RESEARCH ARTICLE

Estimating Circular Economic Potential of Organic Fraction of Municipal Solid Waste in Small City

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Received: 01 November, 2023, Accepted: 10 December, 2023, Published: 12 December, 2023

Abstract
The current waste management paradigm leads to a circular economic approach. To implement it, it is necessary to know the potential for resource recovery from waste, including organic fraction of municipal solid waste (OFMSW). This research aims to investigate the potential for resource recovery from OFMSW generated in Buleleng Regency, Bali Province, Indonesia. Five technologies were assessed for their potential to transform OFMSW into resources, namely anaerobic decomposition (AD), densification and drying to produce solid fuel, composting, processing with black soldier fly (BSF), and processing for eco-enzymes production. The potential for resource recovery is estimated using a simple linear relationship mathematical model using data available from the literature and secondary data of waste generation in Buleleng Regency. The study estimated 37,489.08 tons OFMSW is generated in Buleleng in 2023. The estimate shows that revenue potential from densification and drying about 9,336 million IDR, followe by composting about 2,471 million IDR, anaerobic digestion about 1,939 million IDR, BSF about 145 million IDR, and eco-enzyme about 13 million IDR. Finally, by estimating the quantity of resources available in OFMSW and their potential market value, it can be taken into consideration in planning and managing the circularity of OFMSW.

Keywords: OFMSW; circular economic; resources recovery, technology options

Introduction

Organic waste is the main component of municipal waste. Based on data presented in the National Waste Management Information System (SIPSN) Indonesia in 2023 (https://sipsn.menlhk.go.id/sipsn/public/data/komposisi), at the national level, the composition of waste based is dominated by food waste at 40.3% followed by plastic (18.11%), wood/twigs (12.99%), paper/cardboard (11.3%), metal (3.02%), textile (2.59%), glass (2.21%), rubber/leather (2.14%), others (7.34 %). This condition shows that the composition of waste is dominated by the organic fraction of waste, especially those originating from botanical sources. This is in line with what was reported by Ellen MacArthur Foundation (2017), organic material constitutes the largest proportion (46% by mass) of waste. This percentage varies around the world and is generally higher in low-income countries (64%) than in high-income countries (28%).

However, this waste component often receives little attention because it is considered easy to decompose. In fact, its natural decomposition in landfills has the potential to release greenhouse gas emissions.

On the other hand, resource recovery from organic waste also has economic potential. Unfortunately, this potential is often ignored. However, organic waste is also a resource that can be recovered in various ways. By implementing relevant technologies, resource recovery can be obtained from organic waste. In this way, a circular economic approach is applied in waste management.

According to Geissdoerfer et. al. (2017), a circular economy is a regenerative system that minimizes resource input, waste, emissions, and energy leaks by slowing, closing, and narrowing material and energy loops by providing direction for the recycling and reuse of material resources. This shows that managing waste in a sustainable way is an effort that adopts and implements a circular economy (Wainaina et al., 2020). More specifically, relevant organic waste management can contribute to realizing a circular economy. However, the economically justified potential for resource recovery from organic waste is not well understood (Ellen MacArthur Foundation, 2017). Therefore, studies are needed to determine the circular economy potential of organic waste management.

Various studies have been carried out to investigate opportunities for implementing circular economy concepts in waste management systems (Rada and Cioca, 2017; Wielgosi'nski et al., 2021; Kristianto et al., 2022; Islami, 2022). However, these studies only emphasize quantitative aspects that focus on recycled materials and do not involve much organic waste. On the other hand, several organic waste management technology options with resource recovery are available and widely applied, starting from anaerobic decomposition (AD), drying and compaction to produce solid fuel (Lohri et al., 2017: Gunamantha, 2020: Ajaero et al., 2023), processing with black soldier fly (BSF) to produce animal feed and fertilizer (Arabzadeh et al., 2022), composting, and processing into eco-enzymes (Benny et al., 2023). Currently, the technology commonly applied is composting. In fact, apart from becoming compost, organic waste can be converted into various products through different processing technologies, such as heat, clean fuel from AD, animal feed, and eco-enzymes.

This research intends to analyze the quantity of resources available in OFMSW streams and their potential market value which was generated in small regency.

Literature Review

Implementation of a Circular Economy for Organic Waste

The Circular Economy concept has been gaining momentum since the late 1970s (Ellen MacArthur Foundation, 2013). Several authors, such as Ghisellini et al. (2016), Kirchherr et al. (2017), and Geissdoerfer et al., (2017), Ekins et al. (2029), and the Ellen MacArthur Foundation (2017), attribute the introduction of the concept to Pearce and Turner (1990). By describing how natural resources influence the economy by providing inputs for production and consumption and serving as absorbers of output in the form of waste, they investigate the linear and open characteristics of contemporary economic systems.

In Indonesia, the Ministry of National Development Planning/BAPPENAS (2021) claims that the circular economy “refers primarily to the physical and material resource aspects of the economy – it focuses on recycling, limiting, and reusing physical inputs for the economy, and the use of waste as a resource that causes reduced consumption of primary resources. The Indonesian government has begun to pay great attention to this and is continuously reforming the urban waste management system by making it an important part of the green economy and sustainable development. Cities are a fitting context in which circular solutions for waste and resource management can be implemented, as well as other solutions to environmental challenges (Prendeville and Bocken, 2015). This of course also applies to OFMSW.

OFMSW is one of the most severe hygiene and environmental problems, especially among developing countries (Kyriakopoulos et al., 2019). Nowadays, due to the increasing gap between environmental sustainability and economic growth, the potential of OFMSW valorisation in developing countries as a solution to current waste disposal problems and as facilities to produce fuels, power, heat, and value-added products, is a contentious issue. Ajaero et al. (2023) show how it is possible to obtain energy from OFMSW. According to Ajaero et al., (2023) about 387.234 Nm^3 of biogas could be obtained from anaerobic digestion (AD) of OFMSW generated in the cities each year; about 0.23 tons of methane can be recovered from the landfill gas technology, while drying and densification will produce about 0.387 tons of solid fuel per ton OFMSW. Ddiba et al (2022) estimated the resource recovery potential of organic waste streams are faecal sludge (FS), sewage sludge (SS) and the organic fraction of municipal solid waste (OMSW). The resource recovery options are anaerobic digestion (AD), drying and densifcation to generate solid fuels, black soldier fly (BSF) processing to generate animal feed and fertilizer, and composting. The quantities of nutrients that can be recovered from FS are signifcantly higher than the recoverable quantities from OMSW and SS. but more energy can be recovered in products from OMSW than from FS or SS. Also, by using by using the mathematical model and secondary data, Ramadhan et al. (2021) found that the potential of electrical energy that can be produced can reach 8.6 GWh/day. Ramadhan et al. (2021) used mathematical model for WTE with thermal conversion, with energy conversion efficiency 18% for incineration and 25% (gas turbine) for gasification.

Basically, what Ajaero et al (2023), Ddiba et al. (2022), and Ramadhan et al. (2021) have done has placed more emphasis on waste to energy, except for Ddiba which also involves composting and processing with BSF. Currently, there is also a lot of interest in using organic waste to become eco-enzymes. Through fermentation with the addition of molasses and water, organic waste can produce eco-enzymes. Eco-enzyme liquid also contains alcohol and acid acetate. Therefore, ecoenzymes have many benefits (Benny et al., 2023). Therefore, this technology is also involved in this research. Another thing that differentiates it from previous research is that as far as possible it uses research data in the local area to consider the proximity of waste characteristics.

Key concepts and Indicators related to technology Options.

Anaerobic Digestion

Anaerobic digestion is a well-established process for processing organic waste, converting it into methane-rich gas that can be destined for energy generation. This methane-rich gas is usually known as biogas. Biogas is a versatile renewable energy source consisting of 50% methane (IPCC, 2006). Therefore, it can be used to replace fossil fuels in the production of electricity and heat. The amount of biogas produced depends on the biodegradability of the waste. Biodegradability is associated with the number of volatile solids (VS) because this parameter represents the organic content in the waste material. VS is a percentage of total solids (TS) and part of the VS will be degraded to produce biogas. The potential biogas yield from organic waste is usually expressed as biomethane potential (BMP) which is a measure of how much methane can be produced for each unit of VS in the waste material (Ajaero et al., 2023). Therefore, the potential of QB biogas in Nm^3 that can be produced from AD is calculated using equation (1).

$$QB = QS_{AD} \; x \; \frac{TS_m}{100} \; x \; \frac{VS_m}{100} \; x \; \frac{VS_D}{100} \; x \; BMP \; x \; \frac{100}{50} \qquad (1)$$

QS_{AD} is the quantity of organic waste streams (vegetables, fruit peels, kitchen waste, market) in ton, TS_m is the total solids content as a percentage of the total wet mass, VSm is the quantity of volatile solids as a percentage of the total solids, VS_D is the percentage of the volatile solids degradation rate which shows the VS fraction that decomposes into biogas during the AD process, and BMP is the biomethane potential of the waste organic fraction in Nm^3 CH_4/ton VS. It was determined that TS ranged from 5 – 37% (21%), VS organic waste ranged from 50 – 98% (74%), BMP 350 – 420 L CH_4/kg VS (350 – 420 m^3 CH_4/ton VS) with an average rta 370 m^3 CH_4/ton VS (PUPR, 2018). Referring to Vogeli et al. (2014), VS_D is set at 60% of VS. It is assumed that the biogas produced from the process will have a methane content of 50%, which is within the typical range (IPCC, 2006); hence, the last term of Equation (1) converts the amount of methane to the amount of biogas. According to PUPR (2018), 1 m^3 of biogas has an energy content of around 22 MJ. As for the efficiency of biogas transformation into electrical energy, for internal combustion engines it is 35%. So, the electrical energy (EL) obtained from biogas is calculated using Equation (2).

$$EL\ (kWh) = (QB\ x\ 22\ x\ E_M)/3{,}6 \quad (2)$$

EM is the efficiency of the internal combustion engine; 3.6 is the conversion from MJ to kWh.

The revenue that can be generated from biogas is calculated using equation (3).

$$Potential\ revenue\ from\ biogas = \ EL\ x\ HL \quad (3)$$

HL is the price of electricity in IDR/kWh based on the price determined by the Ministry of Energy and Mineral Resources of Indonesia (2014) for electrical energy from biomass and biogas of IDR. 1,080/kWh.

Apart from biogas, the AD process also produces digestate as a residue. Digestate can be applied to agricultural land, further processing is required to stabilize and reduce pathogens (Mastellone, 2020) assuming it involves drying and composting processes. The calculation to determine the amount of AD residue that can be obtained is based on the percentage of TS that becomes digestate (Y1) and digestate that becomes compost (Y2). The values Y1 and Y2 are adopted from Mastellone (2020). Then the quantity of digestate that has been stabilized or turned into compost, C_{AD} in metric tons, is calculated using Equation (4) in metric tons.

$$C_{AD} = \ QS_{AD}\ x\ \frac{TS_m}{100}\ x\ (Y1) x\ (Y2) \qquad (4)$$

The revenue that can be generated from digestate compost is calculated using Equation (5).

$$Potential\ revenue\ from\ digestate\ compost = \ K_{AD}\ x\ C_p \qquad (5)$$

Cp is the estimated price of the product on the market which is equivalent to compost, soil amendment or soil conditioner in IDR/ton, and C_{AD} is the quantity of compost digestate in tons.

Densification and drying to generate solid fuel

Densification involves compacting organic waste by applying mechanical force or sometimes a binding agent to create cohesion between particles, producing homogeneous briquettes or pellets with consistent shape and size, and whose bulk density ranges from 450 to 700 kg/m^3 (Lohri et al., 2017). Densification facilitates easier handling, reduces storage and transportation costs, increases consistent physical properties, and improves fuel quality, making compacted waste suitable for application as fuel. However, using organic waste to produce solid fuel for combustion, the main quality parameter that must be considered is the calorific value because this indicates the quantity of energy contained in the waste (Ajeore et al., 2023). The amount of solid fuel (SF) in tonnes produced from organic waste is expressed in equation (6). The assumption is made that the compaction process has a negligible impact on the overall mass of organic waste converted into solid fuel.

$$SF = QS_D \ x \ \frac{TS_m}{100} \qquad (6)$$

QS_D is organic waste including twigs and leaves (tons).

The energy content of the fuel, Esf (kWh), was calculated using the same approach as that used by Ajeora et al. (2023) shown in Equation (7).

$$E_{sf\ (kWh)} = QS_D \ x \ \frac{TS_m}{100} \ x \ 1000 \ x \ GCV \ x \ \eta \ x \ 0{,}277778 \qquad (7)$$

GCV is the gross calorific value of organic waste, which is the same as LHV in MJ/kg TS; η is the efficiency of conversion into electrical energy, and 0.277778 is the constant for the standard conversion of MJ to kWh. The calculated TSm is 21% (PUPR, 2018) and GCV (or LHV-MSW) is 17 MJ/kg (Gunamantha, 2020). The efficiency of collecting conversion into electrical energy of 25% is adopted from Cardenas-Rodriguez et al. (2021). The revenue that can be obtained from solid fuel is calculated using Equation (8).

$$Potential\ revenue\ from\ solid\ fuels = E_{sf} \ x \ HL \qquad (8)$$

HL is the price of electricity in IDR/kWh based on the price set by the Ministry of Energy and Mineral Resources of Indonesia for electricity from biomass of IDR. 1,080/kWh.

Black soldier fy processing

The use of BSF is a new technology in processing organic waste. This processing process involves the transformation of bio-organic waste into insect protein and insect oil (Lohri et al., 2017). The BSF can degrade organic waste by using its larvae to extract energy and nutrients from vegetable waste, food waste, animal carcasses and feces as food (Lohri et al., 2017). Bioconversion of food waste by black soldier fly (*Hermetia illucens* (L.) (*Diptera: Stratiomyidae*)) larvae (BSFL) is a promising solution for the management and valorization of organic waste streams (Dortmans et al., 2017; Arabzadeh et al., 2022). BSFL can feed on a variety of organic substrates, including food waste, processing residues, and human and animal waste to efficiently convert organic matter (OM) into a high-value biomass protein and fat source that provides a sustainable solution for both organic waste management and food security (Lohri et al., 2017; Arabzadeh et al., 2022). Frass is an important byproduct of the BSFL bioconversion process. Frass consists of larval feces, exuviates, and unconsumed raw materials; a few recent studies have reported its use as an organic fertilizer (Lopes et al., 2022; Arabzadeh et al., 2022). Like other organic amendments such as compost or vermicompost, frass is considered a very valuable source of nutrients for horticultural crops to improve soil structure, provide slow-release micro and macro nutrients, minimizing excess nutrients and runoff into the environment (Arabzadeh et al., 2022). Frass originating from BSFL raised from food waste had an average NPK value of 4.54; 1.23; 2.44 (Arabzadeh et al., 2022). Beesigamukama et al. (2021) evaluated the frass produced by BSF larvae fed a diet of spent brewer's grain containing 21 g kg^{-1} N, 11.6 g kg^{-1} P, and 1.7 g kg^{-1} K.

In BSF processing, the bioconversion rate (BCR) is an important factor that shows the efficiency of BSF larvae production (Hosseindoust et al., 2023). BCR is the percentage ratio of the dry mass of larvae produced to the dry mass of the substrate (Hosseindoust et al., 2023). This indicates the efficiency of waste conversion by BSF larvae into useful energy (Beesigamukama et al., 2021). According to Dortmans et al. (2017), the conversion rate of waste-to-biomass (larvae) is up to 25% of their total weight. Equation (9) is used to calculate the number of BSF larvae (tons) that can be obtained from organic waste (food waste).

$$BSF = QS_{BSF}\ x\ \frac{TS_m}{100}\ x\ \frac{BCR}{100} \qquad (9)$$

BCR is in percentage, QS_{BSF} is the quantity of organic waste streams (vegetables, fruit peels, kitchen waste, market waste) in tons, and other parameters as explained in the previous section.

BSF larvae contain around 35% protein and 30% fat (Dortmans et al., 2017), so that the protein and fat content in the number of BSF larvae are calculated using Equations (10) and (11), respectively:

$$Protein\ content\ in\ BSF\ larvae\ (ton) = BSF\ x\ 0.35 \qquad (10)$$

$$Fat\ content\ in\ BSF\ larvae\ (ton) = BSF\ x\ 0.30 \quad (11)$$

The revenue that can be generated from BSF larvae is calculated using Eq. (12).

$$Potential\ income\ from\ BSF\ larvae = \ BSF\ x\ BSF_p \quad (12)$$

BSF_p is the estimated price of BSF larvae in IDR/ton on the market. The basic production price for BSF maggots is Rp. 2,700/kg (Widodo et al., 2021) with a selling price of around IDR. 5000/kg.

Residues from BSF processing are used as compost through a drying and composting process for stabilization (Dortmans et al., 2017). Calculations to determine the amount of stabilized residue from the BSF treatment process consider the reduction in dry weight because of bioconversion by BSF larvae and during composting. Referring to Dortmans et al. (2017), 70% total reduction was used. Therefore, calculations are carried out using Equation (13).

$$R_{BSF} = QS_{BSF}\ x\ \frac{TS_m}{100}\ x\ \left(1 - \frac{DMR_{BSF}}{100}\right) \qquad (13)$$

R_{BSF} is the amount of stabilized BSF residue in DM metric tons, DMR_{BSF} is the percentage reduction in the dry weight of the residue due to drying and composting.

The revenue that can be generated from residual compost after BSF processing and stabilization is calculated using Equation (14).

$$Potential\ revenue\ from\ BSF\ residue = \ R_{BSF}\ x\ C_p \qquad (14)$$

Cp is the estimated price of a product equivalent to soil amendment or compost on the market in IDR/ton (IDR 500/kg).

Composting

Composting involves the controlled aerobic decomposition of organic materials by microorganisms resulting in a relatively stable organic product called humus. According to Elfeki et al. (2017) 40-50% of the initial substrate becomes compost through an aerobic composting process. Setyawati (2013) reported that 46.4% of compost was produced from organic waste through aerobic composting. In this paper it is set at 45%. Therefore, the amount of compost that can be obtained, C_m (tons) is also calculated based on the TS of waste using Equation (17).

$$C_m = QS_C \; x \; \frac{TS_m}{100} \; x \; Y \qquad (17)$$

Y is the percentage reduction in dry weight of waste due to the composting process. The revenue that can be generated from compost is calculated using Equation (18).

$$Potential\ revenue\ from\ compost = C_m \; x \; C_p \qquad (18)$$

Cp is the price of compost in IDR. 750/kg (Situmeang, 2020).

Eco-Enzym

Eco-enzyme is a type of natural compound that can be extracted normally from citrus fruit peel or waste and various other organic waste. Changes in kitchen waste such as vegetable and fruit peels. These Eco-enzymes are produced by complex fermentation. Eco-enzyme is a type of vinegar made by fermenting food waste with sugar to form alcohol. Eco enzyme is a fermentation solution made from a mixture of sugar, fruit peel and water mostly in a ratio of 1:3:10 (Benny et al., 2023). Making this eco-enzyme only uses kitchen waste at home such as vegetables, fruit peels and food waste. Eco-enzyme solution contains many types of natural enzymes derived from fruit and vegetables, as well as those produced by microbes. Therefore, eco-enzymes have many benefits in the fields of health, agriculture and improving environmental quality, including being used as organic plant fertilizer, compost mixture, healing various types of wounds, aromatherapy liquid, air purifier, hand sanitizer, dish soap, and others. clothes detergent, toilet drain cleaner, and various other benefits (Yuliani et al., 2022; Benny et al., 2023). Yuliani et al. (2022) reported that 0.8 L of Eco-enzyme was produced from every liter of the total mixture of raw materials. Therefore, the amount of Ecoenzyme that can be obtained, L, is calculated by equation (20).

$$Ee = Y_{EE} \left(M + QS_E \; x \; \left(1 - \frac{TSm}{100}\right) + Air \right) \quad (20)$$

Ee is the Eco-Enzyme produced (L); M is added molasses (L); QS_E is the quantity of organic waste flow (vegetables, fruit peels) in tons, Y_{EE} is the conversion yield (0.8); Water is the amount of water added. (the ratio of sugar: waste: water is 1: 3 : 10).

The revenue that can be generated from Eco-enzym is calculated using Equation (21). The price per 10 L of Eco-enzym is IDR. 20,000 (Ramli and Peniyanti, 2021).

$$Potential\ revenue\ from\ Ee - enzym = C_{Ece} \; x \; C_p \qquad (21)$$

Cp is the price of eco-enzyme in IDR/L.

Residues from processing to eco-enzym production also require further treatment for stabilization and the assumption is made that this treatment may consist of a simplified drying and composting process. Therefore, calculations to determine the amount of stabilized residue, the reduction in dry maater due to bioconversion by microorganisms as well as further reduction in dray matter during fermentation. Equation (22) is used for the quantity of waste input in metric tons.

$$R_{EE} = QSE\ x\ \frac{TS_m}{100}\ x\ Y_c \qquad (22)$$

R_{FE} is the amount of stabilized fermentation residue (tons), Y_C is the percentage of compost produced due to fermentation of residue from the eco-enzyme process (13%) referring to the compost obtained from digestate during anaerobic decomposition.

The revenue that can be generated from the residue after BFE processing and stabilization is calculated using Equation (23).

$$Potential\ revenue\ from\ residuals\ REE = R_{EE}\ x\ C_p \qquad (23.$$

Methodology

In this research, a quantitative approach was used to measure the potential for circular economic recovery of urban organic waste flows. This is done by quantitatively estimating the products that can be produced from each resource recovery option based on material flow analysis. In this case, a linear relationship between the physical and chemical quality parameters of the waste stream and the potential quantity of resource recovery products from each technology optios were involved. For each technology, quality parameters that determine the quantity of recoverable resources were identified from the literature. Mathematical relationships between the related parameters and the quantities of recoverable resources and usable products were also adopted and developed based on the data available in the literature. The resource recovery technology options involved were anaerobic decomposition (AD), drying and compaction to produce solid fuel, black soldier fy (BSF) processing to produce animal feed and fertilizer, ecoenzymes, and composting. This technology was selected based on which is currently the most mature and commonly used for resource recovery from organic waste in Indonesia.

Organic waste data managed by the Singaraja city government, Buleleng Regency, Bali, Indonesia is used as a case study. Two scenarios were assessed for both case study sites; the first is based on the amount of organic waste collected by the current city government (Scenario 1) and the other is based on the projection amount of organic waste that can be collected by increasing the coverage and efficiency of waste management infrastructure and logistics up to 2030 (Scenario 2).

This research uses secondary data. There are four main groups of data required. First, data on the quantity of organic waste obtained from management agencies in the local city area. Second, data on physical and chemical quality parameters and energy content of waste. Third, data relating to the processing process and potential quantity of recovery products from each technology involved. Fourth, price data is used to estimate the revenue potential of resource recovery products. The last three data were obtained from the literature, especially from articles published in scientific journals. In more detail, the required data is presented in table 1.

Table 1. Physico-chemical quality parameters and processing process parameters are used to determine the amount of resource recovery product.

Resource Recovery Products	The processing parameters and data are used to determine the amount of resource recovery product.
Biogas	Total Solids (TS), Volatile Solids (VS), Biomethane Potential (BMP), Degradation rate of volatile solids
Solid Fuel	Total Solids (TS), Calorific Value (CV)
Larva	Total Solids (TS), Biomass Conversion Rate (BCR)
Compost	Total solids (TS), Percentage reduction in dry mass during composting (DMR), Nitrogen, phosphorus, and potassium content in compost (NPK)
Eco-enzyim	Total Solids (TS),

Detailed steps for applying the method to estimate circular economic potential**.**

Estimating the sircular economic potential from organic waste requires valuing product from each technology options, which can be achieved using quantity and characteristic of organic waste. The following steps can be taken to apply these methods to estimate the economic circular of organic MSW:

Step 1: Identify the procees, parametres and product in each technology.

The first step in estimating the circular economic is to identify the product that can be valued. This may include compost, energy, or other products that have economic value.

Step 2: Collect relevant data.

Once step one has been identified, the next step is to collect relevant data. This may include data on the characteristics of the organic waste and parameters process, such as the size of the total solid (TS), volatile solid (VS), Biomethanation potential (BMP), efficiency/yield process, etc. It may also include data on the economic value of products, such as the price of compost, electric energy, eco-enzym, and larva.

Step 3: Model to estimate product from each technology.

The linear correlation of the related paramters were used to model for product estimation. This involves transforming input into product. The model can be used to calculate the main product and residu, considering the convertion effeciency. The conversion efficiency (e.g. kg output product/kg OFMSW input) of each each technology was estimated based on data available in the studies and applying conversion factors from literature. The unit of conversion efficiency depends on the type of products produced.

Step 4: Use main parameters to simplify mathematically complex relations that may arise in the estimation product. This involves linear relation.

Step 5: Estimate the circular economic potential.

Once the products have been estimated, the circular economic potential can be calculated by multiplying this value to the price. In this, the potential revenues of the identified products (IDR) were estimated from the output and data on market prices.

Results and Analysis

Referring to Ministry of Environment and Forestry of Indonesia Regulation No. 6 of 2022 concerning the National Waste Management Information System, the calculation of waste generation is based on Tier 1. Tier 1 is a calculation of the estimated waste generation based on the population multiplied by the estimated waste generation factor determined by the ministry that carries out government affairs in the field of environmental protection and management.

potential waste generation = number of populations × waste generation estimation factors

The estimated factors depend on the city classification. Based on the population in urban areas, Singaraja is included in the medium city category because the population has exceeded 100,000 but is less than 500,000. So, the estimation factor used is 0.5 kg/person/day (PUPR. 2021).

Waste growth is calculated based on the contribution of household consumption expenditure to GRDP (gross regional domestic product). This refers to Daskalopoulos et al. (1998) which proposed that the generation of waste is a consequence of human activities. It was further emphasized that human activity is indicated by the contribution of total consumer expenditure (TCE) to GDP. This means that an increase in a country's GDP or rgions GRDP also indicates an increase in TCE. In the local context, the contribution of household consumption expenditure (including non-profit private institutions) in the formation of GRDP indicates people's purchasing power so that consumption increases. This means that an increase in household consumption will lead to an increase in the amount of waste produced.

Based on Buleleng GRDP target on 2023 in the Buleleng Regency Regional Development Plan for 2023-2026 (Buleleng District Regional Government, 2022), in this study, GRDP growth of 3.3% was used. Processed from Buleleng in figures, an average household consumption expenditure contribution of 48.80% are considered. So, waste growth is assumed to be 3.3 x 0.488 or 1.61% annually.

Another thing that is also involved in determining waste generation projections is service coverage. Based on the results of data processing, the current coverage of waste handling services in Buleleng Regency has only reached 28%. Furthermore, service coverage is assumed to increase from year to year as presented in table 2. the percentage of 67.27% organic waste shown in table 2 is the average value of the percentage of organic waste from 2019 to 2022. This average value is then used and assumed to remain constant in subsequent years. The organic waste involved for this purpose is only food waste and wood-twigs, excluding paper/cardboard.

Table 2. Projection of organic waste generation

Year	Popula-tion	Service covering (%)	kg/cap/ day	Organic (%)	Organic waste (Ton/y)
2021	807,000	28	0.50	67.27	27740.60
2022	825803	30	0.51	67.27	30904.27
2023	845044	35	0.52	67.27	37489.08
2024	864734	40	0.52	67.27	44548.81
2025	884882	45	0.53	67.27	52110.84
2026	905500	50	0.54	67.27	60203.95
2027	926598	55	0.55	67.27	68858.42
2028	948188	60	0.56	67.27	78106.12
2029	970281	65	0.57	67.27	87980.53
2030	992888	70	0.58	67.27	98516.89

Based on feedstock requirements, the distribution of OFMSW processed in each technology is shown in the table 3. These organic waste fractions are involved differently for each processing technology. In processing with AD and composting it involves food waste and garden waste as input, in densification all fractions are involved, whereas for BSF and Eco-enzym it only uses food waste as input.

Table3. OFMSW processed in each technology in 2023

Technology Options	Food Waste (%)	Garden waste (%)	Total (%)
Anaerobic Digestion	3.24	64.03	67.27
Densification and drying	-	64.03	-
Composting	-	64.03	-
BSF Processing	3.24	-	-
Eco-enzym Production	3.24	-	-

The results of this study indicate that more energy recovery is obtained from the compaction and drying process compared to the anaerobic decomposition process. For OFMSW was generated in 2023, the potential electrical energy that can be generated from the densification and drying process is 8644.80 MWh. This potential is obtained from 34,869 tons (64.03%) OFMSW which be processed through densification and drying. This means that every ton of organic waste will produce 0.274 MWh or 274 KWh from the densification and drying. This result is lower than Ajaero et al. (2023) who reported that the energy potential of densification and drying processes per ton of treated OFMSW was 0.55 MWh/ton waste (densified solid fuel) but more higher than incineration 0.211 MWh/ton. In anaerobic decomposition process involving food waste and garden waste (leaves and twigs). Through this process the potential electrical energy obtained is 1475.35 MWh or 0.039 MWh/ton waste. In this process, the amount of organic waste considered to be processed was 37,489.08 tons (67.27%). This value is much lower than that obtained from densification. The results is also lower those reported by Ajaero et al. (2023). Ajaero et al. (2023) has reported 0.43 MWh/tonne of waste recovered from the AD process. This is possible due to the low biodegradability of waste. However, the densification and drying process requires a large initial energy for the compaction and drying process.

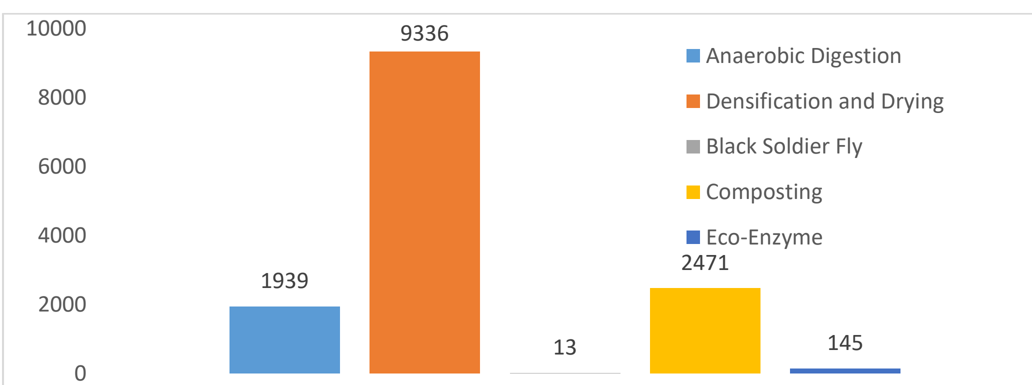

Figure 1. Cellular Economic Potential for organic waste generation in Buleleng Regency for 2023

The potential for collecting energy from this waste is inline to the potential revenue obtained. Figure 1. shows that the potential revenue from densification and drying is much greater than from the anaerobic digestion process. However, consideration of investment, operational and maintenance costs has not been involved. If we look at the installed power, electricity production, and electricity sold in Bali, respectively amounting to 301 MW, 349,328 MWh, and 334,423 MWh (Central Bureau of Statistics, 2022), the percentage of electricity demand in Buleleng Regency that can be supplied by generators waste to energy can be estimated. According to the value reported by Central Bureau of Statistics, the electricity consumed is assumed to be the same as the electricity sold by generators in the Buleleng Region in 2022, which is 334.423 MWh. This means that there is potential to cover 2.58% of this demand through densification and drying technology. Organic waste for energy as a renewable energy source. In this case, it can contribute to obtaining 23% renewable energy in the energy mix in Indonesia in 2025 and 31% in 2050 as stated by the government in the Energy Policy Guidelines (National Energy Council, 2019).

In processing with BSF, 451 tons of larvae potential can be produced from food organic waste generated in Buleleng Regency for 2023. In contrast to anaerobic decomposition, only food waste is processed through a process with BSF. In composting, While with composting, 3,295 tonnes of potential compost is produced with potential revenue of IDR. 1,645,000,000. in 2023. The potential is quite large when it comes to the distribution of subsidized granular organic fertilizer (tons), 2021 in Bali which reaches 2,145.20 (Ministry of Agriculture, 2021). By changing the form of bulk organic fertilizer to granular organic fertilizer, this of course has the potential to save state finances. Table 4 summarizes the potential energy and resources that can be recovered from projected organic waste managed in Buleleng Regency until 2030.

Table4. Projections of resource and energy potency from managed organic waste in Buleleng Regency until 2030

Technology Options	**Resources/Energy**	**Quantity**							
		2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Anaerobic Digestion	Biogas (1000M^3)	690	820	959	1108	1267	1437	1619	1813
	Electricity (MWh)	1475	1753	2051	2369	2710	3074	3462	3877
	Digestate (ton)	461	547	640	740	846	960	1081	1210
	Revenue (IDR. million)	1939	2304	2695	3114	3561	4039	4550	5095
Densification and Drying	Electricity (MWh)	8645	10273	12017	13883	15878	18011	20288	22718
	Revenue (IDR. million)	9336	11095	12978	14993	17149	19452	21911	24535
BSF Process	BSF Larva (ton)	451	536	627	725	829	940	1059	1186
	Residue BSF (ton)	542	644	753	870	995	1129	1271	1423
	Revenue (IDR. million)	13	15	18	20	23	26	30	33
Composting	Compost (ton)	3295	3916	4580	5292	6052	6865	7733	8659
	Revenue (IDR. million)	2471	2937	3435	3969	4539	5149	5800	6495
Eco-enzym Production	Eco-enzym (Liter)	5363	5635	5927	6239	6572	6929	7309	7715
	Compost (ton)	76	91	106	122	140	159	179	200
	Revenue (IDR. million)	145	158	171	186	201	218	236	254

Conclusion

This research shows that there are a number of resources hidden in the organic fraction of municipal waste and these can be recovered using a circular economy approach. At current levels of waste collection, there is

significant potential for resource recovery from the organic waste stream through products such as biogas, densified solid fuels, compost, insect larvae and eco-enzymes. Densified solid fuel has proven to be the best option to introduce the organic fraction into the circular economic model, because the energy content of the biomass. It found out that the potential energy and revenue from the densification and drying reaches 8645 MWh and 9336 million IDR. The second highest potential revenue is through the composting process followed by anaerobic digestion. As for the BSF and eco-enzyme processes, the revenue generated is relatively small, this is because only food waste is considered and can be processed in this way. As a note that, this analysis does not yet consider investment, operational and facility maintenance costs. H
owever, the research can support efforts to implement a circular economy in organic waste management. Given that the results are influenced by the quantity and quality of the organic waste stream, it is important to check the data used. For example, the physical and chemical characteristics of waste can of course vary with time and source. TS and calorific value are determined by the type of organic waste that dominates it. This highlights the need for detailed waste characterization as part of the feasibility process for any technology option.

Declaration

Acknowledgment: The authors are grateful to the Research Institute and Community Service of Universitas Pendidikan Ganesha.

Funding: The research was funded by Universitas Pendidikan Ganesha

Conflict of interest: The authors declare no conflict of interest.

Authors contribution: I Made Gunamantha: devised the project, the main conceptual ideas and proof outline, conceived of the presented idea, derived the models and analysed the data, supervised the project, and contributed to the final manuscript. I Gede Astra Wesnawa: verified the analytical methods, encourage and supervised the findings of this work. Ni Made Vivi Oviantari: collected the data, performed the analysis, and worked on the manuscript. Ni Wayan Yuningrat: analysis of the results and worked on the manuscript.
Ni Putu Lilik Pratami Kritiyanti: collected the data performed the analysis. Komang Widiadnyana: collected the data and performed the analysis.

Data availability: This research relies on literature and secondary data. The mathematical models were adopted from literature. Data sets of organic waste generation and composition were estimated from population and the average waste composition on the last three year in area study.

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