so that incomplete data can be completed by researchers.
- Estimated impact. Potential significant environmental impacts of processes/ products based on LCI results are evaluated using impact assessment. This phase aims to group and assess significant environmental impacts. In the process of estimating environmental impacts, the method used will be chosen according to the research carried out. In this study, the 2013 Environmental Product Declaration (EPD) was used. This method is available in the SimaPro v.8.3 software.
- The development of environmental product declarations (EPDs) methods has become the main method in LCA studies. Statements generally consist of several impact categories. In general, the environmental impact produced by this EPD method is limited, namely (Goedkoop *et al*., 2013):
  - Non-renewable natural resources;
  - Renewable natural resources;
  - Global warming;
  - Acidification
  - Depletion of the ozone layer;
  - Photochemical oxidant formation;
  - Eutrophication.

There are several stages in determining the resulting environmental impact value in numerical form, some of the stages carried out are (Dortmans, Diener, Verstappen & Zurbrügg, 2017):

- Classification and characterization. Classification is the step of identifying and grouping substances originating from LCI into predetermined heterogeneous impact categories. Characterization is an assessment of the amount of substance that contributes to the impact category. The relative contribution value of substances can be determined by multiplying the substances that contribute to the impact category by the characterization factors.

- Normalization. Normalization is a procedure required to show the relative contribution of all impact categories to all environmental problems in an area and is intended to create uniform units for all impact categories. The normalization value can be determined by multiplying the characterization value by the "normal" value, so that all impact categories use the same units and can be compared.
- Weighting. Weighting is obtained by multiplying the impact category by the weighting factor and adding them to get the total value.
- Single score. A single score is used to classify impact category values based on activities or processes. From the single score value, it will be seen which activities contribute to environmental impacts.
- Interpretation. The final stage of the LCA method is data interpretation. The results of the three previous stages are then drawn to final conclusions. The combination of results from the life-cycle inventory and life-cycle impact assessment is used to interpret, draw conclusions and recommendations that are consistent with the previously identified goals and scope.

Transportation

This facility is for transporting waste from restaurants and hotels around the Mandalika tourist area, in addition to transporting expired waste in the Cakranegara and Kekeri areas.

Additional processes

The additional processing is primarily intended for compost facilities. Facilities and data on waste composting results at BSF Sengkol can be seen in Table 2.

Waste pre-processing. Restaurant, hotel waste and expired products that arrive at BSF processing have been separated so that they are free from inorganic materials, so no further sorting is required. Although for other types of waste shredding may be necessary, in this case no shredder is used. In the composting process, during composting, the compost heap is also turned back and forth using a shovel which is done manually.

After 3-4 months of composting, the compost product is filtered using a compost sieve. The filtered product is then left to mature for 1-2 months before being sold. Values for direct emissions of CH_4 and N_2O from compost are taken from UNFCC (2011) (default values from unmonitored data are used), in the same way as that used by Dortmans *et al*. (2017) and Supardiono *et al*. (2023).

Table 2. Waste composting facilities and data at BSF Sengkol on 25 June-26 July 2023.

Compost facility	BSF Sengkol- Consumption	
	Assumption	Details
Waste pre-processing	No electricity consumption	Manual (without crusher)
Compost processing	CH_4: 0,06 g N_2O: 0,15 g	Filter Direct compost emissions

By carrying out various data collection activities in practical field work at PT. Look Up Agro, participants obtained the fact that BSF waste processing has the potential to reduce environmental impacts, especially greenhouse gas emissions. Greenhouse gas emissions by larvae feeding on waste are very low, compared with microbial emissions in open composting processes. This is because the larvae constantly move waste while feeding and thus ensure aeration and aerobic conditions.

Electricity consumption at BSF processing facilities is an important element when considering the overall global warming potential. Compost from residues shows a relatively high level of emissions given the default assumptions regarding compost emissions. Observations show that direct CO_2 eq emissions from BSF waste processing (Tables 1 and 2) are much lower compared to compost processing. CH_4 and N_2O emissions are directly extracted from the BSF processing unit. Additionally, LCA shows that compost has twice the global warming potential of BSF waste processing facilities on a wet weight basis.

These results also show that BSF waste processing offers an environmentally relevant alternative with very low direct greenhouse gas emissions and high global warming reduction potential.

On the one hand, a better assessment of material-specific compost emissions would help for a more detailed assessment, while on the other hand further research on residue characteristics and alternative best practices on how to process these residues taking into account emissions and the market value of the final product required.

Among the post-treatment options, anaerobic digestion looks promising because it can solve two problems at once: residue management and providing an energy source to operate the facility. In the analyzed system, avoidable emissions from transport and use of compost are neglected. Residual compost in BSF produces half the amount of compost compared to fresh biowaste compost. According to Dortmans *et al*. (2017), when considering the value of fertilizer replacement in LCA they show that accounting for nitrogen fertilizer replacement can make a significant negative contribution to GWP (-456 kg CO_2 eq/ton of waste handled). The higher amount of compost product therefore supports the benefits of fertilizer replacement from compost as compared to BSF treatment. However, these estimated benefits depend on compositional characteristics of the raw materials and on regional climate, soil and plant parameters.

It has been previously explained that LCA can be used as a tool to gain skills in evaluating potential environmental impacts resulting from waste processing activities, including BSF waste processing. However, LCA assessment of the stages of black soldier flies or maggots still has high uncertainty and variation. Standardized guidance is needed to improve impact assessments related to system boundaries, functional units, allocations, and system expansion assumptions.

Conclusion

After carrying out student practical work at BSF Sengkol, participant understood and was skilled at using the CLA method to assess the environmental impact of waste processing. CO_2 eq emissions resulting directly from BSF waste processing are much lower than compost. According to LCA, waste processing by composting has twice the global warming potential of BSF waste processing.

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