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Original Research Article

Integrated Waste Management Planning with Pyrolysis and Black Soldier Fly Larvae in Tingkir District Salatiga City

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Abstract

Waste management is one of the problems in developed and developing countries that have not been resolved until now. Garbage and landfill management are now an urgent problem in Salatiga City because currently, they only move the waste from the source to the Ngronggo Landfill without taking advantage of the waste first. Therefore, an MRF plan is needed in Tingkir District, Salatiga City, until 2030 by using pyrolysis technology to process inorganic waste, using BSF larvae technology as organic waste processing and recycling economically valuable waste. This planning uses primary and secondary data collection methods in observation, interviews, questionnaires, and sampling. The composition of waste in Tingkir District consists of 59.51% organic waste and 40.49% inorganic waste. With a waste generation of 161.05 m/day, the results of waste processing at the Tingkir District INTEGRATED WASTE PROCESSING FACILITIESare shredded plastic types PET, HDPE, LDPE, PP, dry maggot, cassava, paper, cardboard, metal, and glass. The planned management system includes five aspects of waste management. Based on the calculations for ten years of planning, it was found that the estimated costs for expenses were Rp. 38,302.102.456,89, income costs were Rp. 97.227.053.500,00, and loss/profit was Rp. 58.924.951.043,11.

Keywords: BSF; MRF; pyrolysis; Recycle

1. Introduction

Lamond, 2012 in Pretty 2015 stated that waste management is one of the problems, both in developed and developing countries that has not been resolved until now. This increasingly difficult challenge will continue to increase due to the trend of urbanization that occurs and grows rapidly in urban populations. Waste and landfill management has become an urgent problem in Salatiga City due to a lack of proper addressing of the issue. According to the 2016 Salatiga City Solid Waste Master Plan, the city still uses a controlled landfill system for waste management. However, the Ngronggo landfill, which is only 5.3 hectares, can no longer accommodate the growing volume of waste. This is because some of the waste entering the Landfill Ngronggo does not only come from Salatiga City, but also from several areas around it. Salatiga City's current waste management system only moves waste from the source to the Ngronggo Landfill without first processing it. Both organic and inorganic waste can be recycled. Organic waste can be used to make compost, which is useful for plants. Inorganic waste, such as plastic, paper, leather, and cloth, can be recycled.

Salatiga City has four subdistricts, one of which is the Tingkir subdistrict. The Tingkir subdistrict consists of seven kelurahan and covers an area of 1,054.85 hectares. It has a population of 45,971 people, the highest population density in Salatiga City at 4,357 people per km^2 (Badan Pusat Statistik Kota Salatiga, 2021). Tingkir subdistrict's population has grown every year, reaching an annual growth rate of

1.39% from 2010 to 2020. In 2017, the amount of waste generated in Tingkir sub-district reached 164,193 l/day (Budiana, 2017), while the amount of waste generated in Salatiga city in a day reached 349.95 m3 and only 344.42 m^3 of waste was transported to the landfill (Badan Pusat Statistik Kota Salatiga, 2021).

The waste problem in the Tingkir subdistrict of Salatiga City stems from the lack of waste processing to reduce the amount of waste generated. One solution is to plan integrated waste facilities that use pyrolysis technology and composting with black soldier fly (BSF) larvae. Pyrolysis can process household waste, including mixed waste, food waste, fruit and vegetable waste, paper waste, plastic waste, and textile waste. Plastic waste such as plastic bags, plastic packaging, styrofoam, and difficult-to-recycle plastics will be processed using pyrolysis (Ramadhan, 2013). According to Popa and Green (2012), the black soldier fly (BSF) is a species of tropical fly that has been studied for its ability to degrade organic waste using its larvae, which extract energy and nutrients from vegetable waste, food waste, animal carcasses, and feces.

In recent years, integrated waste management systems that combine biological, mechanical, and thermal technologies have gained increasing attention as sustainable alternatives to conventional disposal-based approaches (Damanhuri and Padmi, 2016). Black Soldier Fly (BSF) larvae (Hermetia illucens) have been extensively studied for their ability to rapidly decompose organic waste while producing valuable by-products, such as protein-rich larvae and organic fertilizers (Popa and Green, 2012). Pyrolysis technology offers a viable solution for processing low-value and hard-to-recycle plastic waste by converting it into fuel oil and other energy carriers, thereby reducing landfill volume and dependence on fossil fuels (Ramadhan and Ali, 2013). When combined with conventional recycling for high-value materials such as paper, metal, and glass, these technologies form the basis of integrated Material Recovery Facilities (MRFs) or Integrated Waste Processing Facilities.

This research integrates waste production projections up to 2030, detailed facility design, material flow and mass balance analysis, and a ten-year financial feasibility assessment. By adapting the system to local waste composition and demographic conditions, this study provides a practical and measurable model for sustainable waste management that reduces dependence on landfills, generates economic value, and supports the principles of the circular economy. The objectives are to (1) determine the waste generation, composition, and characteristics in the district; (2) evaluate existing waste management performance using the five-aspect framework; and (3) develop a technical and financial plan for an integrated waste facilities capable of operating until 2030.

2. Methods

2.1 Study Area

The study was conducted in Tingkir District, one of the four districts in Salatiga City, Central Java, Indonesia. Tingkir has a total area of 1,054.85 hectares and a population of 45,971 residents, which represents the highest population density in the city at 4,357 people per square kilometre. Administratively, the district consists of seven urban villages. Waste management in the area is currently limited to transporting waste directly to the Ngronggo Landfill without any form of pre-treatment or material recovery.

2.1 Research Design and Data Collection

The research applied a descriptive and engineering design approach. Data collection consisted of both primary and secondary sources. Primary data were obtained through direct observation of waste management operations in Tingkir District, structured interviews with key stakeholders such as the Salatiga City Environmental Agency and local community representatives, and the distribution of questionnaires to households, businesses, and community organisations to identify waste generation patterns. In addition, waste sampling was conducted to determine waste composition and characteristics for both domestic and non-domestic sources. Sampling of waste generation and composition followed

SNI 19-3964-1994 standards, using protective equipment (masks, gloves), trash bags, measuring boxes, and digital scales.

Secondary data were collected from official and institutional sources, including population statistics from the Badan Pusat Statistik (BPS) of Salatiga City, the Salatiga City Waste Master Plan (2016), and technical records from the local government. These data included information on land area and land use, waste generation rates, waste composition, administrative maps, and infrastructure. Technical and financial specifications of equipment and facilities were obtained from suppliers, while unit prices for materials and labour were gathered from local market surveys.

To support the planning and analysis, both primary and secondary data were collected from various sources, covering demographic, technical, institutional, and community aspects of waste management in Tingkir District. The types of data, their sources, and collection methods are summarized in Table 1. Table 1 presents the types and sources data used in the study, together with their respective sources.

Table 1. Types and Sources of Data Collected

Data Type	Source	Collection Method
Population and Growth rate	BPS Salatiga City	Secondary
Waste generation & composition	Field Survey	Primary
Waste Management Facilities	DLH Salatiga	Secondary
Community Participation	Household Surveys	Primary

Based on Table 1, The table shows that the study relied on a combination of official statistics, direct field surveys, and household-level information to ensure comprehensive data coverage. Population and growth rate data from BPS Salatiga provided the demographic baseline needed for waste generation projections. Field surveys were essential for measuring waste generation and composition, while records from the Salatiga City Environmental Agency (DLH) provided insight into existing waste management facilities and operations. In addition, household surveys supplied valuable information on community participation patterns, which are crucial for evaluating the feasibility of the Integrated Waste Processing Facilities. Together, these diverse data sources allowed for a balanced integration of quantitative and qualitative inputs in the planning process.

2.2 Sampling and Measurement Procedures

Sampling was conducted on both domestic and non-domestic sources of waste. Domestic waste samples were taken from selected neighborhoods representing the population density distribution of Tingkir District, while non-domestic samples were collected from commercial areas, traditional markets, and street sweeping activities. Each sample was weighed and sorted into organic and inorganic fractions. The organic fraction consisted mainly of food waste and garden waste, while the inorganic fraction included plastics, paper, metals, and glass. These fractions were then further analyzed to determine their physical and chemical characteristics. The waste sampling process is depicted in Figure 1.

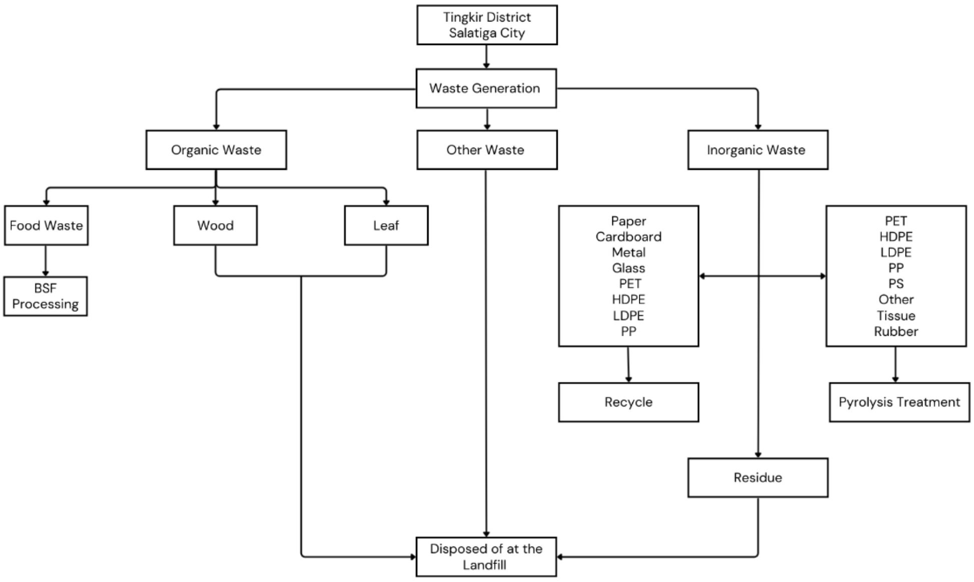

Figure 1. Waste Sorting Flow Chart

Based on figure 1, the flow chart illustrates the overall process of sampling and categorizing waste in Tingkir District. Waste generated from both domestic and non-domestic sources is first separated into three main categories: organic waste, inorganic waste, and other waste. Organic waste, consisting primarily of food residues, leaves, and wood, is directed to Black Soldier Fly (BSF) processing. Inorganic waste, which includes plastics, paper, cardboard, metals, glass, and rubber, is further divided into recyclable materials and fractions suitable for pyrolysis treatment, such as PET, HDPE, LDPE, PP, and PS. Residual fractions that cannot be processed through either recycling or pyrolysis are ultimately disposed of at the landfill. This diagram demonstrates how the integrated system maximizes material recovery while minimizing the amount of waste requiring final disposal.

2.3 Data Analysis

The data analysis process began with population projections using arithmetic, geometric, and least squares methods, with the method showing the lowest standard deviation selected as the most reliable. These projections formed the basis for estimating future waste generation in Tingkir District up to 2030, calculated from measured per capita generation rates and expressed as daily waste volumes. Mass balance analysis and recovery factor assessments were then applied to determine the potential diversion of both organic and inorganic waste streams. Based on these results, facility requirements were defined, including the capacity of Black Soldier Fly (BSF) units for organic waste treatment and pyrolysis reactors for inorganic waste processing. Finally, a financial feasibility study was carried out by estimating investment needs, operational and maintenance costs, and potential revenues from the sale of recyclables, fuel oil, and BSF-derived products.

3. Result and Discussion

3.1 Waste Generation, Composition, and Characteristics

The results of projected generation in Tingkir District for the year 2030 reaches 161.05 m^3/day, equivalent to 72.59 tons/day. The waste is dominated by 59.51% organic waste (95.84 m^3/day), 38.97% inorganic waste (62.78 m^3/day), and 1.52% other materials (2.43 m^3/day). Among inorganic fractions, paper and cardboard together account for almost 20% of the total, followed by LDPE plastics (6.96%) and other polymers. These findings indicate that organic waste remains the dominant fraction, while the significant share of plastics highlights the potential for energy recovery through thermal processing.

The physical characteristics of the organic fraction indicate a moisture content exceeding 60%, which makes it suitable for biological treatment such as Black Soldier Fly (BSF) larvae processing. In contrast, the plastic fraction has a relatively low density (0.15–0.25 ton/m^3), making it feasible to process through pyrolysis technology. Based on the projected population growth in Tingkir District and the measured per capita waste generation rate, future waste generation up to 2030 was estimated. The results of this projection are summarized in Table 2. Table 2 shows the projected waste generation in Tingkir District.

Table 2. Waste Generation Projection 2020-2030

Year	Population	Waste Generation (L/day)
2020	45971	130864.99
2021	46407	133609.78
2022	46843	136412.14
2023	47279	139273.27
2024	47715	142194.42
2025	48151	145176.83
2026	48587	148221.80
2027	49023	151330.63
2028	49459	154504.67
2029	49895	157745.28
2030	50331	161053.86

Based on table 2 shows that daily waste generation in Tingkir District increases consistently from 13,086.49 L/day in 2020 to 16,053.86 L/day in 2030, in line with population growth trends. This steady rise reflects the strong correlation between demographic expansion and the amount of waste produced. The upward trajectory underscores the urgent need for improved waste management strategies, as existing facilities will face increasing pressure in accommodating higher waste volumes over the next decade. These projections also provide the quantitative foundation for designing the required capacity of treatment facilities such as BSF units for organics and pyrolysis reactors for plastics.

Following the estimation of total waste generation, the composition of waste in Tingkir District was examined to identify the relative contribution of different fractions. This analysis is essential because understanding the proportion of organic and inorganic components not only provides insight into the dominant waste streams but also determines the most appropriate processing technologies. The detailed composition results are presented in Table 3. Table 3 shows the waste composition in Tingkir District.

Table 3. Waste Composition

Composition	Weight	
	Kg	Percentage
Food Leftovers	27.607	49.86%
Leaves/Grass	4.39	7.94%
Wood	0.95	1.71%
Paper	5.65	10.21%
Cardboard box	5.42	9.78%
Tissue	0.87	1.57%
Metal	0.33	0.60%
Glass	0.46	0.83%
Rubber	0.01	0.02%
PET	1.51	2.73%
HDPE	1.71	3.08%

LDPE	3.85	6.96%
PP	0.87	1.58%
PS	0.13	0.24%
Other	0.76	1.37%
dll	0.84	1.51%
Total	**55.37**	**100%**

The data in Table 3 indicate that food leftovers represent the largest fraction of waste at 49.86%, followed by leaves and grass at 7.94%, making organic waste the dominant category. Other notable components include paper (5.65%), cardboard (9.78%), and LDPE plastics (6.96%), while smaller fractions consist of glass, rubber, and metals. This distribution highlights two important aspects of waste management in Tingkir District: first, the high share of organics with a moisture content above 60% makes the stream suitable for biological processing using Black Soldier Fly (BSF) larvae; second, the significant portion of plastics and paper provides opportunities for recycling and pyrolysis as complementary treatment methods. The relatively small share of other materials, such as glass and rubber, has limited recovery potential and is more likely to be directed to landfill. Overall, the composition data reinforce the importance of an integrated waste management approach that prioritizes organic treatment while also addressing plastics and paper recovery.

3.2 Mass Balance and Material Recovery Potential

A mass balance analysis was performed to estimate material recovery from the projected waste stream. The results show that 83.98 m³/day (52.14%) of waste can be diverted through recycling, BSF processing, and pyrolysis, while the remaining 69.60 m³/day (47.86%) must be disposed of at the landfill. The analysis indicates that recyclables contribute 51.86 m³/day, BSF larvae treatment handles 32.12 m³/day of organics, and pyrolysis processes 7.47 m³/day of mixed plastics and other combustibles. This demonstrates the potential of integrating biological and thermal technologies to significantly reduce landfill dependency.

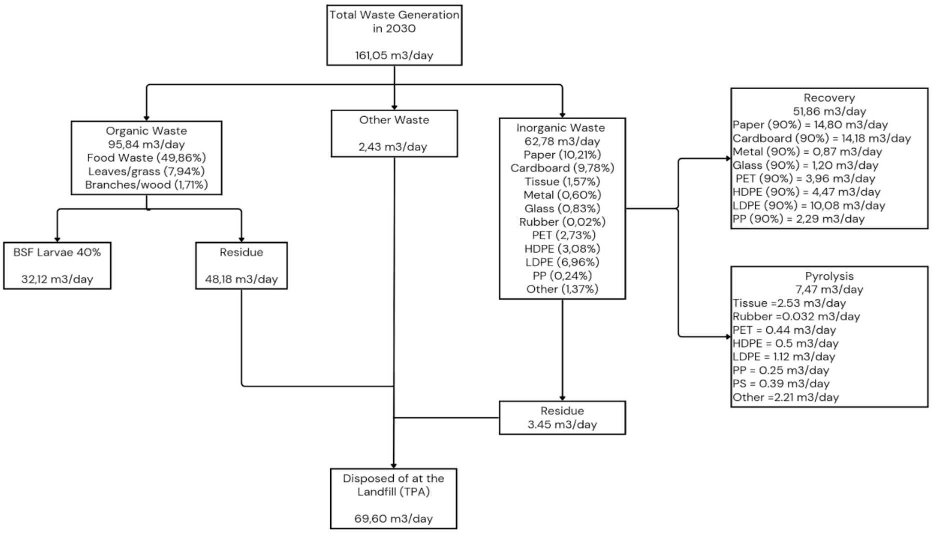

Figure 2. Mass Balance of Waste Management System in Tingkir District

The flow diagram based on figure 2 illustrates the distribution and processing pathways of projected waste generation in Tingkir District for 2030, which amounts to 161.05 m³/day. Organic waste is the dominant fraction at 95.84 m³/day, primarily food waste, leaves, and wood. From this stream, about 40% (32.12 m³/day) is directed to Black Soldier Fly (BSF) larvae treatment, while the remaining portion becomes residue. Inorganic waste, estimated at 62.78 m³/day, consists mainly of paper, cardboard, plastics, metals, and glass. Of this amount, 51.86 m^3/day can be recovered through recycling, with paper and cardboard contributing the largest shares, while 7.47 m^3/day is suitable for pyrolysis treatment, particularly plastics such as PET, HDPE, LDPE, and PP. The residual fraction from both streams, totaling 69.60 m^3/day, is ultimately disposed of in the landfill. This flow analysis highlights that integrated treatment combining BSF, recycling, and pyrolysis technologies can significantly reduce landfill dependency, ensuring both environmental benefits and resource recovery.

3.3 Design of Inorganic Waste Processing Facilities

The facility layout includes sorting lines, washing and drying areas, shredding, baling, storage, and pyrolysis units. The total floor area required for inorganic waste handling is 245–348 m^2, including 80 m^2 for pyrolysis, 67 m^2 for storage, and 45 m^2 for pre-processing. Conveyor design calculations indicate a required loading rate of 23.01 m^3/h, with three belt conveyors of 5 m length each operating at a capacity of 10 m^3/h. These dimensions are consistent with similar-scale Material Recovery Facilities (MRFs) and ensure efficient material flow through the facility.

In planning the design of inorganic waste processing facilities in Tingkir District, it was necessary to calculate the space requirements for each functional unit to ensure efficient operation and smooth material flow. These units include areas for waste reception, sorting, washing and drying, shredding, baling, storage, pyrolysis, and weighing, all of which play a critical role in supporting the integrated waste management system. The detailed area requirements for each unit are presented in Table 4. Table 4 shows the area requirement for inorganic waste processing.

Table 4. Area requirements for Inorganic Waste Processing Units

No.	Calculation	Need	
1.	Loading rate garbage in	23.01	m^3/h
		1.72	ton/h
2.	Sorting	38.50	m^2
3.	Waste washing & Drying	34.00	m^2
4.	Trash Shredder	4.00	m^2
5.	Junk Press	9.00	m^2
6.	Inorganic Waste Storage Warehouse	67.25	m^2
7.	Pyrolysis	80.00	m^2
8.	Weighing of Inorganic Waste	12.00	m^2
	Total	**244.75**	m^2

As shown in Table 4, the total area required for inorganic waste processing is 244.75 m^2, covering all necessary units from waste intake to final processing. The largest portion of the facility is allocated to the pyrolysis unit (80.00 m^2) and the storage warehouse (67.25 m^2), reflecting the importance of both thermal treatment and intermediate storage in the overall process. Other key units include sorting (38.50 m^2) and waste washing and drying (34.00 m^2), which are essential for improving the quality and efficiency of subsequent treatment steps. Smaller but equally critical areas are designated for shredding, pressing, and weighing to support the mechanical preparation of waste before final processing. These space allocations are consistent with design standards for material recovery facilities (MRFs) of similar scale, ensuring that the planned Integrated Waste Processing Facilities can operate effectively and handle the projected inorganic waste load.

In addition to calculating the area needed for each individual processing unit, it is equally important to determine the total area required for the main building of the Integrated Waste Processing Facilities in order to ensure smooth integration of all functional activities. The main building must accommodate not only the operational units for waste processing, such as pre-processing, sorting, and pyrolysis, but also supporting facilities including storage warehouses, tool storage, and weighing areas. This integrated design approach allows for efficient material flow, reduces bottlenecks in processing, and ensures that all units operate in harmony to meet the projected waste load. The recapitulation of the main building area requirements is summarized in Table 5.

Table 5. Recapitulation of the Main Building Area Requirements for Integrated Waste Processing Facilities

No.	Calculation	Need	
1.	Loading rate garbage in	23.01	m^3/h
		1.72	ton/h
2.	Pre-processing	45.00	m^2
3.	Sorting	38.50	m^2
4.	Waste washing & Drying	34.00	m^2
5.	Trash Shredder	4.00	m^2
6.	Junk Press	9.00	m^2
7.	Inorganic Waste Storage Warehouse	67.25	m^2
8.	Pyrolysis	80.00	m^2
9.	Tool Storage warehouse	15.00	m^2
10.	Weighing of Inorganic Waste	9.00	m^2
11.	Residue Waste Area	46.40	m^2
	Total	**348**	m^2

As presented in Table 5, the total main building area requirement for the Integrated Waste Processing Facilities is 348 m², covering both processing and supporting units. Among these, the largest areas are allocated to the pyrolysis unit (80.00 m²), the residue waste area (46.40 m²), and the inorganic waste storage warehouse (67.25 m²), which reflects their central importance in handling and treating significant waste volumes. Pre-processing (45.00 m²) and sorting (38.50 m²) also account for substantial portions of the building space, highlighting their role in preparing waste for subsequent treatments. Meanwhile, smaller but essential areas such as tool storage, weighing stations, and shredding units ensure that operational efficiency is maintained throughout the process. The overall allocation demonstrates a balanced design that not only prioritizes critical waste treatment technologies but also incorporates necessary auxiliary spaces, enabling the Integrated Waste Processing Facilities to function as an integrated and sustainable waste management facility.

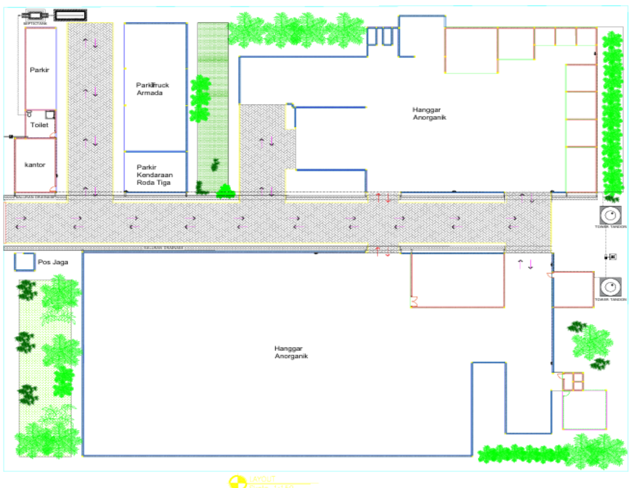

Figure 3. Layout Integrated Waste Processing Facilities

Figure 3 illustrates the spatial layout of the planned Integrated Waste Processing Facilities facility, which has been carefully designed to integrate various waste processing units into a functional and efficient system. The layout ensures a logical flow of waste handling, beginning with the reception and sorting areas, followed by dedicated spaces for washing, shredding, pyrolysis, and storage. Supporting facilities such as tool storage, weighing areas, and residue storage are also strategically positioned to enhance accessibility and operational efficiency. The arrangement reflects not only technical requirements for processing both organic and inorganic waste but also considerations for safety, ease of transportation, and environmental management. With this design, the integrated waste processing facilities is expected to operate as an integrated waste management center capable of reducing landfill dependence while maximizing resource recovery.

3.4 Organic Waste Processing with Black Soldier Fly Larvae

Organic waste treatment is planned using the Black Soldier Fly (BSF) system, processing approximately 2,396.69 kg/day of food waste. After pre-treatment using a shredder with 8.5 HP power and 500–800 kg/rit capacity, the waste is distributed into BSF rearing containers (*lavero*). A total of 1,438 lavero units are required in a 12-day rearing cycle, with daily feeding of 120 units. This system is supported by 288 biopond racks for container placement. The BSF process produces both dried larvae (maggots) as a protein source and kasgot (organic fertilizer) as a soil amendment, demonstrating its potential for circular bioeconomy applications. Table 6 shows the capacity and requirement that needed for BSF based processing.

Table 6 underlines the scale of infrastructure required to sustain BSF-based organic waste processing. The large number of lavero containers and bioponds shows that biological treatment requires significant spatial and operational resources compared to mechanical treatment. However, this investment is offset by the high-value outputs of maggots and fertilizer, which have clear market demand. Thus, the data validate the BSF approach as both environmentally and economically beneficial for handling food waste at community scale.

Table 6. Capacity and Requirements for BSF-based Organic Waste Processing

Breeding Unit Needs		
Information	**Results**	**Unit**
Larvae per day	4793378	
Larvae requirements per day	671	Kg
Egg weight per day (g)	336	Gram
Daily Requirement for brood flies	22369	pairs
Percentage of broodstock larvae requirements (%)	4838116	
Daily larvae requirements (Total)	677	Kg
Larvae requirements per day (kg)	338.67	Gram
Egg weight per day (gram)	22578	Pairs
Daily need for brood flies	45156	
Total brood fly requirements	451558	
Requirements for brood flies/10 days	180623	cm^2
Mating cage area (cm^2)	4.52	m^2
Mating cage area (m^2)	2.12	m^2
P : L	4.12	m

3.5 Financial Feasibility Analysis

The financial analysis over a 10-year operational period shows total revenues of Rp 54.82 billion, compared with expenditures of Rp 38.30 billion, resulting in a cumulative net profit of Rp 16.51 billion. The revenues are primarily derived from the sale of fuel oil produced by pyrolysis, maggots from BSF larvae, organic fertilizer, and recyclable materials. This profitability demonstrates that the proposed Integrated Waste Management Facility is not only environmentally beneficial but also economically sustainable. The financial indicators demonstrate that the Integrated Waste Processing Facilities is economically feasible, with revenues significantly outweighing expenditures. These findings are consistent with previous studies, which reported that integrated waste management systems combining resource recovery and energy conversion can significantly improve economic performance compared to disposal-oriented systems (Damanhuri and Padmi, 2016; Arena, 2012).

In assessing the financial feasibility of the proposed Integrated Waste Processing Facilities in Tingkir District, it is essential to analyze not only the projected revenues but also the operational and maintenance costs required to sustain facility performance throughout its lifecycle. These costs encompass a wide range of expenditures, including daily operational needs such as labor, utilities, and energy, as well as routine maintenance activities for equipment, storage facilities, and supporting infrastructure. By forecasting these expenses over a ten-year period (2021–2030), a clearer understanding can be gained of the long-term financial commitments necessary to ensure that the integrated waste management system operates efficiently and remains economically viable.Table 7 shows the operational and maintenance cost.

As presented in Table 7, the annual operational costs consistently form the largest share of expenses, with values gradually increasing in line with population growth and rising waste volumes, while maintenance costs represent a smaller but critical portion related to equipment servicing and infrastructure support. Over the ten-year period, the total combined expenditure reaches approximately Rp 5.70 trillion, underscoring the scale of financial resources required to maintain integrated waste management facilities in the region. The economic contribution of pyrolysis technology is particularly significant, as the conversion of low-value plastic waste into fuel oil provides a stable revenue stream while simultaneously reducing landfill dependency. Previous research has shown that plastic pyrolysis can be financially attractive at municipal scale when feedstock availability is sufficient and integrated with existing waste management infrastructure (Ramadhan and Ali, 2013; Miandad et al., 2016). Similarly, BSF-based organic waste processing contributes to financial sustainability through the production of high-value protein sources and organic fertilizers, which have demonstrated strong market demand in both agricultural and livestock sectors (Popa and Green, 2012; Diener et al., 2011).

Table 7. Operational and Maintenance Costs of Tingkir District Integrated Waste Processing Facilities

Year	Total Operational Costs	Total Maintenance Costs	Total Operational and Maintenance
2021	Rp 431.614.600,00	Rp 21.580.800,00	Rp 453.195.400,00
2022	Rp 453.195.300,00	Rp 22.659.800,00	Rp 475.855.100,00
2023	Rp 475.855.100,00	Rp 23.792.800,00	Rp 499.647.900,00
2024	Rp 499.647.800,00	Rp 24.982.400,00	Rp 524.630.200,00
2025	Rp 524.630.200,00	Rp 26.231.600,00	Rp 550.861.800,00
2026	Rp 550.861.700,00	Rp 27.543.100,00	Rp 578.404.800,00
2027	Rp 578.404.800,00	Rp 28.920.300,00	Rp 607.325.100,00
2028	Rp 607.325.000,00	Rp 30.366.300,00	Rp 637.691.300,00
2029	Rp 637.691.300,00	Rp 31.884.600,00	Rp 669.575.900,00
2030	Rp 669.575.800,00	Rp 33.478.800,00	Rp 703.054.600,00
Total	**Rp 5.428.801.600,00**	**Rp 271.440.500,00**	**Rp 5.700.242.100,00**

To provide a comprehensive assessment of the financial feasibility of the proposed Integrated Waste Processing Facilities in Tingkir District, it is not sufficient to only consider the operational and maintenance costs; it is also necessary to evaluate projected revenues and their ability to offset expenses over time. Revenues are primarily derived from the sale of valuable by-products such as fuel oil from pyrolysis, Black Soldier Fly (BSF) larvae, organic fertilizer, and recyclable materials, each contributing to the financial sustainability of the facility. At the same time, the balance between these revenues and the expenditures incurred annually determines whether the facility generates profits or experiences losses, especially in the early years when investment and operating costs are still high. By projecting both income and expenditures over the period of 2021–2031, a clearer financial outlook is obtained, highlighting the long-term sustainability of the integrated waste management system. Table 8 shows the income of Tingkir Subdistrict Integrated Waste Processing Facilities.

Table 8. Income Statement of Tingkir Subdistrict Integrated Waste Processing Facilities

Year	Expenses (Rp/year)	Income (Rp/year)	Loss/Profit (Rp/year)
2021	Rp4.667.234.656,89	-	-Rp4,667,234,657
2022	Rp3.624.400.800,00	Rp2,686,394,300	-Rp938,006,500
2023	Rp2.716.629.700,00	Rp3,142,482,300	Rp425,852,600
2024	Rp2.854.189.200,00	Rp3,651,022,000	Rp796,832,800
2025	Rp2.997.705.000,00	Rp4,215,852,100	Rp1,218,147,100
2026	Rp3.149.548.700,00	Rp4,842,648,800	Rp1,693,100,100
2027	Rp3.312.412.000,00	Rp5,538,929,700	Rp2,226,517,700
2028	Rp3.473.898.100,00	Rp6,310,659,100	Rp2,836,761,000
2029	Rp3.648.860.100,00	Rp7,163,574,200	Rp3,514,714,100
2030	Rp3.832.455.200,00	Rp8,108,334,100	Rp4,275,878,900
2031	Rp4.024.769.000,00	Rp9,157,154,000	Rp5,132,385,000
Total	**Rp38.302.102.456,89**	**Rp54,817,050,600.00**	**Rp16,514,948,143.11**

As shown in Table 8, the Integrated Waste Processing Facilities initially records financial losses in the first two years due to substantial investment and operating expenditures that exceed revenues. However, beginning in 2023, the facility starts to generate profits as revenues from pyrolysis oil, BSF larvae, fertilizers, and recyclables accumulate, with the annual surplus steadily increasing thereafter. By the final projection year of 2031, the Integrated Waste Processing Facilities achieves a cumulative net profit of approximately Rp 16.51 trillion, clearly demonstrating its long-term economic feasibility and confirming that integrated waste management in Tingkir District can be both environmentally beneficial and financially sustainable. The income statement analysis further shows that the IWPF experiences financial losses during the first two years of operation due to high capital investment and initial operational expenses. However, starting from the third year, the facility begins to generate annual profits as revenues from recovered materials and energy products increase. This trend aligns with findings from previous waste management investment studies, which emphasize that integrated treatment facilities typically require a short payback period before reaching financial stability (Arena, 2012; Kaza et al., 2018). By the end of the planning horizon, the steady increase in annual surplus confirms that the proposed IWPF is not only environmentally beneficial but also economically sustainable.

4. Conclusions

The projection of waste generation in Tingkir District for 2030 is 161.05 m^3/day, equal to 3.50 liters/person/day or 0.261 kg/person/day. The waste composition consists of 59.51% organic waste (food residues, leaves, and wood) and 38.97% inorganic waste, dominated by paper, cardboard, and various plastics (PET, HDPE, LDPE, PP, PS, and others), while the remainder (1.51%) includes diapers, sanitary pads, and masks.

The design of the planned Integrated Waste Processing Facility addresses five key aspects of waste management. Institutionally, the facility requires an organizational structure that involves community participation to ensure operational efficiency. Legally, the implementation of comprehensive Standard

Operating Procedures (SOPs) and local regulations is necessary to guide and support Integrated Waste Processing Facilities operations. Financially, revenues are derived from the sale of dried maggots, kasgot (organic fertilizer), and recyclable materials (plastics, cardboard, metals, and glass), with total projected income of Rp 16.51 billion over the planning period. Community participation is critical in waste collection, payment of retribution, and involvement in processing activities.

Technologically, inorganic waste reduction is achieved through pyrolysis, which processes PET, HDPE, LDPE, PP, PS, and other combustible materials, reducing waste by 0.56 tons/day (43.22%), equivalent to 7.47 m^3/day (4.64%). Organic waste reduction is carried out using Black Soldier Fly (BSF) larvae, capable of treating 2,396.69 kg/day (33.52%) of food waste. These results demonstrate that the integration of BSF larvae and pyrolysis at the Integrated Waste Processing Facilities level can significantly reduce landfill dependency while generating valuable by-products that enhance both environmental sustainability and economic viability.

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