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Corresponding Author
Janssen Andrew S. Calvelo
Email
jscalvelo@up.edu.ph

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Original Research Article

Feasibility Study of an Integrated Waste Management Technology System for a Circular Economy in the Philippines

Ericka Renee A. Langit, Christian Aldem S. Parungao, Eliza Tabitha A. Gregorio, Aaron Joseph M. Sabo-o, Beatrice Ann Y. Dulay, Dayniele D. Loren, Kylene Angeli M. Patria, Beatrice Alexis B. Quines, Millicent Vea F. Dacumos, Jazmin Ann C. Catabay, Fiona Grace C. Romano, Joseph R. Lagarde Jr., Ken Marc V. Santos, Kristene Joy M. De La Rosa, Dominique Denise M. Offemaria, John Orly E. Pedimonte, Ma. Beatrice O. Rito, Ma. Alessandra Eunice Alvarez, Janssen Andrew S. Calvelo, and Casper Boongaling Agaton

Department of Community and Environmental Resource Planning, College of Human Ecology, University of the Philippines Los Baños, College 4031, Laguna, Philippines

Abstract

Increasing population and rapid economic growth result in waste management problems in the Municipality of Bay, Laguna. In response, the municipality is planning to invest in an Integrated Waste Management Technology System (IWMTS) that aims to generate public revenue. Key informant interviews, surveys, and focus group discussions were utilized for data collection. Results showed that respondents lack knowledge about IWMTS but perceive positive impacts on waste volume reduction and municipal waste management and little to no negative impacts on health, livelihood, and accessibility. Meanwhile, economic analysis showed that it is estimated to generate an annual revenue of PHP 11.986 million (USD 214,036) with yearly expenses of PHP 3.7 million (USD 66,071). These cash flows are expected to recover the overall capital outlay of PHP 48.14 million (USD 859,642). A net present value (NPV) of PHP 3.164 million (USD 56,500) and a 5.77-year payback period (PBP) were calculated through cost-benefit analysis. The environmental analysis revealed positive impacts on reducing the volume of wastes, water resources, and quality, odor and air quality, and soil and nutrients. Considering these, the study provided recommendations on project implementation to achieve sustainable waste management and circular economy in the municipality.

Keywords— circular economy, composting, municipal solid waste, recycling, waste management

1 Introduction

Proper solid waste management falls under the United Nations' Sustainable Development Goals 11 (Sustainable Cities and Communities), 12 (Responsible Consumption), and 13 (Climate Action). Municipal solid waste management is a complex issue involving an interplay of social, economic, and environmental factors, facing unique challenges and constraints primarily due to rapid urbanization, population growth, and limited resources. In 2020, the world generated 2.24 billion tons of solid waste, which is expected to increase to 3.88 billion tons by 2025 due to rapid population growth and urbanization [1]. Compared to industrialized nations, citizens of developing countries, particularly the urban poor, are more affected by the unsustainable management of these wastes [2]. In these countries, over 90% are often disposed of in unregulated dumpsites or openly burned resulting in serious health, safety, and environmental problems [3].

Addressing municipal solid waste issues requires a holistic management approach that integrates technology, policy, public participation, and environmental considerations to minimize waste and maximize resource recovery [4]. Recent technologies include combinations of recycling, sanitary landfilling, incineration, anaerobic digestion, composting, pyrolysis, and waste-to-energy (WtE) [5, 6, 7, 8, 9, 10]. These technologies return wastes to the circular economy such as organic wastes into fertilizers and composts; agricultural wastes into briquettes; plastic wastes into eco-bricks and plastic materials; metallic wastes into raw materials for construction; combustibles into energy, among others [11, 12, 13]. These circular economy strategies maximize economic efficiency, reduce resource consumption, and improve environmental quality, thereby mitigating the pressures faced by individual countries [14, 15].

Recent studies evaluate these technologies from economic, technological, environmental, and social perspectives. For instance, Peng et al. [16] assessed the economic feasibility of transforming municipal, agricultural, and industrial wastes into energy using anaerobic digestion. Results found that methane captured in the case of Delhi, India could supply 7140 GWh of electricity for 8-18 million households at USD 0.07/kWh levelized cost and 1.17-2.37 years payback period. In another study, Samarasinghe and Wijayatunga [17] assessed WtE coupled with circular economy elements in the context of developing countries. Using the case of Sri Lanka, results found the viability of a centralized incineration plant and decentralized biogas facilities could generate 129.86 GWh and 41.4 GWh of electricity. At the same time, processing digestate could produce 43,000 tons/year of compost and 125 tons/day of recyclable waste. Comparing different WtE technologies, Agaton et al. [9] applied a real options approach to analyze the optimal timing of investment under uncertainties in electricity prices. Results found that minimum electricity prices needed for the technology to be feasible are USD 0.03/KWh for incineration, USD 0.07/KWh for gasification, and USD 0.12/KWh for pyrolysis, making pyrolysis not feasible at the current rate of USD 0.11/KWh unless the tipping is increased from USD 15/ton to USD 18.5/ton. Meanwhile, Afrane et al. [18] adopted a comprehensive multi-criteria decision-making approach in selecting an optimal WtE technology in Ghana. The Analytic Hierarchy Process (AHP) results found that technical and social criteria obtained the highest and lowest priority weight.

In contrast, the fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) obtained an overall ranking order of WtE technologies as follows: anaerobic digestion > gasification > pyrolysis > plasma gasification. In another multidisciplinary approach, De Boni et al. [19] applied a Life Cycle Analysis (LCA), Cost-Benefit Analysis (CBA), and Deliberative, Longitudinal Panel-based, Hierarchical Iteration (DELPHI) methods to evaluate the feasibility of a community biowaste management facility. Results show that the proposed model could minimize the environmental impact through carbon footprint reduction and ensure economic sustainability. Moreover, social acceptability was strongly influenced by the community's level of information and knowledge.

Although waste management technologies have the potential to reduce the ecological footprint significantly, there are challenges in the lack of funding, government strict regulatory policies, proper financial planning, public support, benchmarking processes, knowledge in implementing innovative technologies, awareness among the community, source segregation and recycling commitment, service provider, and various project uncertainties [20, 21, 22]. Evaluating waste processing systems' social, economic, and environmental impacts is considered a crucial element of efficient integrated waste management planning [19, 23].

By proposing a valuation framework for an IWMTS project that integrates social, economic, and environmental aspects from the perspective of stakeholders from rural communities in developing countries, the study aims to bridge the gap between the potential and the lack of resources with the following objectives:

- To analyze the social acceptability of the project as well as its impacts on health, livelihood, cultural practices, and vulnerable groups in the area.
- To calculate the net present value (NPV), internal rate of return (IRR), returns on investment (ROI), and payback period (PBP).
- To apply sensitivity analysis to evaluate the impacts of explanatory variables on the project's economic feasibility.
- To qualitatively evaluate the impacts of the project on air, water, and soil qualities, biodiversity, wildlife, and protected areas.
- To suggest policies to support the adoption of IWMTS facilities to realize the government's goal of a more environmentally friendly and sustainable municipal solid waste management.

2 Methodology

2.1 Case Study Background

The Municipality of Bay is a second-class municipality in Laguna province, composed of 15 Barangays. It is located on the southern part of Laguna de Bay and is adjacent to the Municipality of Los Baños and Calauan, Laguna. Bay is an agricultural municipality with 68% of its total land area utilized for agricultural use including crop, poultry, and livestock production, while several barangays adjoining Laguna Lake are engaged in fishing. Tourism also plays an important aspect of the economy in promoting the heritage and culture of Bay. The municipality has 421 commercial establishments accumulating PHP 1.8 billion (USD 32,142,857 [1]) annual revenue. Bay is projected to experience significant population growth of 67,134 in 2020 and is expected to reach 75,336 by 2027 and 133,586 by 2062 [24]. This rapid population increase exacerbates existing challenges, especially in the area of waste management.

Waste collected from residential and commercial activities in the municipality is composed of 49% biodegradable, 30% recyclable, 20% residual waste (representing solid waste materials that are non-compostable and non-recyclable) and 1% special waste, particularly household hazardous wastes. The increasing population substantially contributes to the increasing solid waste projected at 28.77 tons/day in 2024. In response, the municipality formulated a 10-year Solid Waste Management (SWM) Plan covering 2014 to 2024 [25]. The municipality outlines waste management strategies such as (1) increase of recycling efforts in households and barangay-level with recyclables being sold to junk shops; (2) strengthened material recovery facility operations; and

1 Values in Philippine Pesos (PHP) were converted to US Dollars (USD) using currency converter wise.com considering the 10-year average exchange rate; 1 USD = 56 PHP

backyard composting and vermicomposting of biodegradable wastes; (3) construction of a Category II Sanitary Landfill in Barangay Sta Cruz as the destination of residual wastes from the barangays, and (4) potential investment in an Integrated Waste Management Technology System (IWMTS) Project in the same location of the Sanitary Landfill (see Figure 1) to process all municipal solid wastes and to create a circular economy system in waste management. The study will focus on the socio-economic and environmental analyses of Strategy 4.

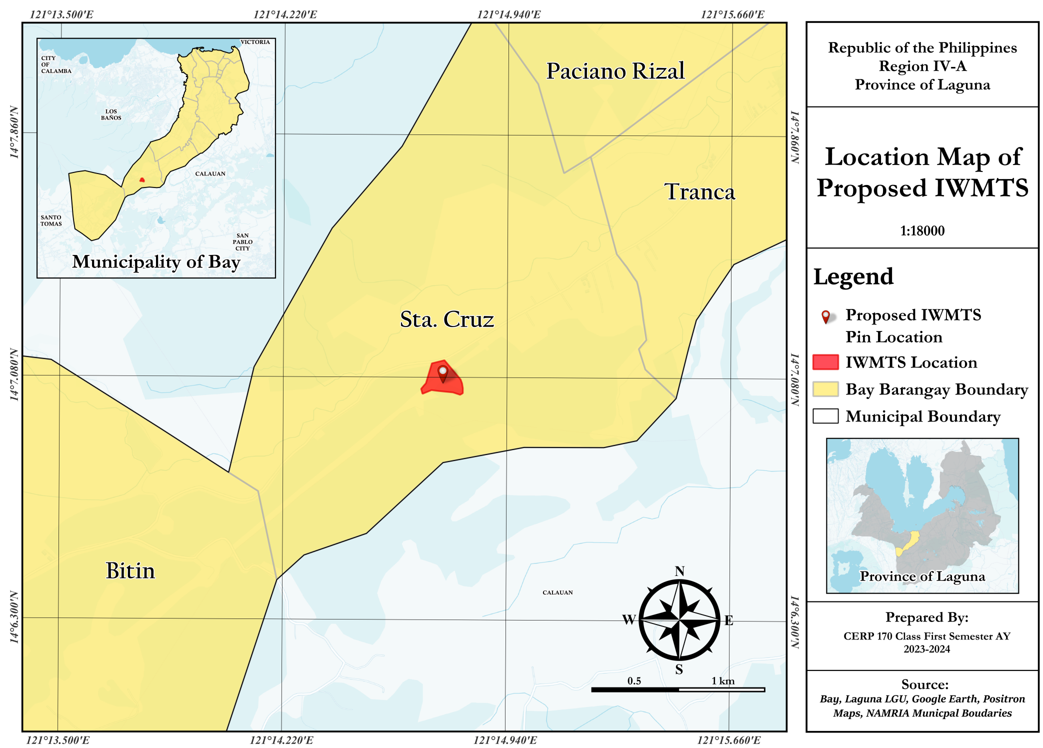

Figure 1.
Location Map of Proposed IWMTS in Bay, Laguna (*source: authors*)

The Municipality of Bay was selected as a case for this feasibility study due to (1) the project addresses the municipal solid waste management problem of the municipality by turning its dumpsite into a circular economy; (2) the municipality is currently looking for technological solutions to address the waste management problem; (3) the manufacturer of the IWMTS is near the area and is willing to provide the technology for Bay; and (4) with its available land, Bay can accommodate wastes generated from the neighboring municipalities without waste processing facilities or with limited lands for sanitary landfill.

2.2 Integrated Waste Management Technology System Project

The project utilizes a technology system offered by L.G. Lopez Industrial Sales Services, Inc., comprised of twelve (12) interconnected machines designed to achieve zero waste. Key products of the system include liquid fertilizers, compost, eco-bricks, briquettes, and compressed valuable wastes, as illustrated in Figure 2.

The collected municipal waste will be subjected to a sorting and preparation process to produce feedstock. The process begins by inputting the waste bags into a waste-opener machine, a sorting line conveyor, and a machine conveyor equipped with a rotary trommel assembly. This phase facil-

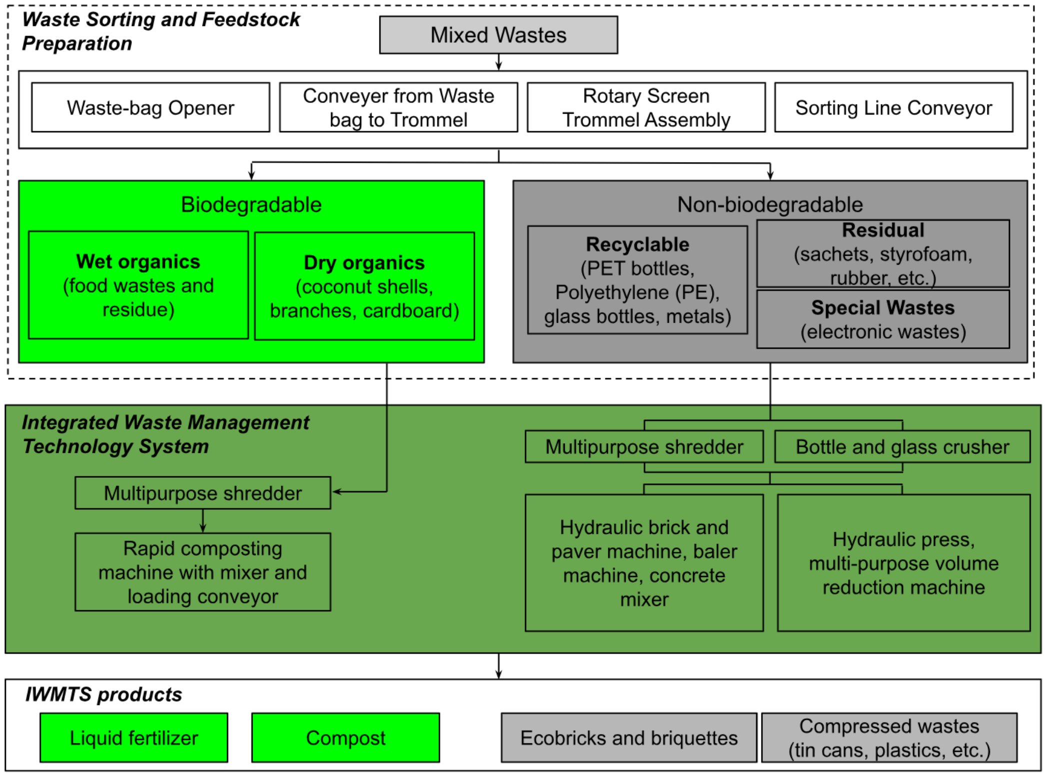

Figure 2.
Waste Characterization and Products of IWMTS

itates the segregation of waste into biodegradable and non-biodegradable classifications. Upon classification, the wastes will be transported to the integrated waste management technology system for further processing. Biodegradables include wet and dry organic wastes. Wet organics comprise human waste, food residues, and sewage, while dry organics, such as coconut shells and branches, undergo further volume reduction through a multipurpose shredder. Both wet and dry wastes are processed through a rapid composting machine (Figure 3). The composting machine incorporates a ribbon-type mixer, loading screw conveyor, built-in shredder, built-in squeezer, bagger screw, leachate tank with a submersible pump, enzyme sprayer with timer, pressure washer for machine cleaning, and three stainless steel fermentation tanks. Each tank features a motorized aerator mixer. The end products of the organic waste processing are liquid fertilizer and compost.

Meanwhile, non-biodegradable wastes are classified into recyclable, residual, and special. Recyclable materials, including cardboard, paper, styrofoam, polyethylene terephthalate (PET) bottles, polyethylene (PE), and special wastes, such as electronic waste and metals, are processed through a multipurpose shredder. The resulting shredded wastes are feedstock for the hydraulic press and brick and paver machine. The machine (Figure 4) has a lever-type hydraulic control valve, PSI indicator gauge, two sets of differently shaped brick molds, and lower and upper hydraulic cylinders. Eco-bricks are produced after the process.

Glass and glass bottles are subjected to a bottle and glass crusher machine (Figure 5a), producing glass powder. This glass powder is subsequently introduced into a hydraulic press, brick, and baler machine (Figure 5c), which yields briquettes suitable for construction purposes. Other residual and special waste, including DVDs, multilayered plastics, rubber, bags, and shoes, are

Figure 3.
Rapid Composting Machine with Mixer and Loading Screw Conveyor (*source: L.G. Lopez Industrial Sales & Services, Inc.*)

Figure 4.
Multi-purpose Shredder (left), and Hydraulic Press, Brick, and Paver Machine (right) (*source: L.G. Lopez Industrial Sales & Services, Inc.*)

processed through a multipurpose volume reduction machine (Figure 5b), producing compressed waste.

While the IWMTS can process most types of waste and transform them into valuable products, certain types of waste, such as ceramics, medical waste, and worn-out textiles, present limitations for the technology.

Figure 5.
(a) Bottle and Glass Crusher (left), (b) Multi-Purpose Volume Reduction Machine (center), and (c) Hydraulic Press Baler Machine (right) (*source: L.G. Lopez Industrial Sales & Services, Inc.*)

2.3 Data Collection and Research Instruments

This study employed a multi-step methodology to assess the potential impacts and acceptability of the construction of the IWMTS (see Figure 6). First, an ocular inspection was done to evaluate the current situation in the municipal landfill and the waste collection and disposal practices. This step also identifies the immediate communities affected by constructing the proposed IWMTS facility in Barangay Sta. Cruz, Bay, Laguna. Second, the sample size was calculated using Slovin's formula in Equation 1

$$n = \frac{N}{1 + Ne^2} \tag{1}$$

where n is the sample size, N is the population size, and e is the margin of error. The determination of the sample size utilized a 90% confidence level with a 10% margin of error. A sample size of 62 households was computed from 612 total households in Sta Cruz. Third, a comprehensive questionnaire and interview guide were prepared. These tools were designed to collect the socio-demographic data of the household representatives and their perceptions regarding the anticipated effects of the IWMTS on the community and the multiple facets of life. Then, the data collection was done to collect both primary and secondary data needed for the analysis.

This research used survey questionnaires and key informant interviews (KII) to collect the primary data. The survey questionnaire was divided into four parts: informed consent, demographic information, social acceptability and perceived social impacts, and the perceived environmental impacts of the IWMTS. The social impacts include questions on awareness, current practices, culture, livelihood, and health. In contrast, the environmental impacts focus on water resources, air quality, soil and nutrients, biodiversity, and wildlife. On the other hand, two sets of KIIs were conducted to determine the possible environmental impacts and the techno-economic aspect of the IWMTS. First, the researchers interviewed the Municipal Planning and Development Office (MPDO) and the Municipal Environment and Natural Resources Office (MENRO) to assess the current municipal waste management plan and strategies and the perceived impacts of the IWMTS from a municipal perspective. The second set of KII focused on identifying the technological specifications of the machines in IWMTS. A representative of L.G. Lopez Industrial Sales & Services, Inc. was interviewed to collect data on capacity, production processes, utility requirements, costing, and projected benefits.

Lastly, the secondary data collection utilized various municipal development plans such as the Comprehensive Land Use Plan (CLUP), the Local Climate Change Action Plan (LCCAP), the Solid Waste Management Plan (SWMP), and the Climate and Disaster Risk Assessment (CDRA), acquired from the Local Government Unit of Bay.

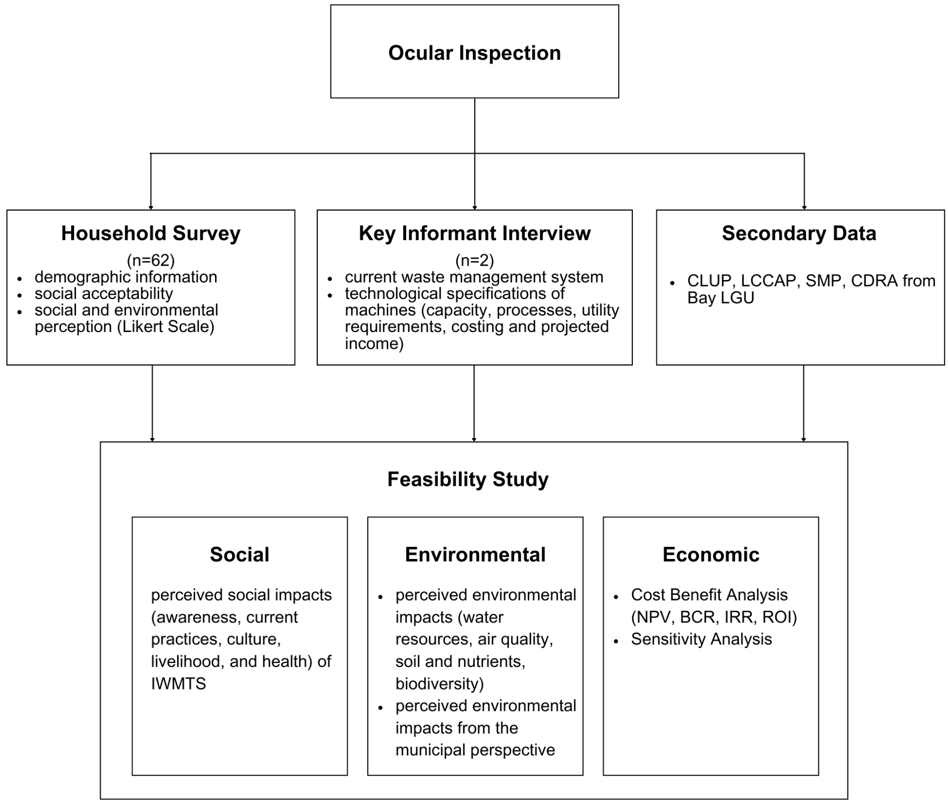

Figure 6.
Multi-step Methodology to Assess the Potential Impacts and Acceptability of the IWMTS

2.4 Feasibility Studies

A feasibility study is an analysis that considers all of the relevant factors affecting the proposed project such as economic, technical, legal, and scheduling considerations to determine the likelihood of success [26]. Previous studies utilized multidisciplinary analysis to evaluate the feasibility of IWMTS. For instance, Del Pero et al. [27] considered environmental, economic, and social aspects of the construction of an integrated sustainable waste management facility in Kenya. In another study, Yousefloo and Babazadeh [28] applied economic and environmental analyses to optimize the decisions for the location of the waste treatment plant, transportation method, waste processing technologies, and the allocation of different wastes to the facilities in Iran. In the circular economy context, Rathore and Sarmah [29] examined the economic, environmental, and social feasibility of converting municipal solid waste into biogas, which is used as a fuel in a thermal power plant in India. Moreover, Prihandoko et al. [30] applied economic analysis using net present value (NPV), internal rate of return (IRR), and payback period as well as people perception to evaluate the feasibility of an integrated waste management facility in Indonesia. Furthermore, Paes et al. [31] integrated the economic and environmental aspects to analyze Brazil's best combination of technologies for the municipal solid waste management system.

The current study aims to contribute to the literature by combining the economic, environmental, and social aspects to analyze the feasibility of IWMTS from the perspectives of the impact on community households and the local government of Bay, Laguna in the Philippines. The study also provides recommendations for the implementation of the proposed technology. For the perceived social and environmental impacts, the Likert Scale was used. On the other hand, the cost-benefit analysis (CBA) was applied for the economic aspect using 5 indicators, namely net present value (NPV), benefit-cost ratio (BCR), internal rate of return (IRR), return on investment (ROI), and payback period (PBP).

The NPV analyzes the project's profitability while BCR shows the cost and benefit relationship. These tools are calculated using Equations 2 and 3

$$NPV = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+i)^t} - I \tag{2}$$

$$BCR = \sum_{t=0}^{T} \frac{DB_t}{DC_t} \tag{3}$$

where B_t is the benefit of the project including the revenues from the sales of all products of the IWMTS; C_t is the operations and maintenance costs such as the utilities, labor, and production costs; I is the investment costs for the machines, installation, and refurbishing of the facility; i is the discount rate; t is the valuation period; and T is the effective technical lifetime of the facility.

The IRR is the discount rate at which a project implementer can ensure that the investment makes more money than its actual cost. It identifies the rate of discount, which makes the present value of the sum of annual cash inflows equal to the initial net cash outlay for the investment. The IRR is calculated using the NPV formula, replacing the i with IRR, and finding the value of IRR by making NPV equal to zero as shown in Equation 4.

$$NPV = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+IRR)^t} - I = 0 \tag{4}$$

ROI is a profitability metric that measures the return on a particular investment relative to the investment's cost. It is expressed as a percentage and is calculated by dividing an investment's net profit (or loss) by its initial cost or capital outlay as shown in Equation 5.

$$ROI = \frac{\sum_{t=1}^{T}(B_t - C_t)}{I} * 100\% \tag{5}$$

The PBP is the length of time it takes to recover the cost of an investment or the length of time an investor needs to reach a breakeven point. It is calculated by dividing the amount of the investment by the annual cash flow as shown in Equation 6.

$$PBP = \frac{I}{(B_1 - C_1)} \tag{6}$$

The investment decision whether to implement/accept or reject the project for the above economic tools is shown in Table 1.

Using the above decision rules, the IWMTS project can only be implemented if the NPV>0 and BCR>1 to ensure that the revenues generated from the investment outweigh the technology costs and the annual operational and maintenance costs. The calculated IRR should also be greater than the hurdle rate (social discount rate) at 10% as set by the National Economic and Development Authority (NEDA) [32] for government projects. Considering the period of the municipal comprehensive development plan (CDP) of 6 years, the ROI must be recovered (100%) within six years of operations.

Table 1. Decision Rules to Accept IWMTS Project

Cost-Benefit Analysis Tool	Decision Rule
Net Present Value	Accept if NPV>0
Benefit-Cost Ratio	Accept if BCR>1
Internal Rate of Return	Accept if IRR> hurdle rate (10%)
Returns on Investment	Accept if ROI>100%
Payback Period	Accept if PBP>6 years

Lastly, a sensitivity analysis was conducted to test the robustness of the CBA results. The elasticity formula in Equation 7 was utilized

$$\rho_k = \frac{\%\Delta NPV}{\%\Delta k} = \frac{\frac{NPV_2 - NPV_1}{NPV_1}}{\frac{k_2 - k_1}{k_1}} \tag{7}$$

where $_k$ is the elasticity of CBA tool concerning k independent variable. The elasticity evaluates the sensitivity of NPV to the changes in technology cost, operations, and maintenance costs, and revenues from the products of IWMTS.

3 Results and Discussion

3.1 Social Impact

The project's social impact was analyzed based on the perception of the community households on the effects of IWMTS on health, income/livelihood, and culture as well as the participants' awareness, knowledge, and practices on waste management. Table 2 summarizes the residents' perceptions of the social impacts of IWMTS. A Likert scale average and unscaled general perception statements were used as some social aspects are better represented numerically while some are narrative.

3.1.1 Health

With a Likert scale average of 3.90, respondents expressed that establishing IWMTS will result in significant waste reduction, contributing to reduced health hazards and risks. However, some also noted that the smell coming from the facility, if not eliminated, may negatively affect the health of the residents. Others remain unsure or neutral towards the perceived total effects of IWMTS on residents' health. This implies the need for odor-regulating initiatives during project implementation.

3.1.2 Income and Livelihood

The majority of the respondents have agriculture and self-employment or business as their source of income, with sixteen (16) and fourteen (14) respondents, respectively, accounting for more than half of the respondents. Agriculture varies from farming, rice-milling, coconut and/or banana harvesting and dealing, horticulture, and general farming, while self-employment/business includes freelancing, and selling through sari-sari stores or merchandising, among others.

Most of their responses show no perceived effects of IWMTS on their livelihood. A few of the reasons include the anticipation that the facility is well-maintained and operated, and the location of the facility is far from their place of work. However, respondents raised concerns about the

Table 2. Summary of Likert Scale Averages and Perceptions of Residents per Social Aspect

Social Aspects	**Likert Scale Average** (1-5, 5 being the most positive)
Health	3.90
Income/Livelihood	4.12
Culture	3.88
	General Perception (unscaled)
Awareness/ Knowledge	- The majority of the respondents do not have prior knowledge of IWMTS. - Most of them believe that the facility will benefit their community by proper management of solid waste. - Most of the households practice waste segregation. - The majority of the residents are aware of the ordinances related to solid waste management in their barangay. - Penalties and incentive mechanisms are implemented to improve the enforcement of these ordinances among the residents.
Road Access/ Transportation	- The majority perceive that the IWMTS would have no negative effect on the transportation and local roads of the barangay. - Concerns about traffic and road damage were raised by some of the respondents. - Most of the respondents believe that their everyday lives and accessibility would not be affected by the proposed IWMTS. - Better traffic management and system, time and scheduling of dump trucks, improvement of roads and construction of an alternative route, health considerations, and communication channels are suggested by the respondents to avoid the potential negative effects of the IWMTS on the accessibility of the barangay.

IWMTS's effects on soil and air quality, emphasizing that it can produce toxic chemicals that may harm their harvest or fertilizers that can help them cultivate their farms.

Implementing IWMTS could provide additional livelihood opportunities to the residents through hiring IWMTS staff, and income generation through trade or business-related activities. As specified by the responses, employment through additional manpower involves sorting, facility operations, manual cutting or labor, garbage collection, and site maintenance. On the other hand, income generation is also possible through scrap trading (*pangangalakal*), selling composts and fertilizers, and alternative fuel from waste (briquettes).

3.1.3 Waste Management Culture

The effect of the IWMTS on culture was determined through the existing waste practices, culture, and traditions of the community. The identified practices include waste segregation, garbage collection every Sunday, clean-up drives, and waste exchange "*palit-basura*" activities. Three (3) respondents indicated they are unaware of the current practices. One (1) individual mentioned having a garbage pit for uncollected waste, while another respondent pointed out that the practices are inconsistent, with some being followed while others are not.

The implementation of the IWMTS can be an opportunity to increase community awareness of waste management and sustain existing solid waste management practices of households. Possible initiatives include information campaigns on proper segregation, launching incentives for recycling, and conducting capacity-building initiatives on waste management. The IWMTS can also be a potential site to learn waste management practices which community members can visit. These initiatives may contribute to preserving culture and tradition on notions of cleanliness and maintaining the community environment.

3.1.4 Awareness and Knowledge of IWMTS

The majority of the respondents (67.27%) expressed a lack of prior knowledge about the IWMTS. Nonetheless, the preceding responses collectively agree that the IWMTS aims to reduce the waste generated in their locality through the proper collection of waste for the benefit of the whole community. Regarding household practices, twenty-nine (29) respondents practice waste segregation, burning of leaves and biodegradable materials, digging compost, exchanging recyclable wastes for money, and declogging drainages.

Forty-seven (47) respondents know the ordinances related to waste management. Respondents perceive that policies are enforced effectively through penalties and incentives. Meanwhile, eleven (11) respondents perceive the ordinances as ineffective through enforcement inconsistencies, including leniency in implementation and lack of waste segregation during waste collection. Consequently, some practice various waste management strategies, but they are unsure how these contribute to the effectiveness of waste management ordinances. Overall, there is still a need to increase community awareness of IWMTS and waste management practices. Some of the possible initiatives include IEC (information, education, and communication) programs and public consultations.

3.1.5 Road Access/Transportation

Among the respondents, thirty-one (31) individuals expressed that the establishment of IWMTS has no negative effect on the transportation and local roads in the barangay due to the location of the facility and the number of vehicles that will pass through the barangay. On the contrary, ten (10) respondents perceived a negative impact of the proposed IWMTS on transportation and local roads due to the potential increase in traffic and road damage caused by the dump trucks.

The majority of the respondents (72.72%) perceive that the IWMTS would not impact their everyday lives, particularly their access to residences, markets, schools, and other essential locations. Meanwhile, five (5) respondents have expressed concern about heavy traffic and poor road conditions, especially if the dump trucks pass when residents go to class and work. Furthermore, respondents expressed that the trucks may damage their local roads and cause accidents due to downhill roads. Results show the need to strengthen roads for truck passage and traffic management to avoid congestion.

3.1.6 Overall Social Acceptability and Ethical Considerations

The social acceptability of a project refers to the collective judgment and perception of the people towards the plan, operation, and outcome of IWMTS. This instrument is pivotal for investigating stakeholder perceptions regarding the social acceptance, benefits, barriers, and opportunities associated with project implementation. It involves affected parties' social, cultural, psychological, and physical acceptance [33, 34]. Based on the results, the residents of Bay generally trust and expect that the IWMTS will benefit the aforementioned social aspects. Notably, its operation is strongly perceived and expected to benefit the residents' income and/or livelihood. This is followed by the perceived positive impacts of the project on health where solid wastes are aimed to be more properly managed, subsequently improving the health status of the residents, and on culture, specifically on the maintenance of the current solid waste management practices of the households. These findings support previous studies that the success of the implementation of solid waste management systems is founded on strong social acceptance and public trust with an emphasis on local development, by improving public infrastructures, creating new jobs, and improving their quality of life [35, 36, 37, 38].

3.2 Economic Analysis

The overall capital outlay for the project is an estimated PHP 48.14 million (USD 859,643). It comprises the IWMTS, the facility renovation, the establishment of a solar power system within the facility, training for operators, and information, education, and communication (IEC). Miscellaneous expenses include a contingency fund to cope with any unforeseen scenarios the project may encounter at any time. The breakdown of the capital outlay is detailed in Supplementary Material Table S1. It should be noted that these expenses apply only to those that will be carried upon by the municipality, and do not include those to be incurred by various barangays in the municipality for their respective solid waste management (SWM) programs/projects. Likewise, this summary does not include the cost of existing vehicles and other past municipality SWM-related expenditures.

Operational costs will be taken from the annual municipal funding and it must be efficient to maintain the costs at a minimum without sacrificing environmental and design requirements and standards. For this project, the annual operating expense is estimated at PHP 3.7 million (USD 66,071), consisting of utilities, salaries and wages, materials for packaging, and equipment repair and maintenance. The breakdown of the annual operational costs is detailed in Supplementary

Material Table S2.

The IWMTS will also be managed as the municipality's economic enterprise. Once processed through the solid waste management systems, the collected waste from households will be transformed into products that can be used for construction and agricultural purposes, enabling a circular economy and guaranteeing a zero-waste society. It has an estimated value of PHP 11.99 million (USD 214,107). The summary of the different revenues from the project is shown in Supplementary Material Table S3. The quantity of the products was based on the projected waste generated in 2023 from municipal SWMP (2015-2024) and the number of products the machines can produce per day [25]. The unit price for each product was based on the price of recyclable materials on the sales of the MRF conducted by the EMB Central Office [39]. The calculated annual revenue is based on the product of the unit price and the quantity produced per day. However, it should be noted that the product for the liquid fertilizer was calculated using the number of weeks instead of the number of working days. For this project, the assumed number of days is 260 instead of 365 to account for the number of working days in a single year, and an assumed number of 52 weeks.

3.2.1 Cost-Benefit Analysis

The CBA was carried out to evaluate the feasibility of setting up an IWMTS in Bay, Laguna. The analysis utilized the following indicators: (a) Net Present Value (NPV); (b) Benefit Cost Ratio (BCR); (c) Internal Rate of Return (IRR); (d) Profitability Index (PI); (e) Payback Period (PBP) and; (f) Return on Investment (ROI). Table 3 summarizes the results from the financial analysis.

Table 3. Cost-Benefit Analysis of IWMTS

Indicators	Value	Decision
NPV	3,164,281 million PHP	accept
IRR	12%	accept
ROI	1.73	accept
PBP	5.77 years	accept
BCR	1.04	accept

The CBA used a project valuation of 10 years with a social discount rate of 10% based on the rate set by the National Economic and Development Authority [32] for government projects. It was assumed that IWMTS is implemented and completed at year = 0 and the revenues and operational costs commence at year = 1.

The NPV result shows that the project will generate an additional PHP 3,164,281 (USD 56,505). Based on the IRR, the project will generate 12% of what the LGU had before the implementation of the project. This value is greater than the set hurdle rate at 10% and is thus accepted. Based on the ROI, the project will gain 173% of the initial investment cost after ten years, and it will take a PBP of 5.77 years to generate the initial investment cost. Based on the BCR, it was also calculated that for every PHP 1 million (USD 17,857) invested in the project, it would generate PHP 1.04 million (USD 18,571) in return. From these results, it shows that the project is economically feasible.

3.2.2 Sensitivity Analysis

Table 4 summarizes the elasticity of the economic indicators on the independent variables, including the investment cost for the IWMTS, the annual operations and maintenance (OM) costs, and the benefits from produced products. Investment costs, annual OM costs, and benefits were increased by 10%.

Table 4. Sensitivity Analysis of NPV of IWMTS

Indicator	**Elasticity**				
	Investment Cost		Annual OM Costs		Benefits
	Technology	Facility	Water	Labor	Quantity of Products
NPV	-1.36	-0.23	-0.28	-0.51	2.33

Technology and Facility are the variables used to assess the elasticity of investment cost because they have the highest value and are most likely to change. The elasticity computation of technology shows that for every 1% increase in technology investment, there is a 1.36% decrease in NPV. For the facility, a 1% increase in facility investment causes the NPV to decrease by 0.23%. For the investment cost, technology has the higher elasticity; therefore changes in technology cost significantly change the NPV of the project.

Water and Labor are the variables used for the elasticity of annual OM costs because their value is the most likely to change over time as water prices fluctuate, and minimum wages increase. The result from the elasticity computation shows that every 1% increase in water cost reduces the NPV by 0.28%. For every 1% increase in labor cost, there is a 0.51% decrease in NPV. The water changes are less significant to the NPV of the project than the changes in labor cost.

For the elasticity to revenues or benefits, the quantity of products is the variable assessed because it is the most likely to change depending on the amount and type of waste collected and processed. The result from the elasticity computation shows that for every 1% increase in the number of products, the NPV increases by 2.33%. The change in NPV is higher than the percentage change in the independent variable, this means that any changes in the quantity of products can significantly impact the NPV of the project.

3.2.3 Overall Economic Impact

Cost-benefit analysis (CBA), as an economic impact tool, is a systematic and analytical process of comparing the benefits and costs in evaluating the worthwhileness of a project. It provides an informed decision on the viability of a project by ensuring that the expected benefits outweigh the costs, as well as an overview of how long it takes to recover the cost of an investment (Agaton & Guno, 2024).

In this feasibility study, CBA results revealed that the benefits of IWMTS outweighed costs, as indicated by a positive NPV, a BCR>1, an IRR>hurdle rate for environmental projects, ROI>100, and a short PBP. Moreover, the sensitivity analysis demonstrated that these results are robust in terms of the changes in technology cost, operational and maintenance costs, and the potential benefits (sales from the products) of IWMTS. These support previous studies on the economic viability of integrated waste facilities that even considered highly capital intensive, revenues from the sales would be enough to guarantee the viability of the project at 100% equity with IRR of 33.7% and ROI of 24.5% per year [40]. Meanwhile, a centralized integrated facility can provide several advantages in the case of Bay, Laguna where space for decentralized MRFs in Barangays is scarce. There is extra profit in a large-scale facility such as having a centralized system for huge quantities of waste management and possible carbon credits that are modest in the case of small-scale facilities [41]. Furthermore, large-scale facilities produce more outputs and in turn, higher revenues, which reduces the average cost of production [9].

3.3 Perceived Environmental Impact

The environmental impacts of the IWMTS project were analyzed based on the community households' perception of air quality, noise pollution, wildlife, soil quality, and health and safety. The summary of the responses to the survey is presented in Table 5. A combination of Likert scale average and unscaled general perception statements were used as some environmental aspects are better represented numerically while some are narrative.

Table 5. Summary of Likert Scale Averages and Perceptions of Residents on Environmental Impacts

Environmental Aspects	**Likert Scale Average** (1-5, 5 being the most positive)
Air Quality	3.52
Noise (1-5, 5 being the most quiet/ no effect)	3.74
Water Quality	3.58
Wildlife	3.56
	General Perception (unscaled)
Health and Safety	- The majority believe that the IWMTS would not have any significant impact on their health and safety as long as there is proper management. - Most of the respondents also believe that there won't be any accidents occurring during the construction of the facility. - Effective and proper management during construction would help decrease the possibility of accidents. - Overall, the IWMTS holds positive benefits for their health and safety due to the regular collection and processing of garbage in the area.

3.3.1 Odor and Air Quality

As stated by the Municipality's CLUP (Municipality of Bay, 2019), the leading cause of morbidity in the Municipality of Bay, Laguna since 2015 is an acute respiratory infection. A significant increase in the number of acute respiratory infection was observed from 2015 to 2017. In response, a comprehensive set of zoning ordinances is enforced in Bay, Laguna including the Environmental Conservation and Protection Standards. Section 37 emphasizes that non-conforming entities (buildings and structures) should not create nuisance effects in their surroundings, encompassing various forms of pollution, undesirable traffic, and other related concerns.

The Likert scale average response stands at 3.53. This denotes a moderately positive acceptance among the household representatives. The respondents expressed that the facility will reduce the foul odor produced by the community's waste as there will now be improvements in systematic waste gathering and disposal. However, some respondents expressed concerns about the potential impacts of burning waste on the environment, specifically on air quality and climate change. Meanwhile, the project is expected to have no adverse impact on the municipality's air quality, as it excludes processes such as incineration or burning waste materials. The abovementioned initiative is anticipated to mitigate the risk of diseases associated with unpleasant garbage odors for residents near the municipality's dumpsite, including Barangay Sta. Cruz.

3.3.2 Noise Pollution

Residents perceived that the operation of IWMTS will have minimal to no production of noise due to the distance of the facility to the residential area as well as to the habituated noise currently present due to frequent trucks passing by, making them accustomed to the noise that the facility may produce. Additionally, based on the responses, the quietest or calmest times of the day are from night to dawn when people are mostly asleep, followed by morning when students are currently in school, and midday and afternoon. This data may imply that the operation of IWMTS, if it may produce noise, must be done during midday and afternoon when the residents are relatively active and may not be negatively affected by noise. These respondents also suggest that the authorities should communicate with the public regarding the garbage collection schedule so that they know the arrival of trucks in the area.

3.3.3 Water Resources and Quality

The Barangay Sta Cruz source of water supply is divided into two parts: supply from LARC (Laguna Water District Aquatech Resources Corporation) and a water tank that supplies the residents of the community. The water pumps ("*poso*") and water wells are used for agricultural irrigation. Findings suggest that the development of IWMTS may not negatively influence the water quality supplied for households in Barangay Sta Cruz since the IWMTS will not contaminate LARC and the existing water tank in their community.

In terms of the potential effects of IWMTS on the municipality's agriculture, respondents expressed that the facility might affect the quality and health of certain trees and crops due to the chemicals that may leak from the facility. Three (3) respondents expressed that the establishment of the facility may cause death and disease among fisheries if the facility were to be placed near any natural bodies of water, specifically citing the nearby rivers surrounding the area.

Overall, the IWMTS facility is perceived to have no impact on the water supply from LARC but may affect the water quality in agriculture due to possible chemical leakage from the facility through the soil and if it is placed near bodies of water. This suggests additional initiatives to ensure that chemicals used will not contaminate nearby waters and that the facility is at an adequate distance from bodies of water.

3.3.4 Ecosystem, Biodiversity, and Wildlife

Most residents stated that the project has no impact on wildlife. Seven (7) respondents are unsure if there will be any impacts on wildlife until the facility starts its operation. Five (5) respondents presumed that the facility would negatively affect wildlife, such as plants and other animals grazing on the site, such as horses and cows, when chemical leakage occurs. Moreover, three (3) respondents saw the potential of the facility in improving the growth of various crops (agriculture) through the organic fertilizer it will generate. Meanwhile, it is anticipated that the proposed project will not have significant potential impacts on biodiversity and wildlife unless waste management issues arise. The respondents' perception of this environmental aspect implies that the operation of the facility should be strictly monitored in compliance with ordinances on ecosystems, biodiversity, and wildlife. There is also increasing positive anticipation of the end-products that the facility will produce, noting that organic fertilizers from it will potentially help improve agriculture.

3.3.5 Health and Safety

Most respondents believed that the facility would have no significant impact on the general population as long as it is well-managed and follows an efficient system. However, eight (8) respondents hold a negative perception due to the possibility of accidents for the workers if safety protocols are not well-implemented construction is not well-managed, and traffic accidents if the materials used for construction occupy a substantial portion of the roads. It is noted that the area is accident-prone, so extra precautions are necessary to avoid accidents. To address these, respondents emphasized effective and proper management during construction, which involves the implementation of a system for safety protocols with guidelines for attire and security measures. In addition to this, it is important to ensure the structural integrity of the facility being built, provide proper training for the personnel, include caution or warning signs on the site, and designate personnel to enforce traffic and machinery maintenance. Meanwhile, respondents emphasized the importance of community participation or involvement. They recommend the proper introduction of the project and the construction to the general community, which would help raise awareness of the potential hazards in the area.

3.3.6 Additional Environmental Implication: Soil and Nutrients

For the implementation of this project, soil quality and nutrients must be considered. Solid waste contains high levels of contaminants that may be composed of toxic metals, hazardous wastes, and chemicals. The improper disposal of solid waste may affect the soil stability, strength, and fertility. Furthermore, chemicals such as cadmium, lead, and mercury can be absorbed by plants and may be ingested by both animals and humans [42].

3.3.7 Overall Perceived Environmental Impact

Environmental Impact Assessment is a comprehensive evaluation of the potential effects of a project on the environment, which provides decision-makers with information about the likely environmental consequences of their policies and includes recommendations for mitigating and managing the negative environmental impacts [43]. In this study, the ecological impact of the IWMTS was analyzed based on the perspectives of municipal officials and immediate household members residing within the proposed project site. The analysis showed a positive overall environmental impact of the IWMTS (compared to the existing sanitary landfill) in terms of reduced foul odor; better air, water, and soil quality; minimal noise from the facility and hauling; no impact on ecosystem, biodiversity, and wildlife; and negligible impacts of human health and safety. These results support previous findings on the environmental implications of integrated waste facilities on improved human health, ecosystem quality, and resource scarcity usage, while significantly reducing soil and water contaminants, pollutants, and GHG emissions [44, 45]

4 Conclusion and Recommendations

This study addresses Bay, Laguna's issues in waste segregation, underutilized materials recovery facilities, and lack of household recyclable waste collection that costs millions of losses in potential revenue while exacerbating the waste management problems. The study analyzed a proposed IWMTS project that utilizes an innovative and systematic circular economy approach to waste management through source reduction, recycling and composting, waste transportation, and landfilling. The socio-economic and environmental analysis highlighted the immense potential of the project to generate public revenue and various benefits including (a) generating revenue from the sale of reprocessed and recycled materials, (b) exploring the possibility of carbon credit generation, and (c) leveraging economies of scale in large-scale facilities to enhance operational efficiency and lower production costs. Yet, problems and challenges were identified, which serve as a basis for recommendations to make IWMTS feasible and a more sustainable solution to waste management and circular economy.

The **social analysis**of the IWMTS presents possible impacts on Bay, Laguna residents. Foul odor, noise, road damage, IEC (information, education, and communication), and public awareness were identified as important considerations from conducted interviews. The analysis provides the following recommendations.

- The IWMTS operation must have minimal to no foul odors released that can affect the residents. The introduction of advanced odor control technologies, such as biofilters and proper composting, can ensure minimal release of foul odors.
- The noise produced by the IWMTS must be lessened and at a specific time of the day only. Sound-proofing measures and sound-reducing technologies can be implemented to minimize the disturbance caused by IWMTS operations.
- Road maintenance and quality must be improved to withstand heavy transportation loads from dump trucks. Rehabilitation of road infrastructures to withstand high-bearing vehicles and the potential increase in traffic.
- IEC (information, education, and communication) programs must be done regularly to ensure the consistency of the households' waste management practices. Public consultation can be explored, including the implementation of a monitoring and evaluation system that aims to regularly assess the effectiveness of the IWMTS.

The **economic analysis** of IWMTS in Bay, Laguna has shown mostly positive results. If all prices stay as they are and do not fluctuate, the same positive results are shown, although if some changes in prices do occur, the different scenarios present in the analysis will cover those uncertainties. The analysis provides the following recommendations.

- Financial assistance from external sources and partners could be explored to augment the local government budget in funding initial investment costs.
- The municipality should allocate a contingency fund to prepare for potential shocks and fluctuations in prices.
- Given that garbage collected from the municipality may be reduced, it is suggested to explore the potential of offering the IWMTS to nearby municipalities to continually generate revenue.
- Pricing and costs of equipment must be regularly updated to ensure comprehensive financial analysis.
- Identify targeted consumers and buyers of the IWMTS products such as eco-bricks, briquettes, and solid and liquid fertilizers and monitor the volume and bulk of the demand.
- Waste characterization and estimated volume of waste must be regularly monitored and updated.

The **environmental analysis** of the IWMTS revealed possible impacts that could greatly affect the environment of Bay, Laguna. To minimize or prevent adverse impacts, feasible interventions in water sources, air quality, soil and nutrients, biodiversity, and protected areas while maintaining and improving the environmental standards of the municipality must be implemented. The analysis provides the following recommendations.

- Strategies that could contain and prevent hazardous waste and/or leachate from the IWMTS must be developed. Programs addressing waterborne diseases brought by landfills could be implemented.
- Soil and nutrient quality should be monitored. The usage of chemicals must be regulated and/or organic alternatives can be explored to mitigate any adverse effects.
- Regular monitoring of the air quality index and gas emissions is recommended to ensure that the

air quality in the municipality is satisfactory to air quality standards. Municipal ordinances on vehicular emissions could be strengthened and prioritized being the leading cause of air pollution in the Bay.
- Waste worker safeguards and policies must be in place to ensure IWMTS employees' safety in handling solid waste.
- The Municipality of Bay could continue implementing existing environmental protection regulations and ordinances. Updates to the Bay's environmental code are also required in conformity with international accords and treaties. Strict implementation of waste management ordinances is paramount, especially segregation and waste reduction.
- The local government may also explore the expansion of staff in the Municipal Environment and Natural Resources Office (MENRO) to sustain and widen efforts towards waste management.

In conducting the case study, the following recommendations, aligned with the present study's limitations, are formulated:
- Future researchers may categorize their respondents based on socio-demographic data such as gender, age, and income. This opens discussions and further studies focusing on differences in social perceptions towards a certain project/plan based on each of the socio-demographic data.
- The scope of the study could be expanded to include other barangays or areas. It allows possible comparison of differences in points of view of people regarding waste management practices and facilities.
- Future research aiming to gather data from a large sample should increase the number of interviewers and encoders to maintain the quality of inputs over time.

Supplementary Materials

Data for Economic Analysis

Statements and Declarations

Funding Information

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Conflicts of Interest

The authors declare no conflicts of interest related to this work.

Ethical Considerations

The research protocol was approved by the DCERP Urban Lab and the Municipality of Bay. Laguna. The study adhered to the principles of the Belmont Report and the Declaration of Helsinki for research involving human participants. Informed consent was sought from the participants, which included explaining to them the purpose of the study; their voluntary participation, that they could withdraw at any time in the study; and how the collected data would be used.

Data Availability

The data used in the economic analysis are summarized in the Supplementary Materials. The raw data for the survey questionnaire are not publicly available due to ethical restrictions. However, the datasets are available from the corresponding author upon reasonable request.

Authors Contribution

E.R.A.L., C.A.S.P., E.T.A.G, A.J.M.S., B.A.Y.D., K.A.M.P., & D.D.L: conceptualization, coordination, formal analysis, investigation, writing—original draft preparation, visualization. **J.A.C.C.:** documentation, investigation, visualization. **B.A.B.Q., M.V.F.D., F.G.C.R., J.R.L.Jr., K.M.V.S., K.J.M.D., D.D.M.O., J.O.E.P., M.B.O.R., & M.A.E.A.:** conceptualization, formal analysis, investigation, writing-original draft preparation. **J.A.S.C. & C.B.A.:** conceptualization, methodology, writing-review and editing, supervision, and validation, All authors have read and agreed to the published version of the manuscript.

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