Roadmap for a circular bioeconomy in Banyuwangi

Exploring the value creation potential from organic waste in Banyuwangi, East Java, Indonesia: Roadmap towards 2041

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Lead author

Ketil Stoknes, PhD Senior project leader R&D Lindum

+47 47 01 57 04

ketil.stoknes@lindum.no

Co-author

Amalie Lundervold, M.Sc Bioeconomy, Norwegian University of Life Science

Contributors

Avfall Norge

Clean Oceans through Clean University (CLOCC)

UNTAG University

Summary

Waste is a global problem, threatening the environment and human prosperity if not dealt with properly. In Banyuwangi regency, East Java, waste is 65% organic. This is the key fraction in terms of greenhouse gas emissions (GHG), and proper onsite source separation and valorisation of this fraction would facilitate further sorting and treatment of other waste fractions, cut pollution, mitigate climate change, protect and restore the rich biodiversity in the area, as well as create jobs and business opportunities for the inhabitants. Based on field work and data collection, this report describes available biomass from several sectors - municipal waste, sewage, agriculture and fisheries - and technologies to convert them into protein feed, biogas and biofertiliser.

The proposed roadmap is a stepwise valorisation of the biomass available today, towards a circular bioeconomy where more than 75% of the potential of most fractions is realised within 2041. The total basis today comprises annual amounts of 156,000 tonnes of food waste; 84,000 of sewage (human faecal sludge); 4700 of shrimp aquaculture sludge; 242,000 of crop residues and 45,000 of green municipal/garden waste. In addition there is potentially a very large amount of cattle manure from smallholder farms where only 9% is included in the calculations. Such a development can create annual amounts of 730 GWh available renewable energy, 266,000 tonnes of CO_2 abatement, 13,000 tonnes of renewable fertiliser (equivalent to 12% of today's mineral fertiliser consumption), 17,000 tonnes of compost, 3100 tonnes of protein feed, as well as 400 jobs.

This roadmap is a part of the Clean Oceans through Clean Community (CLOCC)'s work on solid waste management in Banyuwangi, and the report is a co-product of the Integrated Sustainable Waste Management Master Plan for Banyuwangi Regency.

Abbreviations

AD - Anaerobic Digestion (the process of producing biogas and biofertiliser from organic waste)

CHP - Combined Heat and Power (in biogas plants: electricity and heat production from raw biogas)

BSF - Black Soldier Fly. Insect reared on waste for its larvae/maggots/high quality protein

BSFL - Black Soldier Fly Larvae (maggots)

ISWMP - Integrated Sustainable Waste Management Master Plan

Introduction

This report explores the value creation potential from organic waste in Banyuwangi regency, Indonesia, and draws a roadmap towards a circular bioeconomy for the area. The work has been conducted as a part of the CLOCC program, a community network and network-driven initiative established by Avfall Norge in cooperation with the International Solid Waste Association (ISWA) and Indonesian Solid Waste Association (InSWA) (CLOCC, 2023). CLOCC is funded by Norad, the Norwegian Agency for Development Cooperation. CLOCC's goal is to reduce marine plastic pollution and microplastics, through improving waste management in countries where high quantities of waste leaks into the environment.

Banyuwangi intro

With its 5. 720 km2, Banyuwangi is the largest regency in the East Java province, with a population of 1.788.112 spread across 25 sub-districts. It is located at the easternmost end of Java Island, surrounded by mountains and forests to the west; by sea to the east and south. Banyuwangi is separated from Bali by the Strait of Bali. Muncar is the highest populated sub-district with 8% of the population. However, the density of people is highest in the Banyuwangi sub-district. The annual population growth rate is close to 1% (CP, 2020).

Banyuwangi's agricultural sector represents 82% of the total economic activity in the regency. It also has a large fish processing and shrimp aquaculture industry and is a tourist destination.

Waste - a huge environmental challenge

Waste is a global problem, and if not dealt with properly is a huge threat to public health and a source of pollution (UNEP, 2015). Open burning, burial and dumping of waste, directly or indirectly, affect public health, e.g. infectious diseases and developmental disorders among children (UNEP, 2015). It also leads to global warming, pollution of groundwater, soil and marine environments. Therefore, waste management is high on the global agenda. Waste management is now embedded in over half of the United Nation (UN) Sustainable Development Goals (SDGs), explicitly or implicitly. This means that working towards better global waste management is a huge contributor to achieve the SDGs (UNEP, 2015). At the same time, a paradigm shift is seen in the EU, which now demands an increasing amount of circularity in all kinds of products and services (European Commision, 2020). In addition to global pollution, resource scarcity and the loss of biodiversity and soil fertility is an undercommunicated issue. In light of the current situation with increased prices on food, fuel and fertilisers, a circular bioeconomy has the potential to reduce the pressure on virgin and scarce resources, restore and protect biodiversity, recover nutrients, reduce fossil fuel use and improve social and economic sustainability.

By 2050, global annual waste generation is assumed to increase by 70% (European Commision, 2020). Waste generation is a direct result of increased population and economic growth, and is highly related to GDP. With an increasing Indonesian population and economic growth in SouthEast Asia, the amount of waste is assumed to increase. An assumption of the Integrated Sustainable Waste Management Plan (ISWMP) is an increase in generated waste from a current 850 tons per day to 1400 tons per day in 2040 in Banyuwangi regency (ISWMP, in press). This highlights the urgent need for systems, infrastructure, solutions, skills and human capital to handle this in a sustainable way.

The area is now experiencing how poor waste management affects their life foundation. The most common disposal practice is burial, open dumping in landfills and burning or disposal to local rivers. As a consequence of this, Banyuwangi has signalled a strong desire to improve solid waste management and waste practices to protect the environment. Therefore, Banyuwangi was selected by CLOCC to be included as a case for a fully integrated waste management system.

Banyuwangi has an untapped potential to monetize and value its organic waste through conversion to feed, biofertilizer and renewable energy. The Banyuwangi Waste Data Baseline Report (CLOCC, 2021) showed that food waste is the main waste fraction of municipal solid waste, both in rural and urban areas, across all income levels, both household and non-household. The waste consists of 65% organics. Food waste accounts for 50% and green waste 15%. In addition, 72% of the total weight of land-filled waste is organic, of which 50% is food waste.

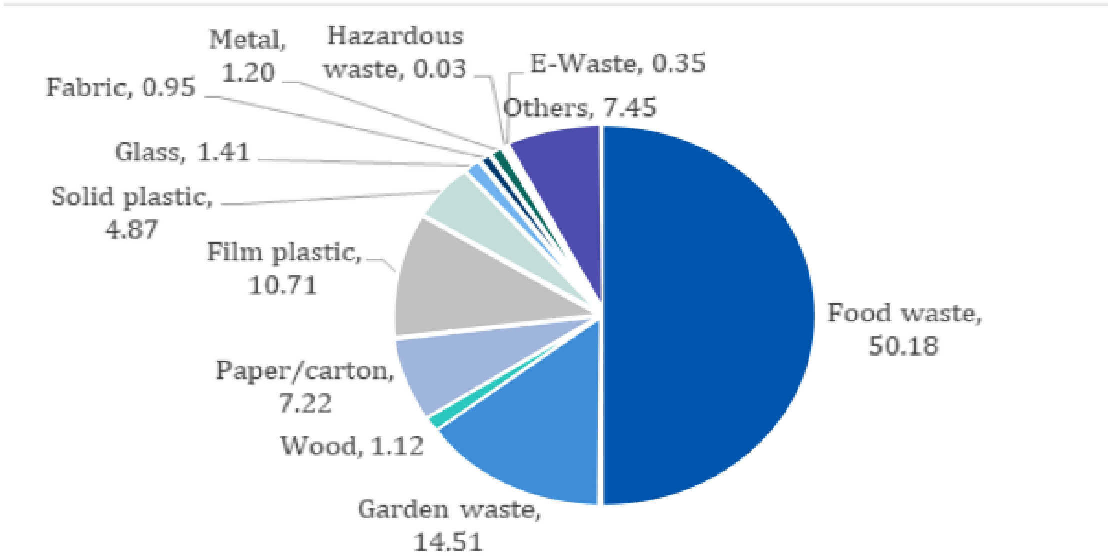

Figure 1: Baseline waste composition of all MSW household and non-household combined (CLOCC, 2021)

Organic waste or biodegradable waste is waste generated from living material or residues from animals, plants, agriculture, aquaculture, which can be degraded by microorganisms. About 554 tons of organic waste is generated daily in Banyuwangi, equal to approx. 202 212 tonnes per year of theoretically available biomass for valorisation, excluding aquaculture and agriculture. Organic waste is a key fraction in terms of greenhouse gas emissions, due to the release of methane when land-filled. Methane is a 20 times more potent greenhouse gas than CO2. During the first 20 years after its release into the atmosphere, it is approximately 85 times more potent. According to ISWMP the annual emissions are likely to be from 0.3 to 1 ton CO_2 equivalents per ton mixed waste landfilled, depending on several factors like organics content, operational factors, climate and compression of waste. There are huge costs and emissions related to collection, sorting, treatment, transport and landfilling of waste. Therefore, by removal of the organic fraction through segregation (source separation) and collection, a theoretical potential of 65% reduction of waste transported and dumped at landfill is possible. This will dramatically reduce the costs and emissions from disposal of waste and at the same time contribute to a cleaner environment while creating new income and jobs.

Wastewater (sewage) is closely connected to the generation of municipal organic waste. Poor or missing treatment is a serious threat to health, as it can contaminate drinking water. Nearly 70 per cent of the 20,000 household drinking water sources tested in Indonesia as part of a recent study (UNICEF, 2022) are contaminated by faecal waste. This facilitates the spread of diarrhoeal disease, which is the leading cause of death in children under five years. The global average person generates 47 kg of faecal waste per year (Jain et al, 2019). It is probable that ⅔ of sewage is not treated safely, as an average figure for Indonesia (Nisaa & Hajrah, 2018). Non-treated wastewater does not only contaminate drinking water; even more directly than other organic waste, it leads to pollution of aquatic environments. So clearly a lot remains to be done within sanitation and wastewater systems in Indonesia. The opportunity is that this can be synergistically combined with treatment of other organic wastes in anaerobic (biogas) digestion plants.

Challenges of agriculture and fisheries

Agriculture

The majority of crop production in Banyuwangi is based on mineral fertilisers. Nitrogen (N) is produced from natural gas, while other elements such as phosphorus (P) potassium (K) and magnesium, are extracted from mines mostly in China, Morocco, Russia, Belarus and the USA. Besides being unsustainable (e.g. P reserves being limited, GHG released during manufacture and use, surplus leached into waterways and long term use leading to loss of soil carbon and fertility), this leaves Indonesian farmers vulnerable to international wars and politics. Indonesia is now also cutting subsidies on mineral fertilisers (Global Trade Alert, 2022). Our survey also confirmed, as expected, an extensive use of pesticides. Over time, this also degrades soil and the health of the agro-ecological life support system, as well as the health of farmers spraying them.

Residues such as straws are often burned in Banyuwangi. As found during our study, this is particularly the case for rice, corn, soy bean and chilli. Open burning of agricultural residues and waste in general emits black carbon particles (soot). This has direct negative effects on climate, human and animal health, as well as on agricultural yields.

Industrial animal farming (where animals are held together within a limited space) is not common in the area. However, there are a significant number of cows spread in the rural districts. These animals are in periods fed, and thus animal manure accumulates within concentrated areas, which, if not handled, leads to fly problems, odours, emissions and local pollution.

Seafood industry and aquaculture

The processing industry generates residues and sludges. The factories in the area produce frozen and canned products, as well as fish meal and oil. Such processes typically produce effluents high in organic content and nitrogen. Wastewater discharged untreated may lead to marine eutrophication like algae blooming, asphyxiation, fish death, emergence of invasive species and decline in biodiversity (the latter an important asset for a tropical tourist destination). Even though the facilities visited by the team in this project had high levels of resource recovery and good wastewater treatment plants, it is uncertain how much nutrients are discharged into the environment in the area.

Shrimp ponds take in freshwater and seawater (to form “brackish water” in which the shrimp lives), which eventually is discharged back into the sea. According to Boyd et al. (2007), the water use in such ponds may be 20000-100000 m^3 per tonne of production. Feed spills and excrements form solids which sediment into sludge (despite ever better adjusted feed formulae); in addition smaller suspended solids are formed. 30 % of nitrogen, 80 % of phosphorus, 60 % of organic matter and 90 % of solids commonly follow the theoretically harvestable solids (Campanati et al, 2021). Organic material, when dispersed in the water column at high concentration, is a threat to shrimp health. Thus, if organics were removed, higher production densities would be possible. In other words, better handling of wastewater may be beneficial for both farm productivity and for the surrounding environment.

Circular bioeconomy as a solution

Bioeconomy has been identified as a key component in the global sustainability transition. The world's heavy reliance on non-renewables and fossil based products has severe ecological, socio-economic and environmental impacts (Bastos Lima, 2022). The last 60 years, human activity has been highly consumptive and extractive, causing a massive loss of biodiversity, extensive waste generation and huge pressure on resources (Ellen MacArthur Foundation, n.d.). Hence, this roadmap for a circular bioeconomy in Banyuwangi will explore the benefits from increasing segregation of organic waste, utilisation and valorisation, as a step towards a sustainable waste management system in Banyuwangi. The new bioeconomy has the potential to substitute fossil based products, while at the same time, promote circular economies, create jobs and valorise biodiversity and biomass products - an agenda that comply well with the global sustainable development goals.

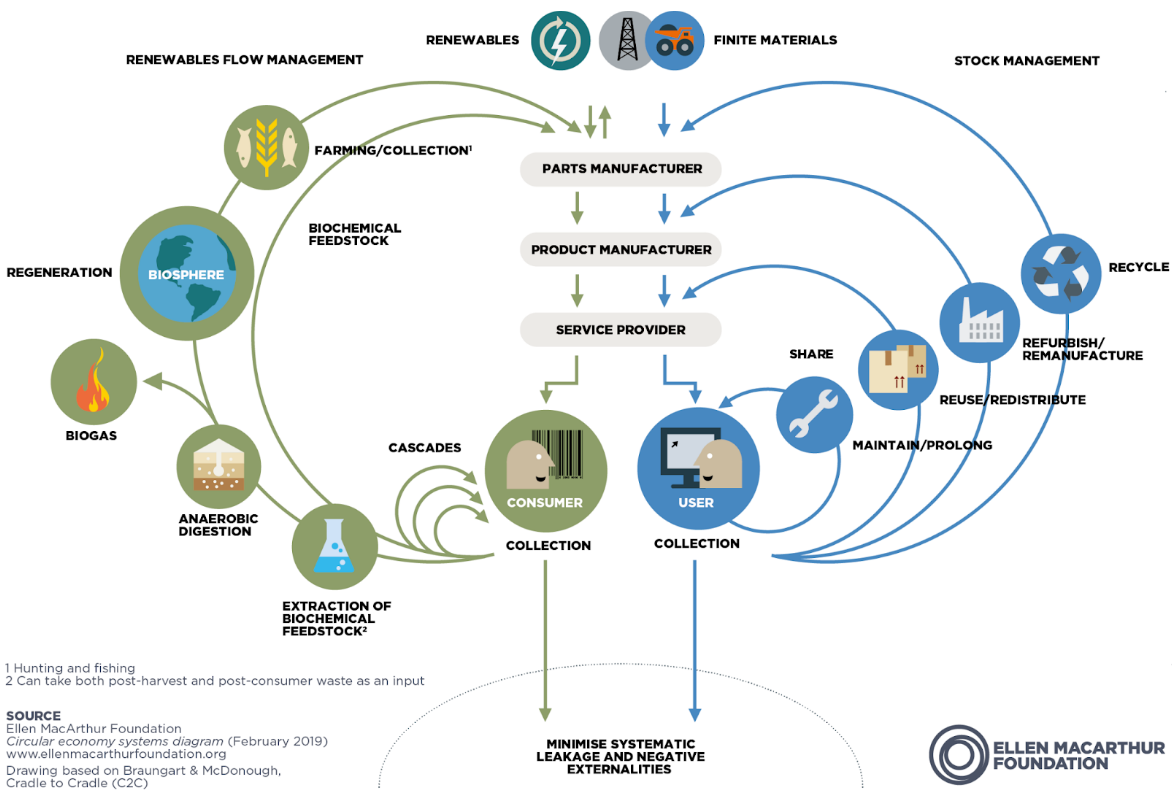

Figure 2. The Ellen Macarthur Foundation (2019) vision of a circular economy for the biological (green left) and technical (blue right) cycles. This study deals with the green cycle.

A well acknowledged way of thinking to create or enable a circular economy is the framework developed by the Ellen MacArthur foundation. A circular economy has a philosophy to keep materials in use for as long as possible, at the highest quality possible. This has historically been the case for materials such as valuable metals and plastics. However, the principles can easily be translated into the biological materials as well; keep them in loop as long as possible, at the highest possible quality. "Cascading use", is the idea of using what materials we have, all the time in the most valuable way, through consecutive steps. In Banyuwangi, a good example of this is to convert fresh food waste into insect larvae for feed, then use the remaining waste as fertiliser. From being extractive and consumptive for so many years, this thinking represents a phenomenal opportunity to regenerate the biological system. Towards enabling a circular bioeconomy in Banyuwangi, we can flip the perception from how to minimise negative impacts to how to create more profitable systems and products. Examples are systems that hold more water, regenerate top soil or promote resilience to climate damage. By keeping organic materials such as food waste, fibres, human waste and plant residues in the loop as long as possible and feeding them back into the system we can achieve systems more resilient to climate change

Figure 3. An example of a circular concept which creates synergies and benefits for all parties involved. The Magic Factory (2023) is a biogas plant in Norway receiving municipal and commercial source separated food waste as well as manures from cow, pig and fish. The output is biomethane (CBG, which fuels public buses, trucks and local food industry, and LBG, serving more distant markets), biofertiliser (digestate), which has substituted most of the mineral fertiliser in the area, and CO_2, which is used in a greenhouse.

Relevant technologies for valorising organic waste

Preventing food waste from entering the landfills has a huge positive effect on both greenhouse gas emissions and global food security (UNEP, 2015). Food waste is high in nutrients and organic matter and therefore has a great potential as substrate for protein production (e.g. insect larvae or mushrooms), biogas production, and biofertilisers which can substitute mineral fertiliser. We consider bioconversion and anaerobic (biogas) digestion (AD) the two most relevant technologies for valorising organic waste in Banyuwangi.

Bioconversion

Bioconversion is the direct transformation of organic materials (such as plant residues or food waste) into valuable products by biological processes such as enzymes or microorganisms (Surendra et al, 2020). Black Soldier Fly (BSF) is an insect that's gaining rising attention, especially in low- and middle income countries, due to its possibility to grow on several organic materials such as food waste, manure and agricultural residues, as well as its ability to substitute conventional animal feed (Surendra et al, 2020). Food conversion rate (FCR) is a measure of how efficient food sources are converted into a desired product like flesh or weight gained. From fresh food waste, a FCR of 4:1 is assumed for BSF. This equals to approx 1:1 in dry matter conversion to fresh larvae. The life cycle of BSF is explained in the figure below. Two days after the male and female mate, females lay approx. 500-900 eggs. The eggs hatch after about 4 days, then larvae need about two weeks to develop. Later, the prepupae disperse away from the food source to finalise the development towards an adult (Surendra et al, 2020).

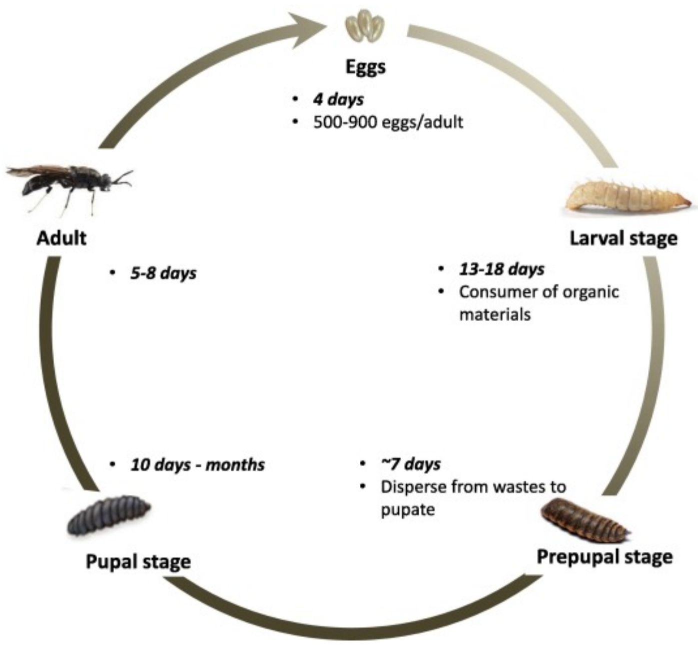

Figure 4: Life cycle of Black Soldier Fly. Source: Surendra et al, 2020

BSF converts food waste into protein- and fat rich larval, prepupal and pupal biomass that can be utilised as animal feed and organic fertilisers. Inclusion of BSF larvae in animal diets has shown promising results as a substitute for conventional feed ingredients such as soybean meal and fish meal (Surendra et al, 2020). Hence, BSF farming is one way of lifting food waste from disposal at the bottom of the inverted triangle, to provide valuable protein for animals (see figure 5). In addition, the residues left by the BSF larvae is a valuable biofertiliser.

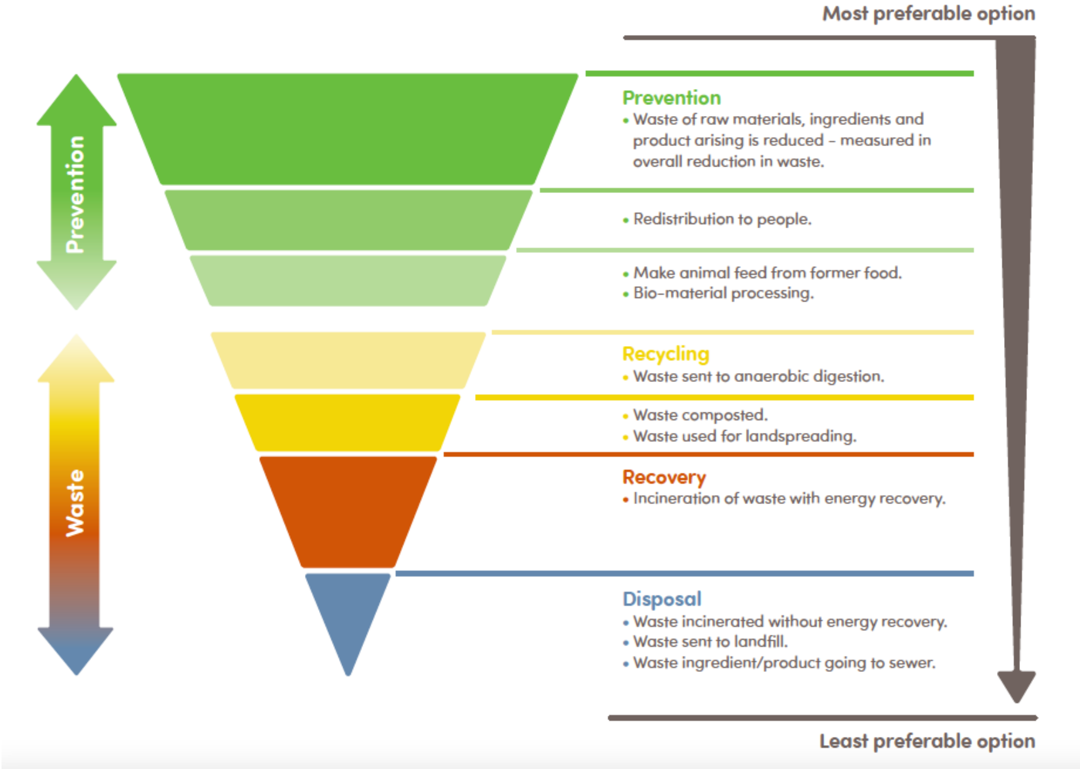

Figure 5: Food waste disposal hierarchy. Source: (Primmer, 2021)

Anaerobic biogas digestion

The principle of lifting waste streams higher in the food waste hierarchy, also applies to anaerobic digestion (AD). AD is a biological process in which microorganisms degrade organic matter in the absence of oxygen. The digester residue, known as digestate or biofertiliser, contains all the nutrients such as nitrogen, phosphate and potassium, which can then be returned to food production.

Methane emissions from land-filling mixed waste *can* be eliminated by incinerating the waste, and even better in the form of waste-to-energy, by first making refuse derived fuel (RDF), which can substitute coal in power plants. However, AD has a whole set of advantages compared to these solutions. As summarised by Primmer et al (2021): "When organic wastes are recycled through an AD plant, carbon savings are delivered across multiple fronts:

- the harmful GHG emissions they would otherwise emit are prevented
- the energy they contain is extracted in the form of biogas, which is a mixture of biomethane and CO_2, displacing fossil sources of energy and associated CO_2
- the nutrients within organic wastes are recycled into an organic fertiliser (or 'digestate'), replacing the need for artificial fertilisers which are very energy intensive to produce
- the carbon in the digestate is returned to soil (regenerating soils)
- unlike fossil fuels, which are extracted from the ground, the carbon in biogas originates from the atmosphere and is contained within the organic wastes

- CO_2 can be captured and stored, making the process carbon negative and actively reversing carbon emissions. Alternatively, CO_2 gas may be used within industry – e.g. food and drinks manufacture, refilling fire extinguishers etc – or to create platform chemicals. CO_2 and biomethane are also compatible with a hydrogen future and the creation of bio-based fuels for aviation and shipping." (p. 8).

At the same time, it is very versatile in scale, from household to large industrial, and in terms of suitable substrates, which may be most forms of organic material, wet or dry, such as food waste, wastewater slurries, manures and crop residues. The production of biogas is also continuous (baseload) and does not suffer from the fluctuation of other renewables, making biogas a perfect integrator to solar, wind and hydro. Biogas can produce heat, electricity and fuel, all off-grid, and depending upon the geography and setting, one or the other uses may be more beneficial. The central role of AD in the new bioeconomy is clear from figure 3 (and 12 below).

At its full potential, if all available wastewaters, manures and organic wastes are treated in AD, it is estimated that it can cut global GHG emissions by 10%. Half of this comes from reduction in emissions from the waste, and the other half from displacement of fossil fuels and artificial fertilisers (Primmer et al, 2021). Biogas can also be converted through "precision fermentation" into microbial protein ("methylotrophic" bacteria living on methane, ammonia and other nutrients which can be provided from digestate). This is an emerging technology and may add to increasing the abatement potential of biogas even further.

Composting

Composting is also a good circular solution for diverting organic waste from landfills, with the potential to return carbon and nutrients to soils in the final product. However, there are some disadvantages, including not providing useful energy to substitute fossil fuels, it is not suitable for wastewaters and other liquid slurries, and a lot of the nitrogen is lost during composting. Compost as an end-product is a great soil amendment or component of potting soil, but the lower level of plant available nutrients makes the product just that, meaning, it is not regarded as a fertiliser to substitute mineral fertilisers directly (which digestate can). The fact that composting also has been attempted at recycling stations in Banyuwangi, without much operational success, added to the decision not to select it as the key solution in this project. However, we see it as an important solution for green (garden) waste, and fibre fractions from pre-treating crops residues before AD.

Study objectives

The primary purpose of the assignment is to get an overview of the biowaste volumes and composition from various sectors, both commercial markets, industry (cut offs and residues from agriculture, byproducts, fats and sludge from fish processing and canning), hotels and restaurants.

The targets of this roadmap towards a circular bioeconomy is to provide a specific approach and map organic waste resources and sectors that produce a significant amount of biowaste and provide a potential solution to valorize biowaste as part of a circular bioeconomy. The objectives of this report are listed in the following

- Map the key stakeholders and decision-makers within the biowaste
- Analyse existing solutions and infrastructure for biowaste valorisation (compost, biogas, black soldier fly (BSF), refuse derived fuel (RDF), and other)
- To explore the demand for solid/liquid fertiliser/feeds for the target industry (agriculture, fishing, etc)
- Access the fishing canning industry in Muncar (sub-regency) and see the potential for valorising the waste from the fishing industry
- Identify the existing and potential new value chains of biowaste
- Explore and discuss the problems and obstacles in providing economically valuable solutions for biowaste among the stakeholders
- To recommend a sustainable system for circular bioeconomy for the regency's biowaste, including recommendations for potential investments and cross-sectoral cooperation.

In addition to these targets, a map including all fish industry, shrimp farms, agricultural hot spots and infrastructure to show potential substrates available for valorization and the infrastructure connected was wanted. Moreover, to focus on increasing the knowledge of potential benefits of valorizing organic biomass as biofertilizer, animal feed, BSF production and renewable power supply among the community. Also, how this may contribute to less expenses, and at the same time reduce the pressure on poor infrastructure, reduce emissions to air, water and soil and clean up the environment.

Data collection and methods

The waste data baseline for Banyuwangi is generated primarily using WasteWise City Tools, a UN-Habitat developed method for monitoring waste in cities. This method enables evidence based waste planning and fact based data, resulting in enhanced environmental sustainability and improved quality of life for inhabitants (UN-Habitat, n.d.). Since this report is a co-product of the ISWMP, data from ISWMP is used for background information. In addition to data from the baseline report, field trips, interviews and literature review for supporting data was used. Additional data needed for a more comprehensive understanding of the current situation were provided by UNTAG university in Banyuwangi after the field trip. This included an overview of shrimp farms and the fish processing industry. Also, data from the agricultural sector, including commodity type, waste generated per hectare, fertiliser use and current management was obtained from UNTAG after the field trip. These data were obtained from the Agricultural department and are considered reliable and trusted data. The field trip was conducted in November 2022 and included several on-site visits to agriculture and aquaculture sites, as well as landfills, village offices and recycling stations ("TPS3R"). During the field work, interviews with people in charge were made, followed by a guided tour to learn more about processes and routines. The field work gave a good understanding of the possibilities, challenges, bottlenecks and level of knowledge among citizens.

Available biowaste and biomass

Food waste

The baseline report (CLOCC, 2021) states that out of the 853 tonnes of municipal solid waste generated daily, 65% is organic waste. It includes both food waste and green waste. Residues from agriculture and aquaculture come as an addition to food and garden waste.

If we assume that all of the 50% with food waste generated from households is collected and utilised, this equals a theoretical amount of 426 tonnes of food waste from households available for valorisation each day, equal to **156,000 tonnes per year**. However, field work indicates that livestock (particularly in rural areas), are fed with food scraps and therefore these waste streams are considered a sufficient utilisation due to production of protein for human consumption. Also, livestock generate manure which is valuable as fertiliser and soil amendment, and by this reduce the need for mineral fertilisers in rural areas.

Although a sufficient amount of food waste is generated from households, additional data provided by UNTAG after the fieldwork, revealed a sufficient amount of food waste from hotels and restaurants to seed the replication of BSF pilots with immediate start. Data from fifteen restaurants and hotels in the regency, reveals a total amount of food waste generated each year at 300 tonnes (180 from hotels and 120 from restaurants). PEGA Indonesia, an innovative company who produces BSF from food waste collected for free in the nearby area, already valorises food waste. Fruit and vegetable market waste (today driven to landfills, probably a part of the food waste included in figures above) can also be a readily available high quality feedstock for BSF.

Agriculture

Crop residues

Banyuwangi regency is a large agricultural area (which represents 82% of the total economic activity in the regency), cultivating primarily rice, dragon fruit, maize, chillies and oranges as the main crops Table 1). Both rice and corn cultivation generate substantial amounts of green straw waste (60,000 and 65,000 tonnes of dried material, respectively). However, due to agricultural practices, much of this material dries on the field and/or is used as animal feed. In fact, for rice, maize/corn, soy bean and chilli, burning of plant residues was reported. Dried straw is more mechanically challenging as a substrate in an anaerobic digestion (biogas) process, and would need a more complicated pre-treatment to be used than would fresh green straw. Its collection and valorisation potential in such a value chain needs further investigation, even though we assume all of the crop residues not used as feed today can potentially be collected. Dragon fruit leaf cuttings, on the other hand, are succulent (thick waxy leaves that don't dry as easily) and lack alternative uses today. This juicy waste can be pre-treated by a simple screw press to generate a liquid substrate for biogas production. The total amount is estimated to be 66,000 tonnes and emerges as the most promising biomass resource for combining with food and fish wastes in a biogas value chain.

Our analysis reveals a total amount of **approx. 242,000 tonnes per year** of potentially available crop waste from agriculture in Banyuwangi Regency. From this, dragon fruit leaves contributes the most readily available biomass. Our data survey also contains fertiliser consumption per hectare. According to Knoema (2023) the average fertiliser consumption in Indonesia is 248 kg/ha[1].

Commodity Type	Planted Area, ha	Typical yield of crop, kg/ha	Crop residue, tonnes	Fertiliser use, tonnes	Fertiliser use, kg NPK/ha (assuming 15-10-12)
Rice	119108	5000	91113 straw(65%), husk(26%), bran (9%)	65,509	204
Corn	32602	5000	81505 straw & husk(80%), cob(20%)	27,712	315
Soybean	5135	4000	2568 straw	1,284	93
Dragon Fruit	3685	20000	66330 succulent leaves	8,107	814
Oranges	7532	-	0	7,532	370
Small chilli	79.6	-	159	-	-
Large Chilies	125.5	-	251	-	-
Melon	175	-	70	-	-
Watermelon	1110	-	444	-	-
Total			**242,000**	**110,144**	

Table 1: Total amount of agricultural green waste distributed between commodities. A full table including current assumed crop waste management is given in Appendix 2. Spreadsheets used can also be provided from CLOCC.

[1] Our data is based on the average number of 50 kg fertiliser bags (sacks) used per hectare of which an NPK of 15-10-12 is common. However, other types of fertiliser are also used, such as pure N fertilisers. Thus, the data in the table is only an approximation

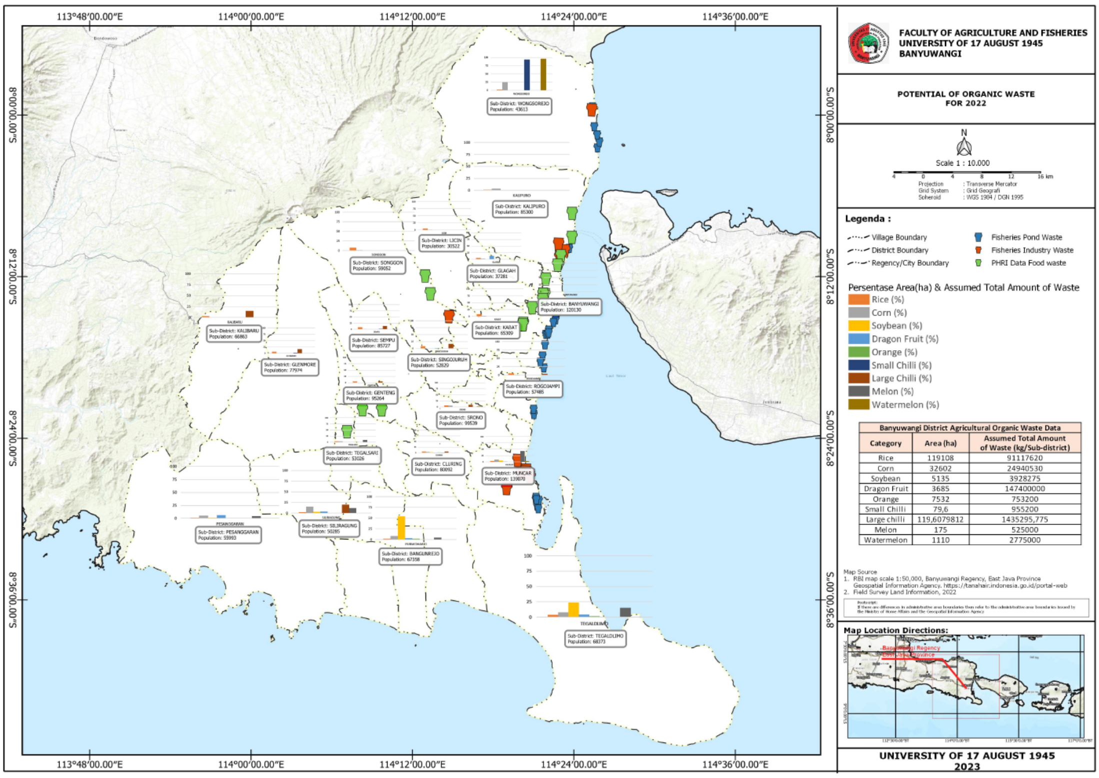

Figure 6. A high resolution map has been made showing Banyuwangi's distribution of agricultural crops with amounts, location of shrimp ponds, fish processing factories and points of available restaurant and food waste.

Manure

Cattle farming is important in Indonesia, but mostly in the form of smallholder livestock farms. We have made a preliminary assumption, using cattle only, which is the most important animal producing most manure in one place (e.g. during feeding), where it can theoretically be collected. However, since industrial production is not developed, herds are small and spread, and we have therefore so far assumed limited treatment and biogas production from manure in Banyuwangi (in our roadmap scenario presented below, only 9 % is used by 2041, comprising only small farm scale digesters. Because of poor road standard it is not likely that a large fraction of manure can be transported and utilised in larger more centralised AD plants).

Assumption on amount of cattle manure:

East java cattle 2018 (CEIC, 2023)	4,657,567
East Java human population (2019)	40,000,000
Number of cattle per person in Banyuwangi if average of East Java	0.116
Number of cattle, total in Banyuwangi if average of East Java	208,206
Manure produced per cow, 20 kg/day (Ariningsih et al., 2022), tonnes/year:	7.3
Manure produced total for Banyuwangi, tonnes/year	**1,519,906**

Seafood industry

Fish processing factories

Banyuwangi has the biggest aquaculture and fish processing industry in Indonesia. Wild caught fish (e.g. sardines and tuna) is processed into various products, frozen, canned, fish meal and fish oil. Steam for canning, fish meal and fish oil cooking is produced by burning coal. Trimmings, by-products are commonly converted to fish meal and oil, and in the factories the authors visited, even material in wastewater from the processing lines was recycled back to products, thus, “waste” handling is profitable, which therefore apparently limits emissions from these factories.

It is still unclear how much of the organic material and nutrients pass the factories own wastewater treatment plants (WWTP) and end up in the environment (such as mineralised nitrogen, which is normally not removed in WWTPs). It is also unclear if all these facilities have WWTPs. This has to be assessed further in cooperation with factory owners. According to Campanati et al. (2021) considerable amounts of effluents high in organic materials and nutrients are produced from such industries. The low volumes of sludge we identified during our visits are not included in our calculations below. Then what about the nitrogen? According to Campanati et al. (2021), referring to other studies, 17 L of effluent is produced / kg of fish canned (15 L /kg skinned), containing 20–470 mg/L total nitrogen. Even if effluents after the WWTPs of Banyuwangi factories were still in the higher range, a calculation based on the total production in the area (of 2673 tonnes of product) gives a total of only 20 tonnes of nitrogen. This is very little compared to sewage sludge, which contains 600 tonnes of nitrogen in total.

Shrimp aquaculture

With a total area of shrimp ponds at 187 hectares Banyuwangi is one of the largest producers of shrimp in Indonesia (Delphino, et. al. 2022). The distribution of shrimp ponds can be seen in the map above (Fig 6). Shrimp residues such as heads and tails, sediments, sludge and wastewater, all together add up to significant amounts of waste. Shrimp residues contain a high content of protein and fat, which can boost biogas production when mixed with other organic content. The fact that shrimps are cultivated in brackish water, with a salt content higher than optimal for anaerobic digestion, is a challenge. However, if the sludge is dewatered before co-digestion with other substrates, these waste streams can be valorised.

Shrimp farm (Tambak Windu Bulusan) north of Banyuwangi centre visited Nov 22 by the authors. Photo: Ketil Stoknes

Shrimp pond farming can be more or less intensive. More intensive production with more water handling, aeration and cleaning, means more feed can be added to a higher number of shrimps per area of pond. Most ponds in Banyuwangi are intensive. There is water exchange in the ponds, which produces some sediment sludge in external sedimentation basins at some farms, but most ponds do not have sludge collections systems, making them necessary to empty and clean out at certain intervals. The water is a mix of fresh and sea water (brackish water with a salt concentration approx. a third of sea water).

Super-intensive systems, and even recirculating systems (RAS) using biofloc technology, represent a greater potential to collect the sludge, and in the case of biofloc even reuse nutrients, as well as a greater potential for improved shrimp survival and reduced emissions (Emerenciano, et al. 2022). Collecting and removing sludge reduces the production of compounds toxic for the shrimps (i.e. ammonia and H_2S). Of course, the more intensive the more investments are needed. Thus, an intensification of shrimp aquaculture, at least systems for collection of sludge, demands capital, but may simultaneously represent an opportunity for more profit and for diverting sludge away from natural waterways to become valorised as additional commodities in the form of biogas and biofertiliser. Since the sludge is brackish (contains salt) it is necessary to dewater before co-digesting it with other organic wastes such as food waste or crop residues from agriculture.

Some pond farmers in the area are looking at sludge collection in connected sedimentation basins. Even though this represents an opportunity for valorisation, improving production and reducing discharges to the sea, removal of sludge sediments from large rectangular ponds is challenging. Intensification of shrimp aquaculture, such as converting to smaller circular mechanised ponds can, on the other hand, go hand in hand with more efficient methods for collecting sludge (see fig. 7). In such systems even more of the suspended particles and dissolved substances can be removed, enabling more recirculation (using less water).

Fig. 7. Circular ponds in Situbondo, north of Banyuwangi, which enable more effective sludge collection. Picture: © MMAF, from Bulkini (2021)

According to collected data on shrimp farming obtained from UNTAG, Banyuwangi has 187 hectares of shrimp farming, with total application of feed at 4468 tonnes of feed each cycle. If we assume 3,5 cycles per year, a total of 15 637 tonnes of feed is applied to shrimp ponds in Banyuwangi each year. If collected, these waste streams from shrimp farming can contribute to approximately 5000 tonnes per year of shrimp sludge of quite high dry matter content; exact value to be investigated further. In the roadmap calculations in the coming section below, the following assumptions have been made: sludge production rate of 0.3 compared to feed use (information given from the industry through UNTAG). 4 % total nitrogen / dry matter in the sludge (based on various articles), and a dry matter content of 30% (dewatered sludge). The biomethane potential has been set conservative (low, equal to manure) since the volatile solids content may be low in sludge which has resided for months in the ponds and because of a high salt content.

PEGA informed us that the BSF larvae were fed to catfish. Possible catfish aquaculture in the area should be investigated. Google maps indicates such activity in Banyuwangi.

Sewage

In general, sanitation systems in Indonesia are divided into two types: onsite and offsite. Open defecation practice, however, still occurs in some places in Indonesia. The onsite sanitation system consists of a private and a communal septic tank (improved toilet where desludging is needed), an integrated communal shower-handwashing-toilet facility (the toilet discharges directly to the decentralised separate sewer), and an unimproved toilet with a lined tank with impermeable walls and an open bottom (e.g. cubluk). Meanwhile, the offsite system comprises a citywide centralised sewerage system, a decentralised system for the domestic and non-domestic sector with treatment reactors (Nisaa & Hajrah, 2018).

In Banyuwangi there is a wastewater treatment plant, the Banyuwangi Regency Fecal Sludge Treatment Installation Service (IPLT) which was built in 1993-1994 and managed by the Banyuwangi Regency Environmental Service (DLH). In mid-2022 (May-June) the management will be (was?) transferred to the Public Works and Spatial Planning Office of Banyuwangi Regency. It is said that the operation was abandoned in 2012 and only started again in May-June 2022. The condition of the IPLT is not good and is still in the process of being rebuilt. The Province has given advice to conduct an audit through the Sanitation Engineering Center of existing buildings and installations. The plant includes an anaerobic treatment step, an "Imhoff tank", which should be capable of producing biogas, which should be used through CHP to power the plant itself and possibly provide heat for other purposes, such as drying digested sludge. The capacity was said to be 66,000 tonnes. In our scenario we have assumed that this plant commences operation and is therefore included in our calculations of treated sewage from start. We have in the later steps of the scenario roadmap assumed that sludge collected from more distant decentralised tanks can be treated in other centralised large biogas plants to be built.

As for volumes we have assumed an average global per capita generation. As mentioned above, the global average person generates 47 kg of faecal waste per year (Jain et al, 2019). As there are no assessments of local sludge production as far as we are informed, we have simply multiplied this with the number of inhabitants.

Market drivers, opportunities and barriers for biowaste valorisation

An overview list of relevant incentives, programmes and policy support schemes is given in appendix 1 and as an attached spreadsheet.

Policies

Climate change

As the world's largest archipelago, with rich biodiversity, and the fourth most populous country with more than 250 million people, Indonesia has an international commitment towards improving sustainability.

Within the submitted Intended Nationally Determined Contributions (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC), Indonesia is developing policies, planning, and intervention programs for NDC implementation, integrating mitigation in five sectors (forestry, energy, IPPU, waste, agriculture) and adaptation (sectoral and regions) into development planning to secure financial support (public fund) and facilitate resource mobilisation (domestic sources and international supports) (NDC, 2021)

Waste management (Regional Strategy Policy, JAKSTRANAS)

For the waste management sector, the Government of Indonesia is committed to developing a comprehensive strategy to improve policy and institutional capacity at the local level, enhance the management capacity of urban wastewater, reduce landfill waste by promoting the "Reduce, Reuse, Recycle" approach, and the utilisation of waste and garbage into energy production from households and small industries.

The Government of Indonesia is committed to further reducing emissions from the waste management sector by 2020 and beyond through comprehensive and coherent policy development, institutional strengthening, improved financial and funding mechanisms, technology innovation, and sociocultural approaches. Indonesia's current policy on municipal waste management has been constituted by Presidential Decree Number 97/2017 on National Policy and Strategy on Solid Waste Management. The decree promotes its policies, strategies, programs, and waste reduction targets by 2025, under Presidential Regulation Number 35/2018 on Acceleration of Construction of Thermal Generation Facilities for Converting Waste into Electricity Energy with Environmental Sound Technology. In the additional decree, biowaste with its amount has a high potential to be valorized through Refuse Derived Fuel (RDF) and biogas. This decree for the first time includes in its strategy the need for valorizing organic waste through biogas from solid waste management, while NDC includes the agricultural and fishing sectors.

President Regulation No. 97/2017 is a roadmap toward the 2025 Clean-from-Waste Indonesia (MoEF, 2020). It targets 30% waste reduction from source and 70% waste handling by 2025. Indicators for waste reduction include decreasing waste generation per capita, reducing waste at source (e.g., plastic bag restriction), and reducing waste leakage to the environment. For the "70% handling" target indicators include increasing waste to be treated (recycling, composting, biogas, thermal recovery, etc.) and reducing waste to landfill (MoEF, 2020). Through these targets, the Ministry of Environment and Forestry aims to reduce 70% of marine plastic by 2025.

30% REDUCTION BY 2025	**Indicators:** 1. Decreasing waste generation per capita 2. Reducing waste at the source (community based 3R) 3. Reducing waste leakage into environment	**Leads to 70% Reduced Marine Plastic by 2025**
70% HANDLING BY 2025	**Indicators:** 1. Increasing treated waste (recycling, composting, biogas, thermal recovery, RDF, etc.) 2. Reducing landfilled waste 3. Reducing waste leakage into environment	

Source: Presidential Regulation No. 97/2017

Figure 8. National Policy and Strategy on Solid Waste Reduction (JAKSTRANAS, 2017)

Further information about local waste policies are found in ISWM master plan (in press spring 2023).

Anaerobic digestion and biofertiliser production

Since 2020, there has been a strong push from the Indonesian government to reduce fossil fuels import, increase energy security and meet GHG reduction targets (Setiawan, et al. 2022). The government has pledged to meet net zero emissions before 2060, and global methane reduction at 30% before 2030. The General Plan of National Energy states that, by 2025, biogas capacity should reach 489.8 million m^3 per year. The biogas industry in Indonesia has been growing since 2010 due to palm oil and tapioca industries (which are often remotely located and have readily available substrates (processing liquor) for covering their own energy needs using AD and CHP). Even though the government has introduced several measures to increase investments in biogas development, the full potential is yet to be realised (Setiawan, et al. 2022).

The current biogas status in Indonesia is a total production of 28.3 million m^3 categorised into basically two different types of plants. The micro scale/household scale and the industrial scale. The Indonesia Domestic Biogas Program (IDBP) is a multi-stakeholder's program which aims to disseminate renewable energy through small-scale household biodigester systems also known as Domestic Biogas or Biogas Rumah (BIRU) in 16 provinces. Its main goal is to create a market for domestic biogas in Indonesia. By the end of 2021, the program has constructed 26,818 units of BIRU in different capacity ranges from 1 m3 to 20 m^3. In East Java there are now 8,700 digesters. Most of the recently constructed ones in this area have digester tanks between 6 and 10 m^3 (IDBP, 2021). "Fixed dome" are concrete digesters often used for co-digestion of human and animal manure, with additional kitchen waste, while the BIOMIRU (Home Mini Biogas) is smaller, taking up less space and mostly for kitchen waste. Sewage can be treated in everything from Fixed dome to large industrial centralised plants (Fig. 9).

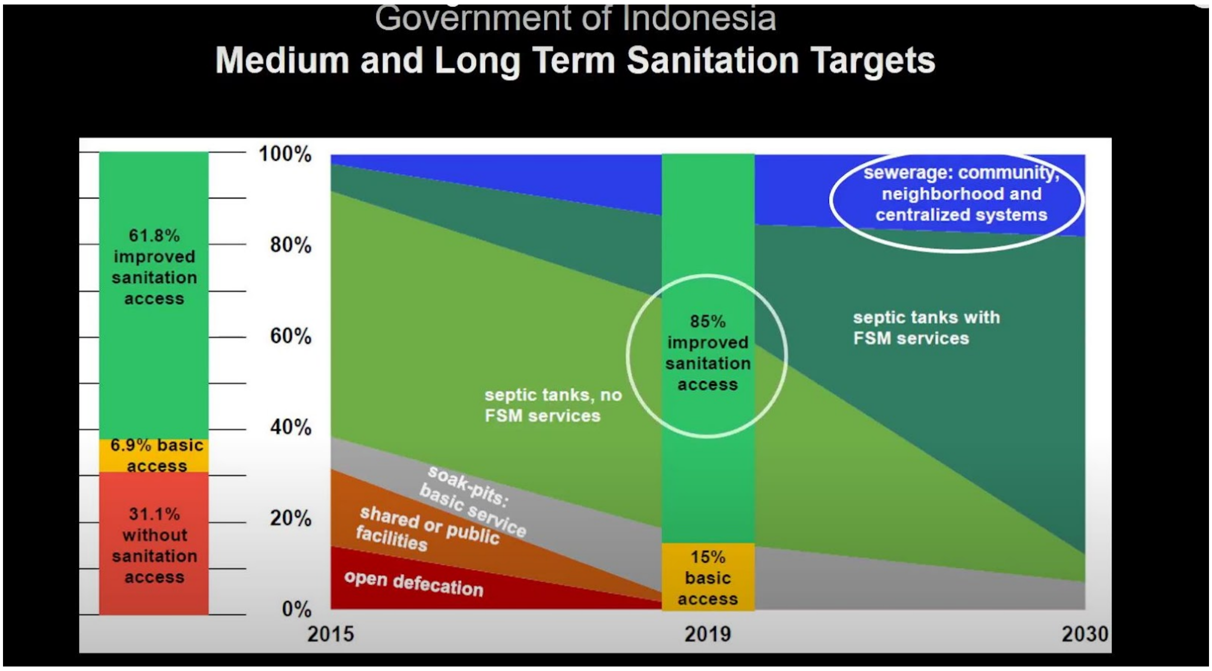

Figure. 9. There is a huge opportunity for biogas in connection with development of sanitation and sewage treatment. The aim is to ramp up the Faecal Sludge Management (FSM) drastically, which implies transport to more or less centralised plants which should at least cover their internal energy needs by using the biogas (Source: Blackett, 2017).

Today, biogas production in Indonesia only accounts for 5.8% of the national target at 489.8 million m^3. Of this, 78 industrial scale plants are in operation and producing 161 MWe. The total biogas potential in Indonesia is 2 952 MWe, and is mainly driven by waste water from tapioca and palm oil industries which produce "digester ready" organic matter that decomposes and releases methane (Setiawan, et al. 2022). As we will see below for Banyuwangi, manure, food waste and agricultural waste contribute to substantial amounts of waste available for biogas production.

There are several drivers for increasing the biogas development in Indonesia. For instance, fertiliser cost equals up to 30-40% of the operational cost in the palm oil industry. If digestate was utilised as fertiliser, large financial savings could be provided for agriculture, and at the same time reduce mineral fertiliser import, increase soil health and recycle valuable nutrients (Setiawan, et al. 2022). Additionally, the Indonesian government seeks to improve energy security, increase electricity supply from renewable sources, reduce fossil fuel imports, comply with the Global Methane Pledge and have intensified financial incentives to increase biogas development in Indonesia (Setiawan, et al. 2022). Hence, the timing for developing the biogas and biofertiliser value chain is good at present. See details about relevant incentives, programmes and policy support schemes given as in the appendix.

Although the timing is good for developing a value chain for biogas, there are still technological, political and financial barriers that prevent the development. Natural gas and fossil fuels have been heavily subsidised and therefore biogas and biomethane (upgraded biogas) competes with cheap fossil fuels. In addition, the grid connectivity in a country consisting of 17.000 islands is relatively underdeveloped and with low technical standards, which would require huge investments to develop a biogas network. Industrial scale biogas plants can help on the reliance on imported fossil fuels, and small scale/household biogas plans could provide the 50 million people currently without energy (Setiawan, et al. 2022).

Digestate is a rather new product, which is a challenge. This may lead to digestate being underutilised due to lack of regulatory guidelines, absence of fixed procurement prices and poor marketability by fertiliser companies (Jain and Javed, 2023).

Mineral fertilisers

In addition to generating substantial amounts of green waste, agricultural practices in Banyuwangi are highly fertiliser consumptive. As presented above on table 1, the total consumption of mineral fertiliser in regular agriculture in Banyuwangi is approx. 110,000 tonnes. However, when the average fertiliser consumption is given (for a crop or area) this is commonly given as a sum of NPK elements in the fertiliser. If a composition of 15-10-12 (meaning the percentage of these elements in the product) is used, this means that 110,000 recalculates to approximately 41,000 tonnes. When this report states that 12% of Banyuwangi's mineral fertiliser use can be substituted with digestate in 2041, this figure is based on the elements themselves.

Fertilizer prices										
Product						Indonesia				World bank
	Contents %					IDR	IDR	EUR	EUR	EUR
					Size	Price /kg,	Price /kg,	Price /kg,	Price /kg,	Price /kg,
Sold in Banyuwangi	N	P	K	S	bag, kg	subsidised	non-subs	subsidised	non-subs	non-subs
Phonska	15	10	12	10	50	2500	19000	0,15	1,14	
SP-36		36		5	50	2800	3600	0,168	0,216	
Urea	50				50	2300	7500	0,138	0,45	
World bank										(Dec 2022)
DAP (di-ammonium-phosphate)	18	46								0,576
Triple superphosphate (TSP)		45								0,538
Urea, E. Europe	46									0,478

Figure. 10. Overview of prices for mineral fertiliser

Coal use in the fish processing industry in Banyuwangi

The fish processing industry is an energy intensive production, running mainly on steam from coal. As described in the chapter for the seafood industry, the authors visited one of the biggest fish processing plants, to examine the waste management and potential substrate for biogas production. However, waste and organic residues from this industry were recycled back into the process through onsite wastewater treatment plants and the discharge therefore seemed limited. It became clear that a potential synergy between biogas plants and fish processing was that of energy. A rough estimate based on figures from the visit (and production volumes from the other factories) indicates a total consumption of coal at 3639 tonnes annually in Banyuwangi. This equals an energy content of 24 379 792 kWh (24.4 GWh). If the fish processing industry in Banyuwangi could be provided with raw biogas for their steam boilers, the biogas produced would have a stable and dependent buyer, ensuring utilisation of the biogas. Additionally, utilisation of biogas in the fish processing industry has the potential to significantly reduce the environmental footprint, provide energy security, contribute to circular bioeconomy, and with the right incentives, reduce operational costs as well. Hence, exploring the synergies between biogas plants and fish processing seems to be a feasible solution to decrease coal consumption, and decarbonise the industry in Banyuwangi.

Protein feed (BSF)

Valorising organic waste with BSF larvae (maggots) is becoming increasingly popular due to its opportunities to substitute conventional feed. The popularity is increasing in low- and middle income countries especially. The authors visited an established and profitable BSF larvae production facility (PEGA), the product sold as feed to e.g. catfish and chicken.

Today, PEGA Indonesia, sells dried maggots for 70.000 Indonesian Rupiah (IDR) (4,5 USD), and fresh maggots for 7000 IDR (0,46 USD). The food waste is collected for free from surrounding areas, typically weddings. According to the interviewee, the company needs 1 ton each day to have a profitable production of BSF. This implies that cooperation between tourism, hotels and households can contribute to massive value creation both economically and environmentally.

Another company, Gimle Bio Pro (2023), also combines BSF protein with aquaponics and vertical urban farming. This is completely in line with the principles of local valorisation of food waste proposed in this roadmap (see below).

For instance, Banyuwangi's shrimp farming requires 4467 tonnes of imported feed (from soy or fish meal) each cycle, adding up to 15 000 tonnes of feed each year. Shrimp can be fed with dried maggots (as part of feed pellets), while chicken, catfish and duck prefer fresh maggots. If 70% of the food waste generated in the regency including hotels, tourism, households and non-household is collected, converted to BSF maggots and dried into shrimp feed, all shrimp produced in Banyuwangi can be fed on dried maggots (with a total dried BSFL production of 19 040 tonnes). However, research indicates that a diet containing 25%-50% is optimal for shrimps (He et al., 2022). If the diet contains more BSF larvae than this, mortality increases, and weight gain and final body weight decreases rapidly. If this is taken into account, the use of BSFL has the potential of reducing conventional feed with up to 7000 tonnes each year in Banyuwangi.

Roadmap towards circularity

We propose a stepwise development of organic waste valorisation in line with the steps in the ISWM master plan. Because we believe that separating out the organic fraction is a prerequisite for successful handling of the rest of the waste, and because of the urgent need to divert organics from land-fills to reduce methane emissions, we speed up the organic waste valorisation ambition and here draft a scenario where all foreseeable treatment measures are in place within step 4, ending in 2041.

The ISWM master plan includes RDF (refuse derived fuel) as an important solution. Substituting coal with RDF in cement, heat and power generation has a clear positive effect on GHG emissions, and may be necessary in the short term to divert organic waste from land-fills. However, this roadmap does not deal with this solution because it is not high enough in the waste pyramide to be considered true circular bioeconomy. Neither is MBT (mechanical-biological treatment) for the same reason; we recommend taking out organics through source separation at the consumer stage, which, when successful, facilitates further manual or machine sorting of the remaining waste fractions.

The main idea in the ISWM master plan is to start locally with stimulating a shift in people's perception, from that of *waste to get rid off* to an *personal opportunity for value creation*: "A decentralised waste management approach allows village and household-scale involvement to be able to better participate in waste management, especially waste processing and utilisation in an effort to reduce the generation of waste sent to landfill. Banyuwangi Regency has launched the MISAH (Waste Milah) program….The content of this program is waste sorting, waste processing and utilisation which is carried out as close as possible from the source…, and exploration of potential beneficiaries or off-takers of waste processing in the area. Ensuring the existence and creating an ecosystem so that it gives rise to beneficiaries is important for sustainability… waste banks to receive recycled materials, agricultural/plantation areas and household-scale farms to receive compost, livestock/fisheries to receive BSF maggots as a result of bioconversion of organic waste" (extracts from ISWMP draft). We support this approach also from the point of view of infrastructure; roads have a low standard in the area and citizens in Banyuwangi, many living literally on the roadside, will suffer from increased truck transport. This also holds for power generation: Power lines are expensive, take up land and waste energy. Smart local grids may be a better option for the future, even creating better self-sufficiency and empowerment of local communities. Decentralised biogas-to-electricity plants fit well into this, since they can balance wind and solar energy locally. It is also probable that decentralised solutions are more social than centralised.

Urban and household/farm scale agricultural use of circular organic products for valorisation through local loops is in line with the ISWMP. Such agriculture "require guidance and mentoring programs…22 Agricultural Extension Centers, which are in almost all sub-districts… to be engaged in waste management and product utilisation".[2] In many cases urban agriculture also works as an innovation lab for sustainability in larger scale agriculture. Gimle Bio Pro (2023) also describes how they intend to integrate BSF production with aquaponics and vertical farming. Another similar approach is by integrating biogas from food waste directly with vegetable cultivation through "digeponics" (Stoknes and Putnam, 2022).

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[2] See Pauleit et al (2019) for lessons learnt about peri-urban agriculture in Jakarta, and Cetta Family (2022) and JCC-TV214 (2022) about urban farming in Banyuwangi.

Because of the advantages of AD explained above we recommend prioritising AD over composting (larger value creation and carbon abatement potential, i.e. digestate can substitute mineral fertiliser, while compost is perceived less valuable). A combined anaerobic (biogas) - aerobic (composting) type of technology (SIKIPAS, mentioned in ISWMP) was tested in Jakarta, Indonesia (Arifin, 2014). However, the plant closed down, and this approach is not recommended by the authors[3].

We believe that, when most people see or experience directly the benefits of converting biowaste into cooking gas and new food, there can be created a *positive social tipping point* where proper waste handling becomes a norm (both bottom-up and top-down drivers are usually behind such tipping points, e.g. meat substitutes now gaining legal plus social acceptance leading to exponential prevalence in the market).

Source separation done right: Food waste must be collected without plastic contamination. In fact, if pushing this, one can skip errors done in e.g. Scandinavia where household food waste often is collected in plastic bags and commercial food waste is allowed to be delivered to AD plants in its plastic containers and wrapping. Because the pre-treatment machines fail to remove all of this, this leads to contamination of digestate with plastic. This can best be avoided by setting strict limits for plastic contamination in collected food waste in Banyuwangi in the first place.

Bioconversion of food waste through BSF is, as explained above, a solution higher up in the bioeconomy pyramide than AD, and can in many ways be preferred above AD. More value and environmental benefit is created by this direct bioconversion pathway, because the alternative protein value chains usually have very large footprints in comparison. Despite this advantage, in the scenario below still less than 10 % of available food waste is converted by BSF. This is because we also wanted to demonstrate the renewable energy creation potential of most of the waste biomass combined. If BSF is successful, however, it can and should be scaled up to maximise food waste valorisation. Both BSF and AD should be developed at once, and then time will show which of these will work best in Banyuwangi. We also recommend considering mushroom production as a means of converting fibrous crop residues and digestate (biofertiliser) directly into protein for human consumption (Stoknes and Putnam, 2022). Mushroom cultivation is already established in the area.

After a mind for source separation for value creation has been established, then, subsequently, larger more industrial scale biogas plants can be built. They are cheaper per energy unit produced, and large plants may be necessary to enable full treatment capacity of all organic resources in Banyuwangi, combined in a full circular economy (fig. 11).

[3] When implemented in Norway (an industrial scale installation) this technology was not a success due to odour and operational challenges and also this plant had to close down.

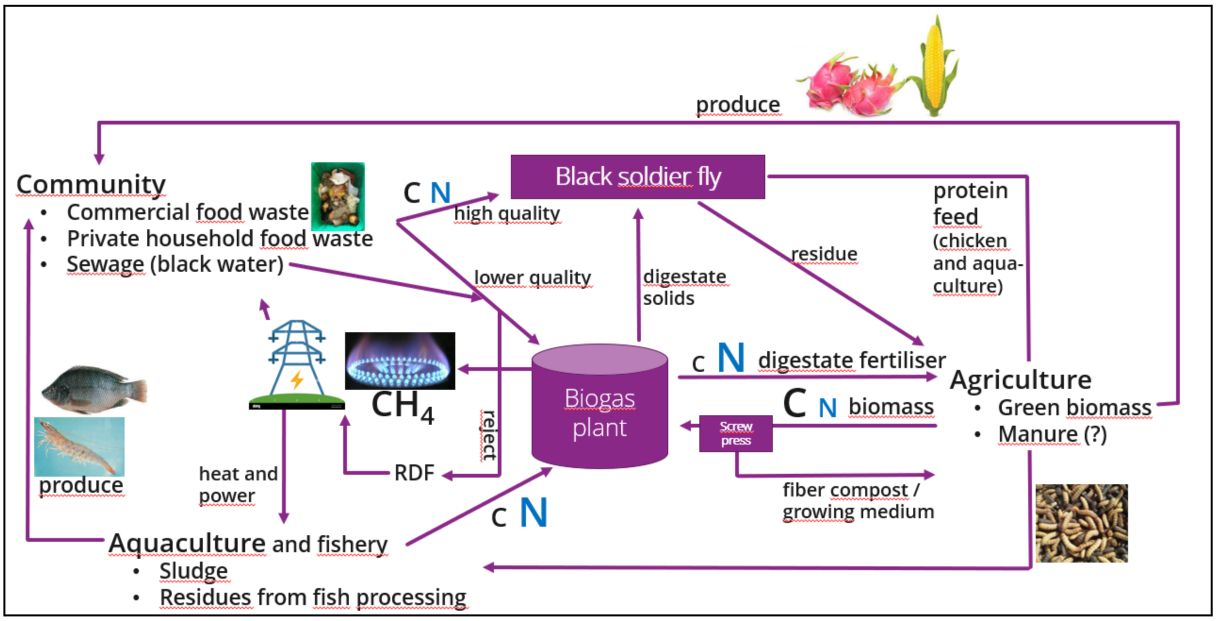

Figure. 11. The connection of bio-resources and sectors of Banyuwangi into a circular economy. There are both energy-related and material synergies, e.g. the fishery and waste sectors have a surplus of nutrients (such as nitrogen (N) and phosphorus), resources essential in agriculture. Agriculture contributes back carbon rich biomass-to-biogas energy for fish processing (canning, fish oil and meal). Many of the synergies are also valid for local decentralised loops, e.g. through small scale biogas and even urban (household/farm scale) agriculture.

A technology "toolbox" for circular bioeconomy of Banyuwangi

Anarobic digesters	Tank size (m3)	Food waste t/yr	Animal manure t/yr	Sewage t/yr	Crop residues t/yr	Biogas use	Digestate use	Investment cost in USD	Total cost USD/kWh (including operational cost)
Micro household	1	5.5				Cooking	Urban farming		
Micro farm scale	10	0.35	88	0.2		Cooking or farm processes e.g coffee rostaeries	Farm crops		
Small district (TSP3R or similar)	100	608				Electricity (CHP ~21kWe)	Local farms/urban agriculture	96,000	0.032
Medium (environmental park or similar)	1,000	6,083				Substitute coal for heat in fish processing or electricity (CHP~210kWe)	Agricultural (liquid and soild)	622,000	0.024
Large (central location)	5,000	15,000			14,000	Electricity (CPH~1,7) MWe or upgrade to biomethane	Agricultural (liquid and soild or upgraded)	4,665,104	0.022

Table 2: Overview of different digesters, their application (as used in the modelling of the steps below) and investment costs. CHP= Combined Heat and Power.

In addition to the digestesters presented in table 2, five other key technologies are necessary:

- BSF (we have assumed this as a manually operated facility with a capacity of 1 tonne high quality food waste per day).
- Upgrading digestate into commercial pelletised bio-fertiliser products. This enables a bigger market geographically (the process is done with various technologies to concentrate nutrients from the liquid biofertiliser fraction, which are combined with the dried fibre fraction into pellets or granules).
- A screw press, which is an easily accessible and relatively cheap technology to press agricultural residues (e.g. straw and leaves) into a liquid for AD + fibrous residue for composting.
- Compositing enables sufficient use of dry fibrous municipal organic waste which is less suitable for AD (+ fibre residue from pressing crop leaves). Application of compost is as soil improver or as growing/potting medium in horticulture, plant propagation and urban farming.
- Shrimp sludge collection and dewatering technology (see section on shrimp aquaculture).

An increase in waste volumes generated in Banyuwangi is expected in the next decades. This is described in the ISWM master plan. However, because there is also an ambition to reduce food loss and waste, we have used today's volumes throughout the scenario.

Moving forward: targets and policies

Following steps 1-4 in the ISWM master plan (in press), we have made the following scenario including targets and expected or recommended policies and support mechanisms:

Step 1 (2023-2026) Stimulating source separation of food waste - BSF pilots - micro- to medium scale biogas and bio-fertiliser pilots – create positive value from organic waste

Targets

- Start-up food waste source separation
- 5 BSF facilities for commercial and household food waste
- 700 domestic and community small-scale biogas digesters installed, 1m³ (food waste) and 10m³ (co-digestion sewage, manure, etc.) ref www.biru.or.id/ (substitute LPG)
- Pilot collection and co-digestion of shrimp sludge with food waste, dragon fruit leaves, etc
- Bio-slurry (digestate) trials in «urban farming»

Policy commitments and support

- NDCs for energy, waste and agriculture
- By 2025: 97/2017: 30% reduction of waste/ leaked into environment, 70% handling. 35/2018 on waste-to-energy. General Plan of National Energy: 490 mill m³ of biogas / year (up from only 28 mill in 2022)
- Support for domestic AD (microfinance)
- Electricity schemes, renewables, tariffs
- Mineral fertiliser subsidies removed
- Funding related to improved sanitation targets

Step 2 (2026-2031) BSF network - rolling out decentralised household and community biogas plants + 2 centralised biogas plants – defossilise industry – bio-fertiliser to agriculture

Targets

- Scaling up BSF to network of facilities
- 50 % dragon fruit leaves to AD
- Transition to bio-fertiliser for dragon fruit farms in (south) and chilli farms (north)
- 10% of shrimp ponds to collect sludge for AD
- Biogas to supply coffee roasteries and fish factories
- Improving fish factory wastewater treatment to recover nutrients

Policy commitments and support

- Removal of fossil energy subsidies
- More market-based, e.g. clear governmental backing for organic waste recycling industry
- Methane pledge and specific NDCs to AD
- Carbon savings from AD included in voluntary carbon markets, such as national 98/202, and international
- Electricity schemes, renewables, tariffs

Step 3 (2031-2036) Towards sustainable agriculture – scaling up sewage power – transition of shrimp aquaculture towards circularity

Targets

- Phasing out burning of crop residues
- 50% rice, corn and chilli residues to AD
- Clean sanitation and sewage sludge handling
- Shrimp farms: sludge collection 50%. Test super-intensive round tanks (RAS)*
- Upgrading biogas to biomethane
- Public bus transport on biomethane
- Upgrading biofertiliser to dry pellets
- Pilots for sequential crops?

Policy commitments and support

- Market-based support (market for environmental benefits delivered by biogas industry) to enable independence from direct subsidy
- Carbon pricing: National
- Sustainable aquaculture schemes (RAS and slurry collection)
- Sustainable agriculture schemes (regenerate soil and subsidy for digestate use)
- Sustainable protein schemes?
- Sustainability schemes can be accompanied with innovation funding for new solutions for circular products, nutrient use efficiency, prevention of ammonia emissions etc

Step 4 (2036-2041) Realising full biogas potential – integrating with other renewables to maximise defossilisation – developing urban and circular food production

Targets

- Realising close to 100% biogas potential of food waste, sewage, fishery waste and sludge, manure, crop residues (and possibly) sequential crops
- Solar and wind power2gas (H_2 -> CH_4)
- Industry to valorise bioCO_2 from biogas?
- Increasing food production with urban vertical farming, mushrooms and BSF-based aquaponics

Policy commitments and support

- Carbon pricing: Effective regional and global covering GHG emissions, methane capture and carbon sequestration using waste in agriculture

* Recirculating aquaculture system

Based on the toolbox of technologies following the same steps, we have modelled quantitatively a scenario which includes substrate amounts, output products, GHG abatements and socio-economic impact through job creation (see coloured tables below). There is also an economic profitability analysis of a large AD plant at the end of this section.

The collection of nutrients from wastewaters of the fish processing industry and shrimp aquaculture is not fully realised in this roadmap. That is because there are still uncertainties about amounts (more measurements and analyses must be made in more locations), and because much of the necessary technology is probably either too expensive or has still not achieved a high enough technology readiness level (TRL). The authors believe, however, that collection and cleaning more of these waters and sludges using methods currently being developed by this industry itself can add significantly to the biogas production potential and nutrient self-sufficiency of Banyuwangi's agriculture.

Step 1 (2023-2026)

As presented in Table 4-1 below, the first move towards a circular system should include an ambitious spread of microscale digesters, piloting BSF production and piloting small-medium sized AD plants. Since 5 TSP3Rs are planned to be established during this period, step 1 includes 5 BSF and 5 composting plants (which can be placed there).

BSF pilots

Such pilots can be based on bioconversion of restaurant and hotel food waste (up to 300 tonnes), first seeding the replication of existing BSF facilities in the regency (such as PEGA and Gimle Bio Pro), then develop a network of facilities at the village TPS3Rs adding household food waste as well, to boost the food waste valorisation and acknowledgement of source separation among people (Table 3).

Scenario	Total biomass available for bioconversion in tonnes	Kg of fresh BSFL assumed 4:1 FCR	Kg dried BSFL	Income assumed 60/40 fresh and dried share in IDR/yr	Income in EUR/yr
Step 1 (2023-2026)	1 825	456 250	136 875	19 545 750 000	1 193 418
Step 2 (2021-2031)	5 110	1 277 500	383 250	54 728 100 000	3 341 039
Step 3 (2031-2036)	8 030	2 007 500	602 250	86 001 300 000	5 250 205
Step 4 (2036-2041)	12 410	3 102 500	930 750	132 911 100 000	8 113 954

Table 3: Bioconversion and potential incomes from BSF larvae production (number of facilities rising up to 34 during this period). Income is based on an assumption of 70.000 IDR/kg fresh BSFL and 7000 IDR/kg dried BSFL.

Even though this scenario highlights the possible incomes, there are still technical obstacles to overcome. According to one interviewee, difficulties in drying the larvae is a bottleneck. Today, regular kitchen microwaves for home use were most common. PEGA uses 5 hours to dry 1 kg of larvae. This is ineffective, and exemplifies the need for improving techniques in order to scale the production to the possible volumes presented in the above scenarios. Until present, accessing a sufficient amount of food waste (preferably 1 ton/day) has been the major obstacle. If cooperation and agreements between BSFL producers and hotels, restaurants, markets and municipalities is stimulated, this could boost the value chain for dried BSFL production.

Biogas pilots

Microscale (BIOMIRU) biogas digesters are well established and thousands have already been built in the Indonesian market, with a solid majority of the households and farms as satisfied users. Olah Limbah (https://www.biru.or.id/en/home) gives a full overview of technology and the market (see IDBP, 2021 annual report). Building on this experience a rapid development of local micro AD can be achieved in Banyuwangi. This is assumed and included in the stepwise estimations.

However, it is assumed that larger AD plants will need a more gradual development, starting with pilots for small to medium plants during the first years (Step 1). Piloting is probably necessary even though the AD technology itself is mature off-the-shelf technology; the whole value chain must be piloted, not just the AD technology it self.

Step 1 (2023-2026)	No. of units	Total waste treatment capacity	Food waste	Sewage	Manure	Shrimp sludge	Crop residues	Garden (green) waste	Total
Theoretically available			155673	84041	1519906	4691	242000	45145	2051456
BSF pilots	5	1825	1825						1825
Micro (Home mini) AD (1m^3)	500	2738	2738						2738
Micro farm (f.dome) AD (10m^3)	200	*24333*	70	38	17520		3299		20927
Composting plants (1000 tonnes)	5	5000						5000	5000
Small district TPS3Rs village AD (100m^3)	7	*8517*	4258						4258
Medium TPS3R sub-district AD (1000m^3)	1	*12167*	6083			150			6233
Existing ILPT sludge treatm.plant in Banyuwa	1	*50000*		50000					50000
Large AD (5000m^3)	0	*0*	0						0
Total treated			14974	50038	17520	150	3299	5000	90981
% of theoretically available			10 %	60 %	1 %	3 %	1 %	11 %	4 %
Energy available from biogas	Sum		15 GWh	41 GWh	7,2 GWh	0,1 GWh	7,8 GWh		71 GWh
CO2e abatement	Sum		12369	35226	2821	0	1485		51900
Nutrients available for crops	approx NPK fertiliser equivalent			110000 tonnes used today, substitute				2 %	2517
Soil improver	50 %	conversion rate						2500	2500
BSF larvae (protein feed)	25 %	conversion ra	456						456
Jobs		permanent							30 jobs
Jobs		temporary							60 jobs

Table 4-1.Quantitative roadmap for a circular bioeconomy in Banyuwangi; predictions based on assumptions about targets and policies in the scenario above (Steps 1-4 having the same colours). The AD plants included are equal to those listed under the Technology toolbox sect. above. Figures are in tonnes if not specified otherwise. Italic figures under Total waste treatment capacity are hydraulic digestion capacities, which are higher than the sum of waste treated because most wastes must be added water to be treated in AD.

Step 2 (2026-2031)

It is assumed that it is possible to develop a network of commercial BSF producing facilities, one on every village TSP3R, scaling up to treating more than 5000 tonnes of food waste, producing 1278 tonnes of BSF protein product (Table 4-2). Step 2 also represents a strong increase in the amount of food waste treated by adding two more medium (sub-district) ADs and two large scale ADs. The biogas from this expansion can defossilise industries such as coffee roasteries and fish processing factories by using it as fuel directly without the costly need of upgrading or converting the biogas to electricity.

At this stage farmers can be engaged in the value chain of crop residues to waste-based biofertiliser. Not only will farmers reduce the need for mineral fertiliser, but are also stimulated away from burning of crop residues which is not sustainable. Corn and rice straw from farms practising burning should be prioritised as substrate for AD before those used as feed for livestock.

The government should remove fossil fuel subsidies, and support incentives that favour development of the organic waste recycling industry, such as developing carbon credit schemes which favour the CO_2 sequestration that AD offers. By engaging farmers in the value chain for biofertiliser, with governmental support simultaneously, we believe that society will benefit economically from stimulating a circular bioeconomy.

In addition to developing a value chain for crop residues among farmers, shrimp farming in Banyuwangi can be more profitable by improving ponds and creating a value chain for pond sludge, as well as wastewater nutrients rather than discharging them to the sea. Consequently, as a part of step 2, we propose developing test schemes, pilots and training for sludge collection in close cooperation between technology providers and shrimp farmers. Additionally, testing of BSFL as a feed ingredient will create further synergies between different industries towards circularity.

Although step 2 aims at ambitious development, there are logistical-and transportational obstacles that need to be overcome. Road infrastructure is not very developed, making transport of organic material a challenge. Decentralised value chains are therefore an integral part of this roadmap.

Step 2 (2026-2031)	No. of units	Total waste treatment capacity	Food waste	Sewage	Manure	Shrimp sludge	Crop residues	Garden (green) waste	Total
Theoretically available			155673	84041	1519906	4691	242000	45145	2051456
BSF facilities (every TSP3R)	14	5110	5110						5110
Micro (Home mini) AD (1m^3)	1500	8213	8213						8213
Micro farm (f.dome) AD (10m^3)	600	*73000*	210	113	52560		9898		62780
Composting plants (1000 tonnes)	14	5000						14000	14000
Small district TPS3Rs village AD (100m^3)	14	*17033*	8517						8517
Medium TPS3R sub-district AD (1000m^3)	3	*36500*	18250			500	5000		23750
Existing ILPT sludge treatm.plant in Banyuwa	1	*50000*		50000					50000
Large AD (5000m^3)	2	*121667*	30000	?			28000		58000
Total			70299	50113	52560	500	42898	14000	230369
% of theoretically available			45 %	60 %	3 %	11 %	18 %	31 %	11 %
Energy available from biogas	Sum		71 GWh	41 GWh	22 GWh	0,2 GWh	102 GWh		236 GWh
CO2e abatement	Sum		58067	35279	8462	0	19304		121112
Nutrients available for crops	approx NPK fertiliser equivalent			110000	tonnes used today,		substitute	5 %	5329
Soil improver	50 %	conversion rate						7000	7000
BSF larvae (protein feed)	25 %	conversion ra	1278						1278
Jobs	Sum	permanent							88 jobs
Jobs	Sum	temporary							130 jobs

Table 4-2: Quantitative roadmap for a circular bioeconomy in Banyuwangi; step 2.

Step 3 (2031-2036)

When entering 2031 the goal is to continue towards a more regenerative agriculture, scale up AD with increasing amounts of sewage and transform shrimp aquaculture towards circularity. Building up a circular bioeconomy in Banyuwangi will need governmental support. An ambitious goal is to collect 50% of rice, corn and chilli residues to AD, together with 50% sludge collection. Additionally, implementing technologies to upgrade biogas to biomethane, and biofertiliser to pelletised products will contribute to further valorisation. RAS systems for shrimp farming allows super-intensive and sustainable production, so tests and innovation funding for this should be encouraged. To reach these targets serious political will is needed. At this point the goal is to create independence from subsidies and work towards market based support that values environmental benefits delivered by the biogas industry.

Step 3 (2031-2036)	No. of units	Total waste treatment capacity	Food waste	Sewage	Manure	Shrimp sludge	Crop residues	Garden (green) waste	Total
Theoretically available			155673	84041	1519906	4691	242000	45145	2051456
BSF facilities (every TSP3R)	22	8030	8030						8030
Micro (Home mini) AD (1m^3)	3000	16425	16425						16425
Micro farm (f.dome) AD (10m^3)	1000	*121667*	349	188	87600		16496		104633
Composting plants (1000 tonnes)	22	5000						22000	22000
Small district TPS3Rs village AD (100m^3)	22	*26767*	13383						13383
Medium TPS3R sub-district AD (1000m^3)	4	*48667*	16222			2346	5000		23568
Existing ILPT sludge treatm.plant in Banyuwa	1	*50000*		50000					50000
Large AD (5000m^3)	4	*243333*	30000	20000			71000		121000
Total			84410	70188	87600	2346	92496	22000	359039
% of theoretically available			54 %	84 %	6 %	50 %	38 %	49 %	18 %
Energy available from biogas	Sum		85 GWh	57 GWh	36 GWh	1 GWh	220 GWh		399 GWh
CO2e abatement	Sum		69723	49412	14104	0	41623		174862
Nutrients available for crops	approx NPK fertiliser equivalent			110000 tonnes used today,			substitute	8 %	8267
Soil improver or growing medium	50 %	conversion rate						11000	11000
BSF larvae (protein feed)	25 %	conversion ra	2008						2008
Jobs		permanent							141 jobs
Jobs		temporary							154 jobs

Table 4-3: Quantitative roadmap for a circular bioeconomy in Banyuwangi; step 3.

Step 4 (2036-2041)

When getting closer to 2041 the aim is to work towards full biogas potential including food waste, sewage, fishery waste, sludge, manure and crop residues, together with other renewable sources. AD based energy can now add on to wind, hydro and solar to completely defossilise Banyuwangi. Simultaneously, one can increase food production from urban farming, BSF-based aquaponics and digeponics in addition to regular field farming. 174,000 tonnes of CO_2 abatement can be achieved, as well as several hundred jobs created.

Step 4 (2036-2041)	No. of units	Total waste treatment capacity	Food waste	Sewage	Manure	Shrimp sludge	Crop residues	Garden (green) waste	Total
Theoretically available			155673	84041	1519906	4691	242000	45145	2051456
BSF facilities (every TSP3R)	34	12410	12410						12410
Micro (Home mini) AD (1m^3)	3000	16425	16425						16425
Micro farm (f.dome) AD (10m^3)	1500	*182500*	524	282	131400		24744		156950
Composting plants (1000 tonnes)	34	5000						34000	34000
Small district TPS3Rs village AD (100m^3)	34	*41367*	20683						20683
Medium TPS3R sub-district AD (1000m^3)	8	*97333*	32444			2346	5000		39790
Existing ILPT sludge treatm.plant in Banyuwa	1	*50000*		50000					50000
Large AD (5000m^3)	8	*486667*	35000	25000		1407	180000		241407
Total			117487	75282	131400	3753	209744	34000	571666
% of theoretically available			75 %	90 %	9 %	80 %	87 %	75 %	28 %
Energy available from biogas	Sum		118 GWh	61 GWh	54 GWh	2 GWh	499 GWh		734 GWh
CO2e abatement	Sum		97044	52999	21155	0	94385		265583
Nutrients available for crops	approx NPK fertiliser equivalent			110000 tonnes used today,			substitute	12 %	12877
Soil improver or growing medium	50 %	conversion rate						17000	17000
BSF larvae (protein feed)	25 %	conversion ra	3103						3103
Jobs		permanent							231 jobs
Jobs		temporary							165 jobs

Table 4-4: Quantitative roadmap for a circular bioeconomy in Banyuwangi; step 4.

Biomass-to-energy potential of Banyuwangi

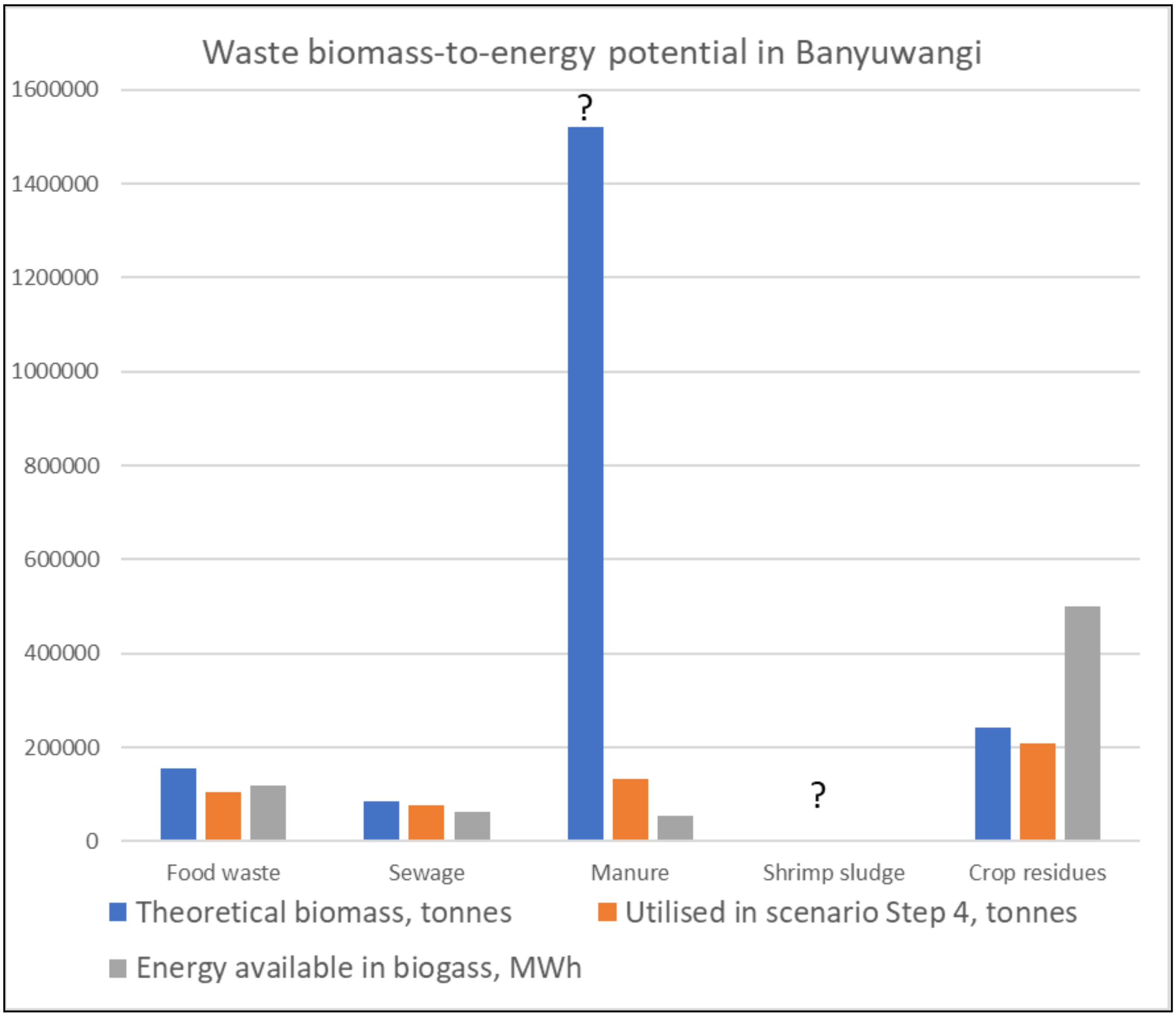

Figure. 12. Chart based on Table 4-4, showing total volumes of biomass available today, utilised in 2041 in tonnes, and energy available from biogas in MWh. Question mark on manure indicates that available volume is based on a pure assumption that Banyuwangi has an average cattle number for East Java. The low collection rate is because of the spread of cattle (only micro farm digesters included) and poor road standard making collection of dilute manure for centralised treatment challenging. The question mark on shrimp sludge indicates that sludge volumes, collection rates and biogas potentials for this substrate must be assessed further.

Based on the current volumes identified, mostly using assumptions of between approx. 70-90% utilisation of theoretically available biomass (except for manure, with 9 % utilisation), a total realistic available energy potential of approx. 730 GWh is identified (Table 4-4). This is equal to 73 mill. Nm^3 of methane, which is interesting to compare with the total biogas production of Indonesia as of today, 28 m^3(see the Market drivers -> Anaerobic digestion section). As can be seen in Fig. 12, crop residues clearly have the largest energy potential in Banyuwangi. In addition, there is a great potential for making agriculture both more productive and more sustainable by introducing “sequential cropping” (Primmer et al., 2021), also called multiple cropping. This is basically annual rotation planting between harvests keeping fields continuously covered. This will produce much more available biomass. Adding to this the huge theoretical amounts of manure not utilised, there could be a great potential of decentralised micro AD treatment combining manure with crop residues and sequential crops creating power for local smart energy grids. This should be assessed further.

Capex and Opex of AD units used

Country	Currency
Indonesia	$

INPUT Capacity (kW)	Annual gas production MWh	Constructional cost estimate ($)	Operational cost estimate ($ over 15 years)	Total ($ over 15 years)	Estimated $/kWh
70	543	96 418	167 953	264 371	0,032
700	5 433	622 049	1 306 304	1 928 353	0,024
5 526	42 889	4 665 104	9 207 442	13 872 545	0,022
	-	-	-	-	#DIV/0!
	-	-	-	-	#DIV/0!

Operational Capacity	88,6%
UK average	73,0%

Life cycle
15

Figure 13. Income and expenditure-calculator. Screenshot retrieved from (WBA, 2023)

Profitability analysis, large AD

In this example a 50-50 mix of food waste with crop residues is used (as in Step 2 (Table X-2)).

INPUT		output	
Plant capacity (kW)	5 526	42 598 829	kWh
Operating capacity	88,0%		
Subsidy support rate ($/MWh)	30		
Wholesale gas price ($/MWh)	2,52	Ave natural gas price (2020) - $7.95/MWh ($2.54/MMBtu)	
Country	Indonesia	Change in 'Expenditure'	
Currency	$	Change in 'Expenditure'	

Number of years to become profitable	Profit rate
5,7	55 %

Scheme duration	
15	years

Figure 14. Profitability analysis large-scale AD. Screenshot retrieved from (WBA, 2023)

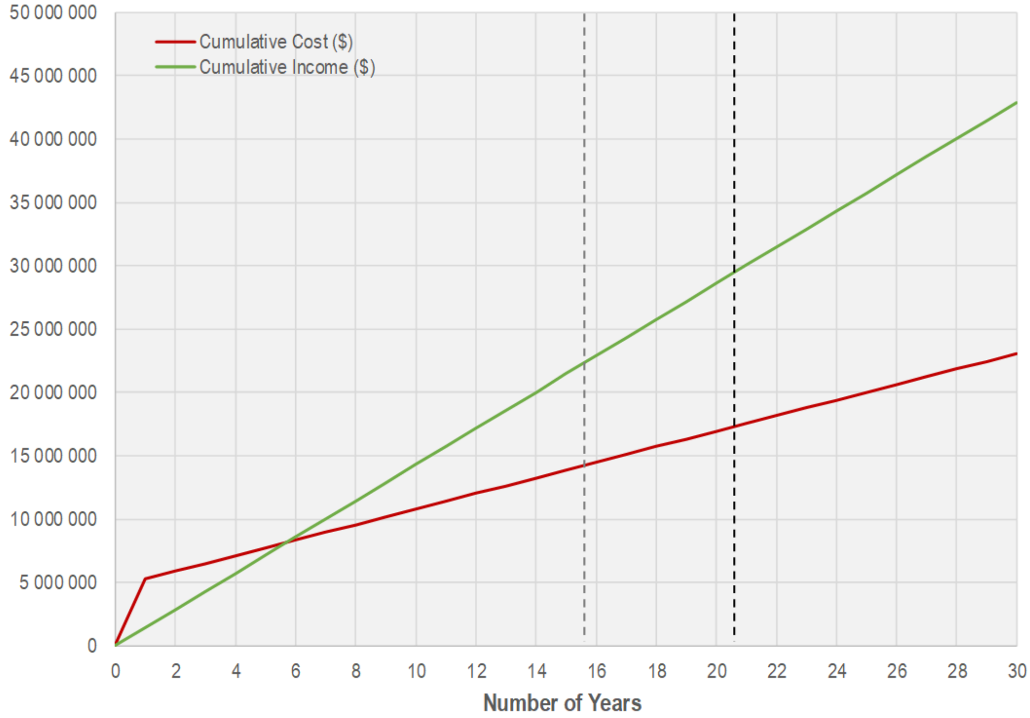

Figure. 15. Break even of AD large scale investment. Screenshot retrieved from (WBA, 2023)

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Appendix 1: Overview of political and economic incentives in Indonesia

Overview of insentives and measures to increase investments in waste treatment and renwable energy in Indonesia								
	Abbrivation	**Name**	**Category**	**Description**	**Project example**	**Note**	**In effect from**	**Reference**
Carbon credits	CDM	The Clean Development Mechanism	Tradeable/saleable carbon credits	The CDM allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tonne of CO2. These CERs can be traded and sold, and used by industrialized countries to a meet a part of their emission reduction.It is the first global, environmental investment and credit scheme of its kind, providing a standardized emissions offset instrument, CERs	A CDM project activity might involve, for example, a rural electrification project using solar panels or the installation of more energy-efficient boilers.			https://cdm.unfccc.int/about/index.html
	ISCC	International Sustainability and Carbon Certification	Carbon credits	ISCC is a globally applicable sustainability certification system and covers all sustainable feedstocks, including agricultural and forestry biomass, biogenic wastes and residues, circular materials and renewables				https://www.iscc-system.org/about/objectives/
Public funding	**LPDB**	Revolving Fund Management Institute LPDB (Government Co-sharing)	Public funding of microscale biogas plants funding	YRE ("Home energy foundation") proposed nine potential Loan Partner Organizations from various biogas credit schemes in Central Java, East Java, NTB, and South Sulawesi to be incorporated in LPDB's 2021 lending pipeline.				https://www.rumahenergi.org/wp-content/uploads/2022/11/IDBP-
	SIO-GFF	The SDG Indonesia One-Green Finance Facility	Public-private funding of Infrastructure development	Considered as the first green finance facility in Southeast Asia, SIO-GFF comprises four pillars focusing on commercial financing, concessional fund for derisking, equity fund, and project development. Intended to support SIO-GFF projects on green recovery and to achieve the SDGs			2018	https://www.adb.org/publications/sdg-indonesia-one
	RUPTL	Electricity Supply Business Plan	National regulations and business plans	23% share of renewable energy by 2030, 2% of this from biomass OR waste 313,1 Mwe from AD plants			2021-2030	WBA Market Report for Indonesia
	BPDLH	National Agency for Environmental Fund Management		Mandated to manage and mobilize finance for environment and allowed to mobilize climate finance from various sources both national and international sources, private and public sources, bilateral and multilateral channels.			2018	https://unfccc.int/sites/default/files/NDC/2022-06/Updated
	Green Sukuk		Public Funding	World's first sovereign green Islamic bond or Green Sukuk exclusively targeted to fund climate change mitigation and adaptation. Minisery of Finance is responsible and allocate money eligible projects, which includes renewable energy and energy conservation.	These eligible projects include new and renewable energy infrastructure development, with a focus on areas that are out of the PLN electricity coverage. In other words, the projects are intended to improve the electrification ratio in off-grid areas across the country using energy generated mainly from solar and biogas		2018	https://www.iisd.org/system/files/2022-02/indonesia-private-investment-renewable-

Private funding	IDBP (BIRU biogas at home)	Indonesia Domestic Biogas Program	Private funding of microscale biogas plants. Company co-sharing scheme	There were a total of 16 companies, cooperatives, and organizations who provided financial support for biodigester construction in 2021. Company co-sharing scheme mostly financed the biodigester constructions in East Java with a total number of 190 units.	Biogas installation in this program provided great impact ranging from household cost saving, manure waste reduction, to business opportunity development. Beneficiaries were also increased their capacities in biogas maintenance training, bio-slurry training, and gender action learning	https://www.rumahenergi.org/wp-content/uploads/2022/11
Presidential and ministerial regulations	**Ministerial Regulation 04/2012**	Electricity Purchase from Small and Medium Scale Renewable Energy and Excess Power	National regulations	Tariff levels are differentiated depending on the installation type, its location and voltage of grid interconnection. Following technologies benefit from the scheme: Biomass, biogas, municipal waste and hydropower plants below generation capacity of 10 MW. State electricity company PT Perusahaan Listrik Negara (PT PLN) is obliged to purchase electricity generated from renewable energy installations.		
	Ministerial Regulation No 22/2017	General National Energy Plan	National regulations	The new and renewable energy mix (NRE) is target by 23% by 2025.		
	Presidential regulation No 35/2018	Accleration of Contruction of waste processing installation into electrical energy based on environmentally friendly techonology	Presidential regulation	Accelerate waste to energy projects in major cities in Indonesia		WBA Market Report for Indonesia
Tax insentives	**Tax holiday**			100% discount on Corporate Income Tax (CIT) for up to 20 years depending on investment value (for 17 pioneer industries, including renewable energy sector)		https://www.iisd.org/system/files/2022-
	Tax allowance			Applied to renewable energy power plants, geothermal businesses, and bioenergy industries. This allowance includes CIT reduction and suspension and elimination of VAT for various renewable energy projects.		
	Tax exemptions			VAT, CIT, and import tax exemption on imported goods for renewable energy projects		
	Accelerated depreciation and amortization			Accelerated depreciation and amortization on assets and goodwill for initial capital investment of renewable energy projects		
	Credit facilities			Various credit facilities for small to large renewable energy projects		
IPP	Independent Power Producers			IPPs sell the electricity they produce to the state utility (PLN) through power purchase agreements (PPAs). For electricity from most small-scale renewable sources a feed-in-tariff (FIT) is set by the Ministry of Energy and Mineral Resources (ESDM), that pays a premium rate for electricity and makes the project feasible; i.e. creates the business case. The FIT is differentiated per technology and per region.		https://cdkn.org/sites/default/files/files/ECN-Policy-Brief-Indonesia-small-scale-IPPs.pdf

Appendix 2: Data sheet agricultural residues for valorisation and fertiliser use

K	L	M	N	O	P	Q	R	S	T
Commodity Type	Planted Area ha	Typical yield of crop (kg/ha)	Crop residue valorisation potential, tonnes	Fertiliser use, tonnes	Fertiliser kg / ha	Fertiliser use, kg NPK/ha (assuming 15-10-12)			
Rice	119108	5000	91113	65509	550	204	N	P	K
Corn	32602	5000	81505	27712	850	315	15	10	12
Soybean	5135	4000	2568	1284	250	93			
Dragon Fruit	3685	20000	66330	8107	2200	814			
Oranges	7532	-		7532	1000	370			
Small chilli	79.6	-	159	-					
Large Chilies	125.5	-	251	-					
Melon	175	-	70	-					
Watermelon	1110	-	444	-					
	169552		242440	110144					

A	B	C	D	E	F	G	H	I
Commodity Type	Planted Area ha	Typical yield of crop (kg/ha)	Waste	Assumed Amount of waste /ha*Year	Units	amount	Management	Crop residue valorisation potential, tonnes
Rice	119108	5000	Product		Kg	595 540 000		91113
			Fertilizer	11	Zak (=sack)	1 310 188	Used	
			Pesticide	7	Bottles		Hoarded, Burned Thrown	
			Straw	500	Kg Dry	59 554 000	Cow Feed, Stockpiled, Burned, Transport Base Melons	
			Husk	199	Kg	23 669 142	Fuel, Bedding, Mixed Feed	
			Bran	66	Kg	7 889 714	Livestock Feed	
Corn	32602	5000	Product		Kg	163 010 000		81505
			Fertilizer sack	17	Zak	554 234	Used	
			Pesticide containers	7	Pieces	228214	Burned and dumped	
			Corn Straw, Corn Husk	2 000	Kg Dried ?	65 204 000	Livestock Feed, Burned	
			Cob (=Janggel)	500	Kg Dry	16 301 000	Burned, Small Part of Mixed Feed, Mushroom Media	
Soybean	5135	4000	Product		Kg	20 540 000		2568
			Fertilizer	5	Sack?	25 675	Used	
			Pesticide	4	Containers	20540	Stockpiled, Burned dumped	
			Straw	500	Kg Dry	2 567 500	Animal Feed, Burned	
Dragon Fruit	1474	20000	Product		Kg	29 480 000		66330
(using lamps)			25 % Light Bulb Off	150	pieces	221 100	dumped	
			Fertilizer	80	Sack?	117 920	Used	
			Pesticide	250	Bottles	368 500	Stockpiled, dumped,	
			Tendril/Stem	30 000	Kg Wet	44 220 000	dumped, Little Animal Feed	
Dragon Fruit	2211	12000	Product		Kg	26 532 000		
(no lamps)			Tendril/Stem	10 000	kg Wet	22 110 000	dumped, Little Fodder	
			Fertilizer	20	Sack?	44 220	Used	
			Pesticide	50	Bottles	110 550	Stockpiled, dumped,	
Oranges	7532							
			Fertilizer Container/Sac	20		150 640	Used	
			Pesticide Containers	500	Bottles?	3 766 000	dumped	
			Fruit	?				
Small chilli	79,6							159
			Fertilizer Container	40		3 184	Used	
			Drug Containers	500		39 800	dumped	
			Plant Stems	2 000	Kg Dry?	955 200	Burned	
Large Chilies	125,5							251
			Fertilizer Container	40		5,02	Used	
			Pesticide Container	500		62 750	dumped	
			Disposable Assumed Mulch	8	Rolls @ 50kg	1 004	dumped	
			Plant Stems	2 000	Kg Dry?	1 506 000	Burnt	
Melon	175							70
			Fertilizer Container	40		7 000	Used	
			Drug Containers	500		87 500	dumped	
			Disposable Mulch Assumption	8	Rolls @ 50kg	1 400	dumped	
					kg (wet or dry?)	70000		
Watermelon	1110							444
			Fertilizer Container	40		44 400	Used	
			Drug Containers	500		555 000	dumped	
			Disposable Assumed Mulch	8	Rolls @ 50kg	8 880	dumped	
					kg (wet or dry?)			
						236 097 122		242440
						50 %		
					167 189 342	83 594 671		