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EVALUATING SOLID WASTE MANAGEMENT ALTERNATIVES IN SELECTED MUNICIPALITIES OF SURIGAO DEL NORTE USING MULTI-CRITERIA DECISION ANALYSIS (MCDA)

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This Special Project of **GELLI JAMAICA FELICES** titled: "**EVALUATING SOLID WASTE MANAGEMENT ALTERNATIVES IN SELECTED MUNICIPALITIES OF SURIGAO DEL NORTE USING MULTI-CRITERIA DECISION ANALYSIS (MCDA)**" is hereby accepted by the Faculty of Management and Development Studies, U.P. Open University, in partial fulfillment of the requirements for the degree **Master of Environment and Natural Resources Management.**

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DECLARATION

This is to certify that:

I. The special problem comprises only my original work towards MENRM except where indicated in the Preface
II. Due acknowledgement has been made in the text to all other material used
III. The special problem is fewer than 25,000 words in length, exclusive of tables, maps, bibliographies and appendices.

<u>**GELLI JAMAICA FELICES**</u>
Name

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Abstract

Significant environmental and operational challenges in municipal solid waste management (MSW) are persistent in island municipalities, particularly in ecologically sensitive areas like Del Carmen and General Luna, Surigao Del Norte, Philippines. To evaluate and rank solid waste management alternatives in these areas, this study uses multi-criteria decision analysis (MCDA) which combines the Analytical Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. Environmental, economic, social, and technical factors in SWM were considered in the identified evaluation criteria. The waste treatment and disposal scenarios determined include S1: 100% Sanitary Landfill, S2: MBT & Recycling, S3: Pyrolysis & Anaerobic Digestion, S4: MRF & Composting, and S5: SLF + Energy Recovery. The perspectives of eleven (11) experts were used for pairwise comparison of evaluation criteria and evaluating scenarios through online surveys.

Criteria such as reducing waste leakage (0.23), mitigating pollution and health risks (0.15), and recovering resources (0.13) were the top priorities based on experts' preference. Out of the five scenarios assessed, all types of waste go to sanitary landfill was the most feasible disposal option (0.92). This option is aligned with local government capacities, operational costs, and technical feasibility. Conversely, advanced technologies such as MBT, pyrolysis, and anaerobic digestion offered environmental benefits but limited by cost, technical complexity, and logistical issues specific to the islands. MRFs and composting appeared to be important based on results but not enough as standalone solutions.

Integrating waste reduction, recycling, circular economy measures, and Extended Producer Responsibility (EPR) frameworks with sanitary landfill operations are recommended to address issues in SWM. Additionally, the study suggests establishing clustered SLF supported by strong monitoring and evaluation systems, capacity-building, and infrastructure investments. Protected area management and enforcement should also include solid waste management to maintain ecological integrity. These findings offer practical guidance for policymakers and local governments. They aim to help design sustainable, resilient, and context-specific waste management systems that protect human health and fragile coastal and marine ecosystems.

Keywords: municipal solid waste; solid waste management strategies; multicriteria decision analysis; analytic hierarchy process; technique for order preference by similarity to ideal solution; island municipalities

I. INTRODUCTION

Municipal solid waste (MSW) generation is rapidly increasing around the world. In 2018, the World Bank estimated that the world generates about 2.01 billion tons of MSW every year. At least 33% of this waste is unmanaged in an environmentally safe way. On average, each person produces 0.74 kg of waste daily, but this amount varies greatly—from 0.11 to 4.54 kg—based on income levels. As incomes rise, so does waste generation, particularly in lower-income countries where growth is fastest compared to population size. By 2050, global waste is expected to reach 3.40 billion tons, increasing at more than double the rate of the global population. Twenty-three percent of the expected total global waste were generated from East Asia and Pacific region. Most significant increases were likely be observed in low income countries expecting thrice increase in total waste generation by mid-century.

In the Philippines, around 62,800 metric tons of waste are generated daily, with average per person production of 0.53 kg (NSWMC, 2025). Largest fraction of the country's solid waste or 52% are biodegradable waste while around 11% are recyclables plastics (DENR-EMB, 2018). National plastic consumption was estimated at 2.15 million metric tons each year, translating to about 20 kg of plastic waste per person prior to COVID-19 pandemic. Despite ongoing waste management efforts, only 9% of plastics are recycled. Furthermore, 33% of waste goes to landfills, and around 35% ends up in the environment (WWF Philippines, Inc., cyclos GmbH, & AMH Philippines, Inc., 2020). These numbers highlight occuring problems, such as increasing waste volumes, inadequate sanitary landfill capacity, and poor enforcement of environmental laws. Therefore, the need for more effective and sustainable waste management strategies is becoming more urgent (Coracero et al., 2021).

To address these issues, the Ecological Solid Waste Management Act of 2000, known as Republic Act No. 9003 was legislated which sets up a solid framework for ecological waste management. RA 9003 assigns local government units (LGUs) as the main implementers of solid waste management programs. These programs include creating Materials Recovery Facilities (MRFs) and establishing sanitary landfills as the only approved final disposal method. However, only 11,625 MRFs currently serve the country's 42,029 barangays, and just 237 sanitary landfills operate across 1,634 cities and municipalities (PIDS, 2024). These gaps were also observed on Siargao Island, where Del Carmen generates about 373 metric tons of plastic waste each year and around 29% goes uncollected. General Luna produces about 1,036 metric tons, with 22% unmanaged (AMH Philippines, Inc., 2024). Uncollected waste significantly harms the environment, especially along coastlines, and poses serious threats to marine ecosystems and the resilience of local communities (Kibria et al., 2023).

To comply with RA 9003, the municipalities implemented door-to-door collection, barangay-level and centralized MRFs, residual containment areas (RCAs), composting programs, and the introduction of waste-to-energy (WtE) technologies (AMH Philippines, Inc., 2024; Anonas et al., 2023). In addition to adequate infrastructure, successful implementation of these strategies necessitates strong stakeholder engagement, active community participation, and well-coordinated governance systems (Kemp et al., 2006).

Due to the existing environment laws, growing public awareness of negative impacts of improper waste management, and rapid technological advancements, the need for advanced decision-support tools has become more evident (Gutierrez-Lopez et al., 2023). By taking into account several, frequently conflicting environmental, social, and economic factors, Multi-Criteria Decision Analysis (MCDA) provides an organized method for assessing waste management options (Garcia-Garcia, 2022; Achillas et al., 2013). MCDA assists decision makers in finding feasible and sustainable solutions by methodically rating and weighing options (Sohail et al., 2023).

This study uses MCDA to assess and rank alternative solid waste management alternatives for the municipalities of Del Carmen and General Luna in Surigao del Norte. The research attempts to offer useful and evidence-based recommendations for creating integrated, ecologically-sound, and community responsive waste management systems by combining empirical data with the opinions of experts and sustainable indicators.

II. REVIEW OF RELATED LITERATURE

Municipal Solid Waste

Any material or substance that is discarded because it is no longer needed, desired, or deemed useful is referred to as waste. Household, industrial, commercial, and agricultural processes are among the many activities that produce it (Gupta, Sharma, & Bhardwaj, 2023). Municipal waste is defined as waste produced within local government units in the Philippines by the National Solid Waste Management Commission (NSWMC). This comprises litter, street sweepings, and a variety of waste from homes, businesses, institutions, and industries.

Municipal solid waste (MSW) is divided into four main categories in the Waste Analysis and Characterization Guide, which was developed by the NSWMC in partnership with the Japan International Cooperation Agency (JICA):

A. Biodegradable waste – waste that can be converted into humus-like material by microorganisms. This category, which includes kitchen or food scraps, garden waste, agricultural byproducts, and livestock waste, usually makes up around half of all municipal waste.
B. Recyclable waste – materials that can be recovered, processed, and used again in manufacturing or other applications. Typical examples include paper, plastics, metals, and glass
C. Special waste – waste that needs to be handled carefully, treated specifically, and disposed of properly. This comprises:

1. Hazardous waste, which includes consumer goods that endanger human health or the environment, chemical residues, and industrial byproducts
2. Medical waste produced by clinics, hospitals, labs, and other healthcare facilities; and
3. Bulky waste is defined as large, discarded items that, because of their size or shape, do not fit into regular waste containers.

D. Residual waste – materials left over after implementing the Reduce, Reuse, and Recycle (3Rs). This group consists of:

1. Residuals that are currently worthless in local junk shops but have the potential to be recycled; and
2. Leftover waste meant to be disposed of in sanitary landfills

Figure 2.1. Solid Waste Classification

Source: NSWMC (2020)

According to NSWMC (2025), the Philippines generates about 62,800 metric tons of waste daily, with an average per capita generation rate of 0.53 kg. Biodegradable waste at around 52% makes up the largest fraction of MSW in the country while roughly 11% account for recyclable plastics (DENR-EMB, 2018). The national plastic consumption was approximately 2.15 million metric tons yearly or equivalent to around 20 kg of plastic per person prior to COVID-19 pandemic. Although there are implemented efforts to improve SWM, only 9% of plastics are recycled, 33% are disposed of in landfills, and around 35% leak into the environment (WWF Philippines, Inc., cyclos GmbH, & AMH Philippines, Inc., 2020). These figures stress the country's escalating challenges in waste such as continuous and rapid increase in generation of waste, insufficient capacity of sanitary landfills, and persistent gaps in enforcement of regulations. These challenges require effective approaches in waste management (Coracero et al., 2021). Additionally, about 8.9% of the 4 million metric tons of mismanaged plastic waste in the country ended up in ocean through 4,820 rivers, exacerbating these problems (Meijer et al., 2021).

Based on estimates, CALBARZON, Central Luzon (Region III), and the National Capital Region (NCR) are among the largest contributors of MSW in the Philippines. The total MSW generation is expected to reach approximately 22.9 million metric tons in 2025 (NSWMC, 2025).

Table 2.1

Solid Waste Generated in the Philippines (tons per day)

Region	**2020**	**2021**	**2022**	**2023**	**2024**
1	2,497.22	2,525.77	2,554.79	2,584.30	2,614.31
2	1,686.97	1,711.69	1,736.84	1,762.43	1,788.47
3	6,633.34	6,782.51	6,936.25	7,094.81	7,258.44
CALABARZON	8,979.41	9,218.51	9,467.01	9,725.27	9,993.80

MIMAROPA	1,518.61	1,549.51	1,581.28	1,613.95	1,647.55
5	2,778.25	2,807.88	2,837.96	2,868.50	2,899.51
6	2,044.86	2,069.29	2,094.16	2,119.47	2,145.23
7	3,444.01	3,517.23	3,592.68	3,670.45	3,750.62
8	1,981.70	1,993.20	2,004.83	2,016.61	2,028.52
9	1,933.20	1,965.56	1,998.68	2,032.61	2,067.35
10	2,606.28	2,645.55	2,685.58	2,726.39	2,767.99
11	3,074.64	3,123.54	3,173.42	3,224.31	3,276.23
12	2,447.04	2,490.70	2,535.52	2,581.53	2,628.77
13	1,394.64	1,418.35	1,442.57	1,467.32	1,492.61
BARMM	1,957.10	2.016.81	2,078.92	2,143.56	2,210.86
CAR	835.61	844.38	853.29	862.34	871.54
NCR	9,057.91	9,134.17	9,211.46	9,289.81	9,369.24
NIR	2,760.09	2,791.65	2,823.69	2,856.20	2,889.20
Total	**57,630.88**	**56,589.49**	**59,608.93**	**60,639.86**	**61,700.24**

(NSWMC, 2025)

Effective solid waste management where materials are constantly reused, recovered, and repurposed necessitates a clean, safe, and sustainable environment (Akram et al., 2021). The systematic oversight of waste from its generation to final disposal is referred as solid waste management (SWM). It involves several key stages such as on-site handling, processing, collection, transportation, monitoring, recycling, and final disposal (Tchobanoglous & Kreith, 2002).

Waste collection in many low-income countries is mainly carried out by municipal or city workers. However, the informal sector also plays an integral part since they collect recyclable waste and other high value materials which they sell to local junkshops or cooperatives before the formal collection takes place. Informal waste collectors often use handcarts, pushcarts, and bicycle cabs to move waste from communal bins and open dumpsites to specific collection points. This system makes it clear that most local governments lack financial and technological capabilities when it comes to investing in waste management technology and facilities (Hondo et al., 2020). Consequently, SWM issues are among the major challenges that hinder effective governance especially in highly urbanized areas where population growth and waste generation rapidly rise (Abubakar et al., 2022).

To have a better understanding of the current state of SWM in the country, it is best to review the legal frameworks and policies that shape SWM. The following section outlines the country's response to the increasing SWM challenges.

SWM-related Policies

The country's first policy on SWM was the Commonwealth Act No. 383, known as Anti-Dumping Law, which prohibits the dumping of any form of waste into rivers in 1938. Then in 1975, Presidential Decree No. 825 was passed, imposing penalties for improper garbage disposal and other related environmental violations. Subsequently, a DENR Administrative Order No. 1998-49 was issued which mandated municipalities responsible for waste disposal through Memorandum Circular No. 1988-39A, and the Presidential Task Force on Waste Management was created. Succeeding guidelines on identifying suitable landfill sites were aligned with these earlier policies (PIDS, 2021).

The significant role of LGUs was further highlighted thru Local Government Code of 1990 (Republic Act No. 7160) wherein LGUs are in charge for providing essential services related to public hygiene, sanitation, beautification, and the management of solid waste collection and disposal systems. Then in 1999, the Clean Air Act or Republic Act No. 8749 was enacted to establish a framework for air quality management. Based on Section 20 of this law, incineration of municipal, biomedical, and hazardous wastes is prohibited, but limited, small-scale traditional burning practices under controlled conditions are allowed.

The table below outlines the legal actions of the government to address the issues in SWM and ensure protection of the environment and public health.

Table 2.2

Summary of SWM-related Legislation, Policies, and Regulations

Year Enacted	Legislations/Policies/Regulations	Description
1938	Anti-Dumping Law (Commonwealth Act No. 383)	Prohibits the dumping of refuse into rivers and the creation of alluvial formations without proper authority, with violators subject to imprisonment, fines, or both
1975	Garbage Disposal Penalty Law (Presidential Decree No. 825)	Mandates cleanliness and proper waste disposal nationwide, imposes penalties on violators, and authorizes the government to convert idle lots into food-production areas, under the supervision of the Secretary of Public Works, Transportation, and Communications
1975	Code of Sanitation (Presidential Decree No. 856)	Requires cities and municipalities to establish and maintain an adequate and efficient system for sewage collection, transport, and disposal within their jurisdictions
1976	Marine Pollution Decree (Presidential Decree No. 979)	Aims to prevent and control pollution in Philippine waters by prohibiting the discharge of harmful substances and imposing penalties for violations, with enforcement carried out by the Philippine Coast Guard and the National Pollution Control Commission
1976	Pollution Control Law (Presidential Decree No. 984)	Establishes the National Pollution Control Commission to prevent and control pollution in the

		Philippines, granting it the authority to issue permits, impose penalties, and coordinate with other government agencies, with violators subject to fines, operational closure, and imprisonment
1977	Philippine Environmental Policy (Presidential Decree No. 1151)	Aims to promote a harmonious relationship between people and nature, enhance environmental quality, and ensure the preservation and improvement of the Philippine environment by requiring government and private entities to prepare and submit detailed environmental impact statements
1977	Philippine Environment Code (Presidential Decree No. 1152)	Protect and preserve the environment by regulating air and water quality, land use, natural resource conservation, and waste management, while also promoting public awareness and encouraging community participation in environmental protection
1990	Strict Enforcement of Garbage Disposal Laws (Executive Order No. 432)	Address the garbage problem in Metro Manila and enforce proper waste disposal, with implementation and compliance overseen by law enforcement agencies and the Metropolitan Manila Authority
1990	Toxic Substances and Hazardous Wastes Act (Republic Act No. 6969)	Regulates the import, manufacture, sale, and disposal of chemical substances and mixtures that pose health or environmental risks, and prohibits the entry and disposal of hazardous and nuclear wastes in the country, with violations

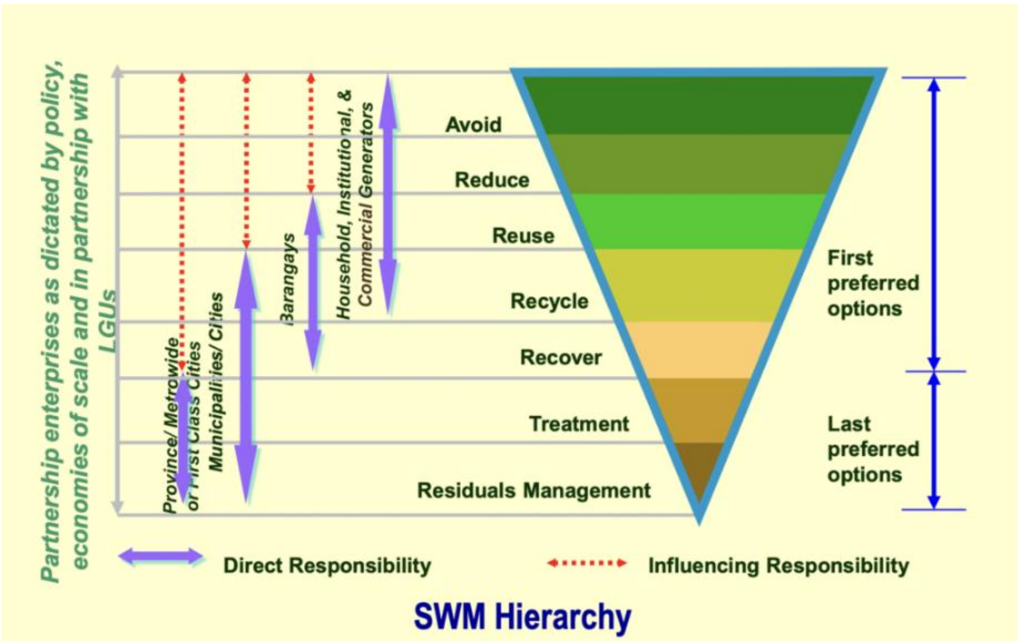
		punishable by imprisonment, fines, and other penalties
1991	Local Government Code (Republic Act No. 7160)	Mandates LGUs to exercise the powers and fulfill the functions necessary or appropriate for the efficient and effective provision of services and facilities related to general hygiene and sanitation, beautification, and the collection and disposal of solid waste
1998	Technical Guidelines for Municipal Solid Waste Disposal (DENR Administrative Order No. 1998-49)	Establishes technical guidelines to help LGUs transition from environmentally harmful open dumps to sustainable solid waste management practices
1998	Landfill Site Screening Criteria for Waste Disposal (DENR Administrative Order No. 1998-50)	Provides guidelines for identifying and screening sites for sanitary landfills, ensuring the safe and sanitary disposal of municipal solid waste while taking into account environmental impacts and local conditions.
1999	The Clean Air Act (Republic Act No. 8749)	Provides a comprehensive air pollution control policy and related provisions. Section 20 prohibits the use of incineration for municipal, biomedical, and hazardous waste, while still permitting traditional small-scale community burning methods
2000	Ecological Solid Waste Management Act (Republic Act No. 9003)	Declares the state policy to implement a systematic, comprehensive, and ecological solid waste management program.

(NSWMC, 2010)

In 2000, a fundamental change occurred through the passage of the Ecological Solid Waste Management Act (ESWMA) or Republic Act No. 9003. This law provides a comprehensive and cohesive policy regarding solid waste management. RA 9003 conceptualizes a holistic approach on addressing the long-standing waste management issues in the country, including specific programs, schemes, and penalties to promote responsible waste management. In fact, it is among the most celebrated laws in the Philippine environment governance regime today (Maskey et al., 2016).

Unlike previous control and command-driven policies, RA 9003 is based on sustainable and resource-based management and considers residual waste as an asset. The law instills reduce, reuse, recycle, and recover or 4Rs as the main strategies in waste mitigation to prevent air, land, and water pollution. It also firmly supports that households have major role in reducing waste and conserving resources because SWM is functional right at the household level.

Figure 2.2. Solid Waste Management Hierarchy



Source: NSWMC, 2004

The law also outlines specific objectives to address issues not only within health and environmental aspects, but also public involvement in SWM, recovery and conservation of resources, and private sector cooperation. Additionally, RA 9003 encourages promotes research and development and environmental education top strengthen SWM in the country. The law mandates LGUs as direct implementers in collaboration with NSWMC, headed by Department of Environment and Natural Resources (DENR) along with other national government agencies as members to ensure SWM activities are implemented effectively (Republic Act No. 9003, 2002).

One of the main aspects of RA 9003 is its focus on planning and accountability. It requires creation of national solid waste management framework as well as local SWM plan. A minimum of 25% waste diversion was established as target within five years through waste reduction, recycling, and recovery efforts.

Central to the law is its keen orientation toward planning and accountability. It mandates both a national solid waste management framework and a local Solid Waste Management Plan to ensure coherence and focus in its implementation. Targets for waste diversion were also established to be initiated with a minimum of 25% waste diversion within five years through a waste reduction, recycling, and recovery program.

Furthermore, the EWSMA strongly pushers for public engagement and allows the public to sue violators. This further strengthens the concept of waste management not only institutionalizes waste management through systems but also involves shared responsibility and collaboration (Republic Act No. 9003, 2002).

Local Policies on SWM in the Selected Municipalities of Surigao del Norte

Municipality of Del Carmen

The Municipality of Del Carmen adopted the RA 9003 within their locality through the establishment of Municipal Solid Waste Management Board (MSWMB) through Executive Order No. 25, Series of 2010. The MSWMB's main role is to create municipal SEM plan, integrating the waste management strategies of each barangay, and facilitating consultations with different sectors of the community. The Municipal Environment and Natural Resources Office (MENRO) was established to lead the implementation of SWM plan (LGU of Del Carmen, 2017).

The municipality also passed Resolution No. 020, Series of 2017, which formally adopted and endorsed the 10-Year Solid Waste Management Plan (2016–2025). Del Carmen also implements a "No Segregation, No Garbage Collection" policy to ensure compliance on waste segregation at the household level (LGU of Del Carmen, 2017).

Municipality of General Luna

The Municipality of General Luna have formulated their 10-Year Solid Waste Management Plan (2019–2028) in compliance with RA 9003. A Municipal Solid Waste Management Board (MSWMB) through Executive Order No. 007, Series of 2019 was also organized to supervise and monitor the implementation of RA 9003 within the municipality. In a bid to ensure strengthened implementation, the LGU also established the Municipal Solid Waste Management Task Force through Executive Order No. 008, series of 2019. It is the main implementing mechanism of the municipal government's initiatives and projects on solid waste management (LGU of General Luna, 2019).

The municipality also enforces “No Segregation, No Collection” policy pursuant to Article VII, Section 7 of Municipal Ordinance No. 002-16, Series of 2016.

General Luna enforces a strict “No Segregation, No Collection” policy pursuant to Article VII, Section 7 of Municipal Ordinance No. 002-16, Series of 2016. This regulation prohibits the collection of waste from households, barangays, businesses, and institutions that do not comply with mandated waste segregation practices. Corresponding to this, Municipal Ordinance No. 003-18, Series of 2018 regulates the use of cellophane, plastic bags, and styrofoam for any good or commodity that would add up to the residual waste. It encourages the use of eco-bags and other environmentally friendly alternatives, thus solidifying the municipality's commitment to lessening plastic pollution and encouraging sustainable resource utilization (LGU of General Luna, 2019).

Issues and Challenges in SWM

Despite the existence of national and local level policies in SWM, the country still faces significant challenges including the increasing volume of generated waste, gaps in law enforcement, lack of available sanitary landfills, and the persistence of illegal dumping (Coracero et al., 2021).

Although well-formulated, these laws were premeditated in a “command and control” style, which did not manage to rally cooperation from the public. There is the Philippine topography’s nature as an archipelago; lack of transit facilities for provinces; public complexities on a bureaucratic manner that slows down the movement for implementation; corruption; aside from these, it is a democratic nation where some officials become reluctant to enforce these laws fully due to threats from public reaction on their chances for re-election (Atienza, 2011).

Driven by population growth, rapid urbanization, and enduring consumption patterns, the waste generation continues to rise, particularly the rampant use of sachets and single-use plastics. The prevalent use of sachet packaging aligns with the purchasing power of low-income consumers which was observed in many developing countries which further contribute to residual waste generation (Rola, 2019).

As of 2024, there are only 11,625 Materials Recovery Facilities (MRFs) operational serving 42,029 barangays and only 237 sanitary landfills are existing to cater 1,634 cities and municipalities (PIDS, 2024). These highlight the significant gap in infrastructure in waste management systems. Moreover, adopting proper SWM practices such as segregation, recycling, and disposal is still hampered by weak coordination among businesses and industries and policy gaps (Hondo et al., 2020).

Both municipalities share common systemic and operational issues which affect the effectiveness of their SWM strategies.

Governance and Institutional Weaknesses

Several governance-related issues hinder the implementation of both municipalities. Inadequate political will, weak enforcement of local ordinances and inactive MSWMB were main challenges that contributed to the slow and intermittent implementation of planned interventions (LGU of Del Carmen, 2017). The lack of fully functioning MENRO is where the gap arises in General Luna since the MENRO has only one permanent staff appointed in 2017. This affects the coordination across the barangays and institutional discontinuity (LGU of General Luna, 2019).

Despite the existence of ordinances that require segregation at source and proper waste collection and disposal, the enforcement of these policies are still weak due to inadequate institutional support and less political will to commit. Consequently, open burning, indiscriminate dumping, and non-segregation at source are still prevailing practices that defeat the objective of SWM (LGU of Del Carmen, 2017; LGU of General Luna, 2019).

Financial and Operational Constraints

Further constraining the implementation of SWM is the financial challenges in both municipalities. Given the low local revenue generation and extensive poverty in Del Carmen, the availability of funds to support SWM activities are allocated in other equally important programs (LGU of Del Carmen, 2017). Similarly, General Luna faces the same gaps in funding which limits its operations to expand collection services, invest in infrastructure and technologies, equipment maintenance, and establish treatment and disposal facilities. The reported malfunction of equipment and deficiency in number of collection trucks aggravate waste accumulation and unsanitary circumstances (LGU of General Luna, 2019).

Although Siargao Island's ecological importance attracts external support from national government agencies and non-government organizations, these supports are commonly short-term, and the financial capacity of the municipalities strain the sustainability of these efforts and long-term impacts.

Environmental and Health Impacts

The environmental impacts of poor SWM are obvious in the municipalities. In Del Carmen, inappropriate waste management practices have silted irrigation canals, reduced rice production, and have generally affected livelihoods in agriculture. Open dumping and burning of garbage in both municipalities lead to air, water, and soil pollution. Both practices result in foul odors, methane gas emission, and the release of toxic substances that expose the population to serious health risks like respiratory diseases, skin diseases, and sanitation-related infections (LGU of Del Carmen, 2017; LGU of General Luna, 2019).

Infrastructure and Technical Capacity Gaps

None of the municipalities have an operational sanitary landfill in effect, they rely on open dumpsites without proper maintenance. Gaps in technical capacities weakens the waste diversion efforts further compounded by limited access to proper equipment and facilities further (LGU of Del Carmen, 2017; LGU of General Luna, 2019).

Both institutional and human capacity constraints are also a hindrance to the implementation of effective SWM. In Del Carmen, the absence of capacity-building efforts such as training and organizational development curbed the local institution building and stakeholder participation (LGU of Del Carmen, 2017). In General Luna, the absence of deputized barangay-level SWM enforcers and a limited number of personnel deterred the implementation and enforcement (LGU of General Luna, 2019).

Community Participation and Social Challenges

The LGUs observed low community participation and compliance, particularly since many households and establishments do not practice proper waste segregation. The common practice of leaving unsegregated waste along roadsides and open areas still were observed as habitual in the communities. Even though both of these have realized the requirement of engaging community members in cleanup activities, these are still not institutionalized regularly (LGU of Del Carmen, 2017; LGU of General Luna, 2019).

Broader Implications of Inadequate Waste Management

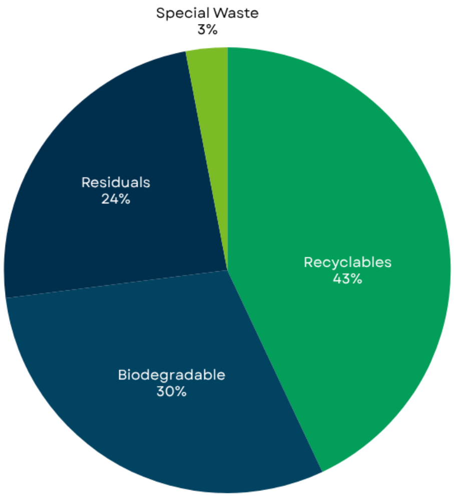
Ineffectiveness in SWM brings broader consequences within environmental, social, and economic attributes. From an environmental perspective, improper disposal of waste generates environmental contaminants due to water, soil, or air pollution as well as GHG emissions, attributing to hazards in the biodiversity, natural resources, and environmental sustainability for human health (Ferronato & Torretta, 2019). In social attributes, SWM generates adverse consequences due to potential hazards linked to spreading epidemics or ill-health arising from improper disposal, while affecting an aesthetic perspective due to improper disposal practices (Weldeyohanis et al., 2022). In economic perspectives or dimensions, costs for treatment, clearance, or lost production due to SWM can create economic burdens on local administrative bodies (Bano, 2025).

Current SWM scenario in Selected Municipalities

Municipality of Del Carmen

AMH Philippines (2024) reported around 0.28 kg of waste per capita per day, which translates to roughly 6,081 kgs of solid waste generated daily. The major source of this volume of solid waste is from households, estimated at about 68%, while the other sources are mostly tourism-driven with an estimated contribution of 1,955 kgs daily. Some of the top sources of solid waste in the Municipality of Del Carmen are food wastes, cardboard boxes, glass bottles, PET containers, and disposed diapers/napkins.

Figure 2.3. Overall Waste Generation Composition of Del Carmen



Source: AMH Philippines, 2024

LGU reported that in 2017, waste segregation at source was 60% compliant in both household and non-household sectors. In support of proper segregation, the LGU has established a total of 75 purok-level MRFs in all barangays to act as temporary holding areas before the materials are moved to the barangay MRFs for eventual transfer to the centralized facility. Despite these interventions, segregating at the household level is not consistent, there being a perception among residents that collectors merely re-mix the segregated wastes, space to store sorted materials is limited, and residents are very busy.

Garbage collection in the area is managed by the Municipal Engineering Office (MEO) and currently services 12 barangays, composing 60% of the whole municipality. All urban and rural barangays are directly served, while inner and island barangays are served upon request. Collection times also vary depending on the area: urban barangays are collected separately on Saturdays, Sundays, and Tuesdays, while inner and island barangays are served twice a week, ten rural barangays, clustering in two groups, are served thrice a week with two trips for the clusters, while the rest are served once a day for their scheduled collection time in their barangays. Biodegradable waste is collected daily, while those for recycling are collected every day in designated days, while residual or special wastes are collected quarterly. Collection of garbage employs mostly $3m^3$ mini dump trucks, with the use of rented $6m^3$ trucks for biodegradable wastes collected in the public market, while motorcycles are used by SWM enforcers for surveillance purposes.

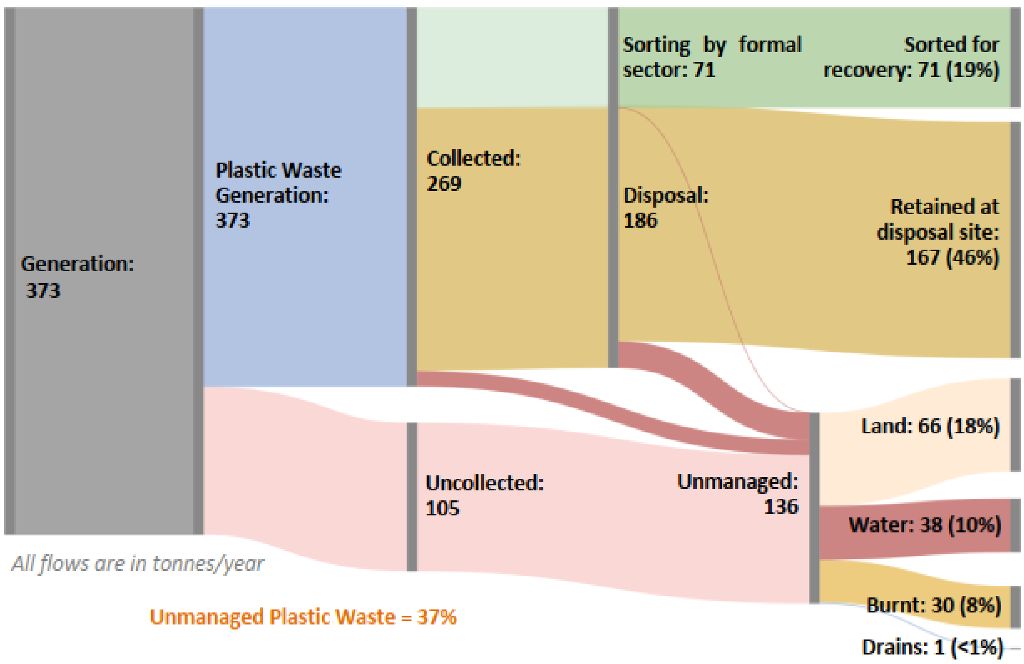
Despite the existing collection system, Del Carmen is still grappling with the processing and diversion of recyclable materials. Glass containers are piling up in the central MRF because of the unavailability of processing facilities in the area, while cartons are also piling up in the central MRF due to the unavailability of local facilities for their processing, with PET containers either stocked or shredded with the hope of using them for souvenir items, although the unavailability of the processes of extrusion or molding hinders the usability of this initiative. Moreover, the municipal government has a biodegradable shredder and composter for soil conditioner production, although these are no longer functional due to damages, thereby pointing towards the need for sustained maintenance services. Moreover, there are no local junk shops accepting plastics, considering the high transportation costs associated with delivering materials from the island, while the market value is low, thereby contributing to the huge bottleneck in disposing of the materials by diversion in due course.

Currently, the municipality uses Residual Containment Area (RCA) for final disposal. However, RCA does not have fencing, daily soil cover, and compaction procedures which should be done to comply with sanitary landfill standards. On the other hand, the LGU proposed a Category 2 sanitary landfill in 2017. However, their focus has shifted to waste-to-energy solutions. They explored the establishment of

Waste-to-Fuel (pyrolysis) and Thermal Decomposition facilities in collaboration with JCA 1221 Holdings, Inc. which they plan to operate within 2025.

Based on WACS Report (AMH Philippines, 2024), Del Carmen has an estimated plastic waste generation of 373 metric tons every year, out of which around 29% goes uncollected and unmanaged. This number emphasizes the existing challenges in terms of recovering and diverting the trash in the municipality.

Figure 2.4. Overall Waste Generation Composition of Del Carmen

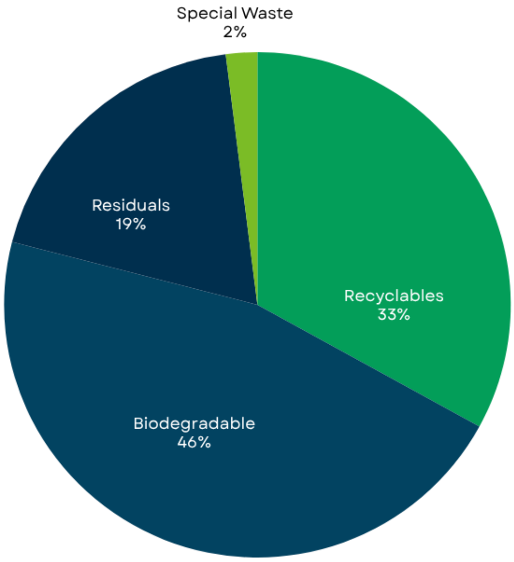


Source: AMH Philippines, 2024

Municipality of General Luna

AMH Philippines (2024) also reported that the municipality of General Luna produces around 0.42kg of waste per capita per day, and in total, the amount of waste is 12,455 kgs of solid waste daily. On the other hand, households contributed about 36% of the total waste, while the remaining are contributions of other sources such as tourism-related businesses, amounting to about 8,007 kgs every day. Food scraps, cardboard, garden waste, PET plastics, and single-layer sachets are among the most common types of waste generated. Particularly, food waste followed by garden waste makes up the most biodegradable waste (AMH Philippines, 2024).

Figure 2.5. Overall Waste General Composition in General Luna



Source: AMH Philippines, 2024

General Luna mandates the segregation of garbage generated from source, as stipulated under Republic Act 9003, such that non-housing establishments are required to maintain their MRF facilities to ensure business permit renewal. However, these MRFs often function as sorting stations with separated containers for different types of solid waste rather than fully operating as processing facilities. Additionally, the households were still inconsistent in waste segregation practice despite the existence of “no segregation, no collection” policy.

Waste collection in the municipality is facilitated by the Municipal Environment and Natural Resources Office (MENRO). Most barangays in General Luna regularly get collected, except for some island barangays which face some limitations. MENRO has a total of five collection trucks with a capacity of 4-5 cubic meters that were originally equipped with a trailer and makeshift side flaps to hold more garbage. Through these collection activities, garbage may be collected along routes or in barangay MRFs that mainly act as holding facilities. In some areas, residents themselves bring garbage to collection points because garbage trucks cannot reach some areas.

The collection schedule also differs per location. The collection is made once to five times a week for urban barangays and Poblacion areas, while once to three times per week in rural barangays. The four island barangays namely, Anajawan, Daku, La Januza, and Suyangan), cut and transport their residuals and recyclable materials to a MRF to be fetched by a motorboat thrice a month. Special collection schedules may also be arranged by high-volume establishments to cater to tourists.

Furthermore, the island configuration of the municipality limits the recovery of garbage due to limited market destinations. Meanwhile, the municipality treats its entire MSW at a 3.2-ha property located at Barangay Corazon, which also contains the Central MRF, the Residual Containment Area, and the final disposal site. Central MRF, at 216m², specifically handles the primary recovery of waste. These include the sorted garbage from non-household sector sources with segregation systems in place, such as PET bottles, HDPE, PP plastics, glass bottles, metal cans, and cartons.

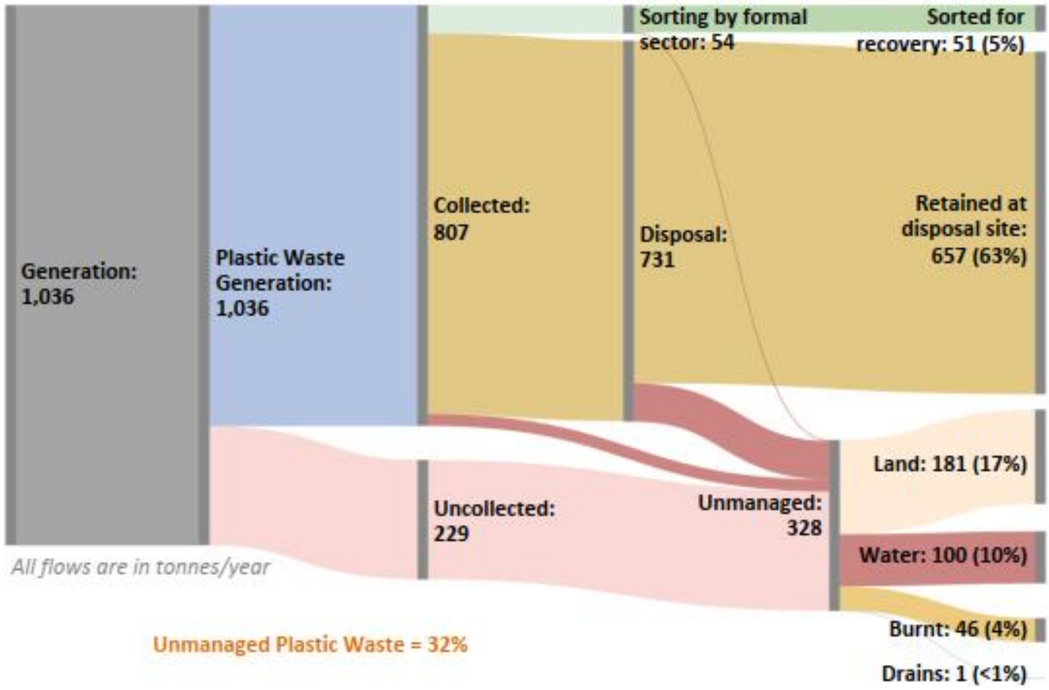
Although the Central MRF has processing technologies such as a bio-composter, bio-shredder, plastic shredder, plastic extruder, glass pulverizer, and hollow block maker, most of these have not been fully utilized primarily due to a lack of technical capacities, maintenance issues, as well as limited markets for the processed materials. Segregated recyclables are collected at least thrice a week by the local consolidator, Envinorcare Company Ltd., which hauls the materials to the recycling plants, the main one of which is in Valenzuela City. Income from the sale of the recyclables amounts to about PHP 17,000 a month, with a portion shared to the personnel of the MRF.

Mixed solid waste collected from households is hauled to a final disposal site where workers further extract recyclable materials. Previously, an RCA was situated along the coastal area in Barangay Malinao in response to a previous temporary open dumpsite that closed down in 2019. However, after Typhoon Odette (Rai) in December 2021, a new location in Barangay Corazon was established to house all activities in connection with waste management.

Presently, the RCA is not fully utilized for the purpose of containing the disposed materials, given that the site is presently utilized for the disposal of municipal wastes. Although the site is pending certification by the EMB prior to the operation of the site as a sanitary landfill, the site is already utilized for the disposal of mixed wastes and residues generated from the Central MRF. Occasionally, soil cover is provided to the disposed materials, but the sanitary landfill standards is not fully applied.

The total plastic waste produced by the municipality is approximately 1,036 metric tons a year, topped by a plastic waste amounting to 22% that has yet to be collected, largely affecting plastic leakage in the environment surrounding these areas (AMH Philippines, 2024).

Figure 2.6. Plastic Waste Flow Diagram of General Luna



Source: AMH Philippines, 2024

Currently, there is no available literature that can show the present status of EMB certification for the sanitary landfill operation for both municipalities. The Pyrolysis and Thermal Decomposition facility in Del Carmen is not among the registered Waste-to-Energy plants/projects under DOE.

Waste-to-Energy Technologies

Facing the pressure of limited land availability, climate change, energy crisis, and growing demand for a livable environment, waste valorization technologies have emerged as a promising solution for the municipalities. Further, waste valorization technologies could address both waste management and energy generation needs. Besides, this approach minimizes emissions related to landfill diversion and brings down health risks linked with air, soil, and water contamination (Alao, Popoola & Ayodele, 2022).

Waste-to-Energy (WtE) technologies involve various treatment methodologies for turning waste resources into feasible sources of energy in the form of electricity or heat or transport fuels like diesel. The different sources of waste that can be treated through WtE include semi-solid waste like sludge generated from effluent treatment plants, liquid waste like domestic sewage, or gaseous waste like refinery gases. The use of MSW for treatment through WtE technologies is presently the most common application of WtE technologies (World Energy Council, 2013).

Typically, the application of WtE technology involves two processes such as biochemical or thermochemical, depending on the nature and humidity levels of waste. Some technologies require specific conditions of waste to be used to ensure efficiency. Pre-processing of waste is usually conducted prior to adding it to the WtE plant (Alao, Popoola, & Ayodele, 2022). Some typical modes of converting waste include anaerobic digestion, methane collection from municipal landfills, gasification, pyrolysis, and incineration. These modes produce supplementary products, which can optionally be converted to produce energy, realizing both environmental and economical gains (Anonas et al., 2023).

Currently, the operational and registered projects under the DOE are anaerobic digestion or bio-methanation, landfill methane recovery, gasification, refuse-derived fuel (RDF) production or thermolysis (briquette), and direct combustion. As of July 2025, there are nine WtE plants or projects registered with the DOE, with five already operational (Anonas et al., 2023; DOE, 2025).

These projects demonstrate that the country is increasingly embracing innovative approaches to SWM aimed at efficiently resolving issues related to energy as well as safeguarding the environment and natural resources.

Table 2.3

WtE Plants/Projects registered with DOE under RA 9513 as of July 2025

Project Name	RE Developer	Location	Technology
Operational Plants			
1.5-MW Landfill Methane Recovery and Power Generation Facility	Pangea Green Energy Philippines, Inc.	Quezon City, Metro Manila	Landfill Methane Recovery
8.19-MW Landfill Methane Recovery and Power Generation Facility	Montalban Methane Power Corporation	Rodriguez, Rizal	Landfill Methane Recovery
350 MT/day Refuse-Derive Fuel (RDF) Processing Plant	Green Alternative Technology Specialist, Inc.	Rodriguez, Rizal	Refuse-derived fuel production
300-MT/day Refuse-Derive Fuel (RDF) Generation Facility	FDR Integrated Resource Recovery Management, Inc.	Naga City, Cebu	Refuse-derived fuel production
624-kW Biogas Power Plant	FDR Integrated Resource Recovery Management, Inc.	Naga City, Cebu	Anaerobic Digestion
Total Capacity	9.69 MW (Commercial Operation) 624 Kw (Own use) 650 MT/day RDF		
Ongoing Projects			
12-MW WTE Plant Project	Green Atom Renewable Energy Corporation	Mabalacat City, Pampanga	Direct Combustion
30 MT/day MSW Briquette Fuel Production Facility	Vistagreen Corporation	Porac, Pampanga	Thermolysis (Briquette)
15,000 MW Integrated Waste Management and Recovery Facility	Lecra Eco Sustain Philippines, Inc.	Brgy. Butucan & Utod, Nasugbu, Batangas	Bio-methanation and Direct Combustion
100,000 MW Manila WTE Facility Project	Manila Integrated Environment Corporation	Tondo, Manila	Direct Combustion (Mixed biodegradables and residuals)
Total Capacity	127 MW 30 MT/day Briquette Fuel		

Source: DOE (2025)

According to Anonas et al. (2023), despite small mentions of WtE technologies as one possible approach to waste minimization within Republic Act 9003, as part of plans for exploration under the National Solid Waste Management Framework, the first law to encourage the use of WtE technologies was RA 9513, or the Renewable Energy Act of 2008. RA 9513 directed DOE to immediately lead, together with DENR, in developing and implementing WtE projects. According to DOE, WtE not only helps with waste volume reduction but also works as an essential component for improving the country's renewable energy resources as well as its electricity supply.

Evidently, the DENR has actively promoted WtE as a viable solution address the country's increasing solid waste problem through the issuance of Administrative Order No. 2019-21 on November 26, 2019. This outlines the procedures and standards in development, evaluation, and decommissioning of WtE facilities. The AO aims to align the WtE implementation with sustainable management of MSW (Anonas et al., 2023).

On the issues raised regarding the possible conflict between RA 9003 and RA 9513, the DOE has stated that WtE in no way promotes the generation of more waste. Instead, WtE is a mechanism designed for the utilization of residual waste, specifically those waste not presently subject to further reduction, re-use, or recycling to convert into energy. WtE is viewed as complementary solution with the more popular methods of preventing waste generation. Along these lines, the DOE adopts a technology-neutral position regarding WtE, promoting the diversification of technology for WtE development, as long as these new WtE technologies comply with environmental regulations and consider advanced methods for emissions control, online monitoring, among other measures designed for minimizing the WtE impact in the environment and making it a positive contributor in both the management of waste and the preservation of the respective environment (Anonas et al., 2023).

Multi-criteria Decision Analysis

As stated in Karmperis et al. (2013), Milutinović et al. (2014), and Morrissey & Browne (2004), among the most popular decision support tools in the context of managing waste is Life Cycle Assessment (LCA), Cost-Benefit Analysis (CBA), and Multi-Criteria Decision Making (MCDM). As LCA is mainly aimed at assessing environmentally related effects and CBA is targeted at looking at financial viability, MCDM is more comprehensive in nature and considers all aspects like financial, social aspects, and environmental-related aspects when arriving at a decision. Recently, there has been an increasing trend in the application of MCDM in managing municipal solid waste, which has proved to be effective in identifying appropriate strategies to manage a complex waste system (Gaur et al., 2022).

Multi-Criteria Decision Making, also known as Multi-Criteria Decision Analysis (MCDA), has recently become one of the most effective methods in analyzing complex decisions. The origins of MCDM can be traced back to Benjamin Franklin, who pioneered the concept of “moral algebra” as an approach for multiple consideration balancing in decisions. Further research initiatives for MCDM techniques were published in the 1950s, investigating their ability to mathematically model decisions and solve conflicting alternatives (Taherdoost & Madanchian, 2023).

MCDA has had a rapid growth in operational research in the last decades of the twentieth century, and indeed has been significantly influenced by seminal papers published in European Journal of Operational Research (EJOR). Some early surveys, including that by Roy and Vincke, outlined several key directions, many of which have seen significant realization in the succeeding decades. Over time, several MCDM techniques were developed, possessing specific characteristics and application fields, particularly in those areas requiring complex decision-making, such as waste management (Greco, Slowinski & Wallenius, 2025; Taherdoost & Madanchian, 2023).

MCDM is applied whenever there are multiple conflicting criteria in the process of making decisions. It allows for organized methods of analysis for making decisions with multiple criteria (Achillas et al., 2013). The techniques found in MCDA can be broadly classified into two areas: one regarding making decisions based on a set number of alternatives that can be defined, and multi-objective optimization, where alternatives are characterized with vectors of decisions with certain mathematical constraints (Greco, Slowinski & Wallenius, 2025). In the field of solid waste management, MCDM helps in making decisions with regard to various strategies based on multiple criteria, which helps in identifying decisions with respect to the most feasible solution regarding solid waste recycling practices (Garcia-Garcia, 2022).

One of the greatest advantages of MCDM is its capacity for the incorporation of judgments/preferences of decision-makers. By assigning weights and scores, decision-makers can formulate comparisons of alternatives; in addition, the optimal choice can also be identified. MCDA can effectively accommodate several decision-making objectives, including the identification of the preferred alternative, formation of rankings, shortlisting of desirable alternatives, or identification of acceptable alternatives from less desirable alternatives (Sohail et al., 2023). The performance matrix occupies a crucial position in MCDA. Each alternative is indicated in a row, while a column signifies each criterion in this matrix; moreover, this makes way for comparison in order to move towards an optimal decision (Achillas et al., 2013).

Although it has various benefits, there are also uncertainties that are sensitive to MCDA, which can originate from data variations, uncertain future environments, as well as vague information, in addition to interrelated preferences, double counting, that can pose challenges in practical applications (Achillas et al., 2013).

The Analytic Hierarchy Process (AHP) is the most commonly used among MCDM methods, appearing in about 65% of relevant studies. AHP mostly used for assessing wastes related to MSW, e-waste, as well as WtE (Soltani et al. 2015; Garcia-Garcia, 2022). AHP was combined with optimization for the following applications: optimizing approaches to prioritize technologies for waste disposal, investigate effects related to source-separating wastes, create an institutional approach for managing solid wastes, locate landfills for solid wastes with the help of GIS, and process organic solid wastes to decrease emissions as well as increase recovery of energy (Alsulaili et al., 2025; ApaydIn, 2025; Azahari et al., 2021; Acuzar et al., 2021; Gunamantha et al., 2023).

AHP is a compensatory approach that uses a linear additive approach for assuming complete aggregation among criteria. Weights and measures of performance by attributes for these pairwise comparisons basically define AHP. The AHP procedure consists of four broad phases: formulating a decision situation into a goal, criteria, and alternatives hierarchy; determining criteria priorities through pairwise comparisons; assessing alternatives on a criterion; and aggregating weighted measures to yield a priority ranking identifying the highly desired alternative (Saaty, 1990; Kasperczyk & Knickel, 2022).

Another popular MCDM method is the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), which was proposed by Hwang and Yoon. In essence, TOPSIS is a multi-attribute decision analysis technique that chooses the best option with the shortest distance from the ideal solution and the longest distance from the anti-ideal solution. The simplicity of TOPSIS, programmability, and practicality have turned it into one of the favorite tools for real-world decisions. To improve robustness and address uncertainties, TOPSIS is often used with other techniques such as AHP and fuzzy logic (Madanchian & Taherdoost, 2023).

Advanced TOPSIS methods have been used in waste management to facilitate prioritization for waste treatment options. For instance, fuzzy TOPSIS and AHP were employed to evaluate the strategies based on social acceptance, cost-saving, and environmentally sustainable factors. Other research studies used a combination of fuzzy logic, TOPSIS, AHP, PROMETHEE II, and DEMATEL to evaluate sustainable strategies for municipal waste management and examined the cause-and-effect relationships involved in the decision-making process (Aghajani Mir et al., 2016; Demircan & Yetilmezsoy, 2023; Mujtaba et al., 2024; Monteron & Villeta, 2024).

These studies show that AHP and TOPSIS applications, especially when combined with other MCDM methods can determine solutions for SWM strategy planning that are more sustainable, efficient, evidence-based, and targeted. They help LGUs and stakeholders to make optimal SWM decisions, considering sustainability factors, as well as ensuring SWM strategy optimization for environmental, social, and economic aims.

III. STATEMENT OF THE STUDY

In 2021, UNEP estimated 9,200 million tons of plastic that were produced worldwide between 1950 and 2017, around 7,000 million tons became plastic waste. What is alarming is the fact that about three quarters" of this volume either ended up in landfills, or were inadequately managed and uncontrolled, or were deliberately discharged into the open environment including in the marine ecosystems. Microplastics ended up in the ocean through many means, including the fragmenting of larger bits of plastic, the leakage of materials from landfills, the sludge from wastewater processing plants, the particulates from the air generated from the wear of tires made of plastic and other plastic materials, agricultural runoff from land treated with plastic mulches, the systematic break downing of ships at sea yards known as "shipbreaking," and the loss of cargo overboard accidentally at sea. Storms, tsunamis, and floodwaters carry large quantities of debris from coastal areas, riverbanks, shorelines, and estuaries into the ocean.

The municipality of General Luna in the province of Surigao del Norte is a world-renowned tourist destination in which ecotourism is a significant engine that has fueled its development and growing economy (Bacasnot et al., 2018). As a famous tourist spot like many other destinations across the world, General Luna is facing increasing pressures regarding handling municipal waste due to growing populations that amount to a total of 22,853 residents and a tremendous flow of tourists on a daily basis. Similarly, a WWF survey undertaken in 2023 established that tourists produce more municipal waste compared to residents by a factor of five.

On the other hand, the Municipality of Del Carmen hosts the one of the most extensive mangrove forest reserve in the Philippines, with an area of more than 8,000 hectares of ecologically important landscapes. However, its rise to being a tourist destination has also meant that it generates increasingly more wastes from its residents and visitors. As the demands for goods and services increases, so did the dependence on plastic packaging and disposable products which aggravate the stress on municipal SWM. This escalating waste problems poses serious risks to livelihood and biodiversity such as bleaching coral reef ecosystems and negative impacts to local fisheries (WWF Philippines, 2023).

IV. OBJECTIVES OF THE STUDY

The main objective of this study is to evaluate solid waste management alternatives in the selected municipalities of Surigao del Norte using Multi-Criteria Decision Analysis. Specifically, it aims to:

- Determine the relative weights of evaluation criteria using Analytic Hierarchy Process (AHP) according to the preference and priority of experts
- Evaluate the proposed SWM scenarios against the environmental sustainability, economic viability, social acceptability, and technical and institutional feasibility criteria through Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)
- Establish data-based recommendations on the most viable SWM options for LGUs and other stakeholders

V. RATIONALE

The study aims to address the significant issues and concerns related to municipal solid waste management in coastal areas. The research seeks to ensure that resources are utilized on programs and activities with high potential of providing greatest benefit by providing LGUs with structured and evidence-based framework.

Aside from validating the existing SWM approaches, the study provides a transparent platform for prioritization with consideration of several factors such as environmental, social, economic, and technological. This helps provide practical approaches that are not just feasible for implementation but could also contribute towards sustainability.

Moreover, identifying SWM scenarios that could potentially reduce marine litter, maintain public health, and implement circular economy approaches thru this study contributes to sustainability outcomes. The combined perspectives of LGUs, national government agencies, non-governmental organizations and other relevant stakeholders are incorporated into the study to further improve the results.

The study also contributes to the growing number of research related to the application of MCDA in solid waste management. The findings of the study are significant in supporting the decision-making process of LGUs and can also be a reference for other coastal areas in the country. It can also help in the decision of other LGUs with similar contexts.

VI. SCOPE AND LIMITATION

By employing MCDA specifically AHP and TOPSIS methods to evaluate the SWM alternatives in selected municipalities in Surigao Del Norte, the study examines existing and proposed SWM options to identify the most feasible SWM option applicable to the municipalities of Del Carmen and General Luna. This includes waste treatment and final disposal strategies that could potentially improve the current SWM systems.

The study utilizes relevant literature to develop the evaluation framework which addresses various aspects of SWM including environmental, social, economic, technical, and institutional. To determine the relative importance of evaluation criteria the study employs AHP through pairwise comparisons based on the perspective of respondents. Subsequently, this study also uses TOPSIS to evaluate and rank the proposed SWM scenarios based on the weighted criteria.

Additionally, the study incorporates available secondary data including municipal SWM plans, Waste Analysis and Characterization Studies (WACS), city-level and barangay-level ordinances, and relevant reports from national government agencies and expert judgments. Given this, the results of this study relied on the availability and reliability of these secondary sources and the subjective nature of experts' assessment.

Behavioral changes of the communities and unexpected policy and political shifts that may affect the performance and sustainability of SWM scenarios are not considered in this study.

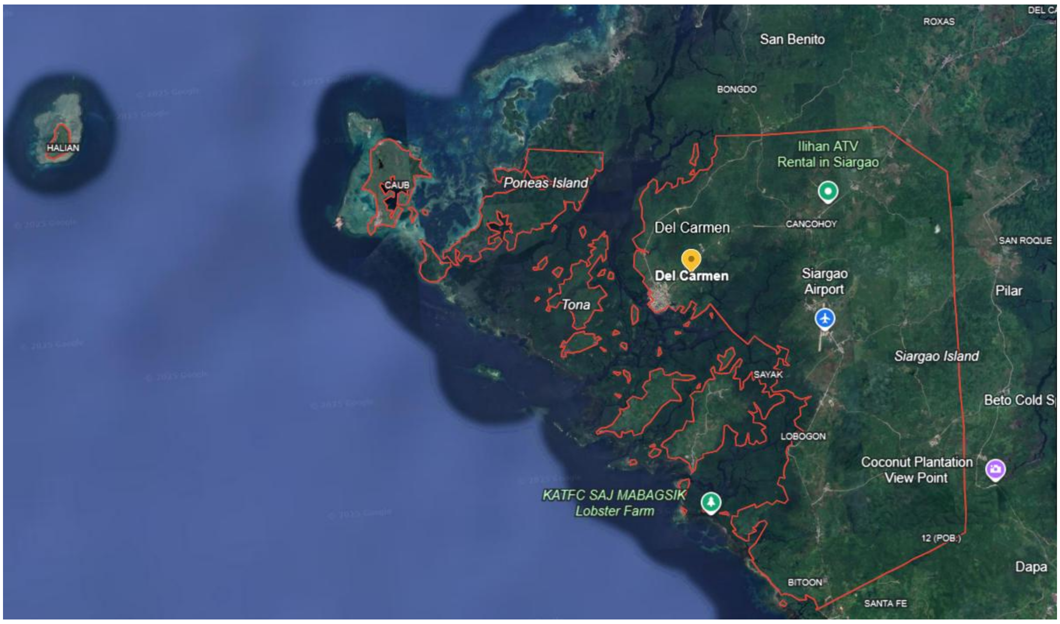
VII. DESCRIPTION OF THE STUDY AREA

Municipality of Del Carmen

Located on Siargao Islands, Del Carmen is a 5th class municipality which is part of the 1st district of the province of Surigao del Norte. It is bounded by the municipality of San Benito in the north, Pilar in the east, Hinatuan Passage in the west, and the municipality of Dapa and the island of Bucas Grande in the south. Del Carmen is about 33 nautical miles from the mainland of Surigao del Norte (Del Carmen LGU, 2016).

It is divided into 20 barangays, two (2) barangays are classified as urban and eighteen (18) are rural barangays. The LGU further categorizes certain barangays based on geographical and functional features. The inner barangays include Antipolo. Tuboran, Mahayahay, and Quezon while coastal or island barangays include Caub, Domoyog, Halian, and San Fernando (Del Carmen LGU, 2016).

Figure 7.1. Administrative Map of Municipality of Del Carmen



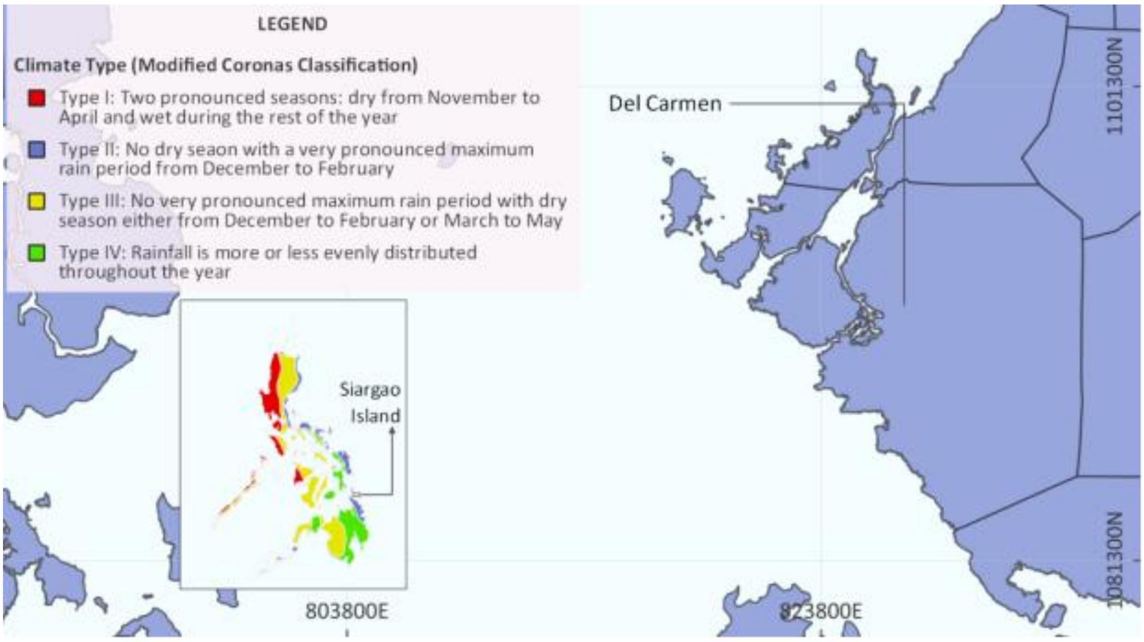
Source: Google Earth (2025)

Based on national census, Del Carmen had a population of 20, 127 in 2020 with 1.91% average annual growth rate from 2015 to 2020 (Philippine Statistics Authority, 2021). The total land area of the municipality is 151.68 km^2 with 133 individuals per kilometer of estimated population density. In 2024, around 21,710 total population was estimated based on the growth rate. Out of the 20 barangays, Barangay Del Carmen (Poblacion) is the most populous with an estimated number of 3,854 residents, followed by Barangay San Jose with an estimated number of 1,999, while Barangay Domoyog is the smallest with an estimated number of 362 residents.

The economy of the municipality mainly depends on agriculture, fishing, and wood products (Del Carmen LGU, 2016). Based on the Cities and Municipalities Competitiveness Index (CMCI), Del Carmen occupies the 22nd ranking out of 316 fifth- and sixth-class municipalities in the Philippines. It scored 37.29 out of 100. It also scored 5.63 out of 20 in the Economic Dynamism component. It holds the 39th ranking.

In terms of climatic condition, Del Carmen has a Climate Type II, classified using the Modified Coronas Climate Classification System; it has no dry season and rainfall peaks in December, January, and February every year (PAGASA, 2014). This is also during the onset of the Amihan or northeast months that bring cooler air and stronger trade winds. The nearest weather station in Del Carmen is located in Surigao City, approximately 54 kilometers southwest of Del Carmen. The average rainfall recorded for every thirty years since 1991 to 2020 is recorded to be 3,757.3 mm; in January it reaches 661.5 mm and in May it reaches only 120.0 mm per month for Del Carmen (PAGASA, 2024).

Figure 7.2. Climate Map of Municipality of Del Carmen

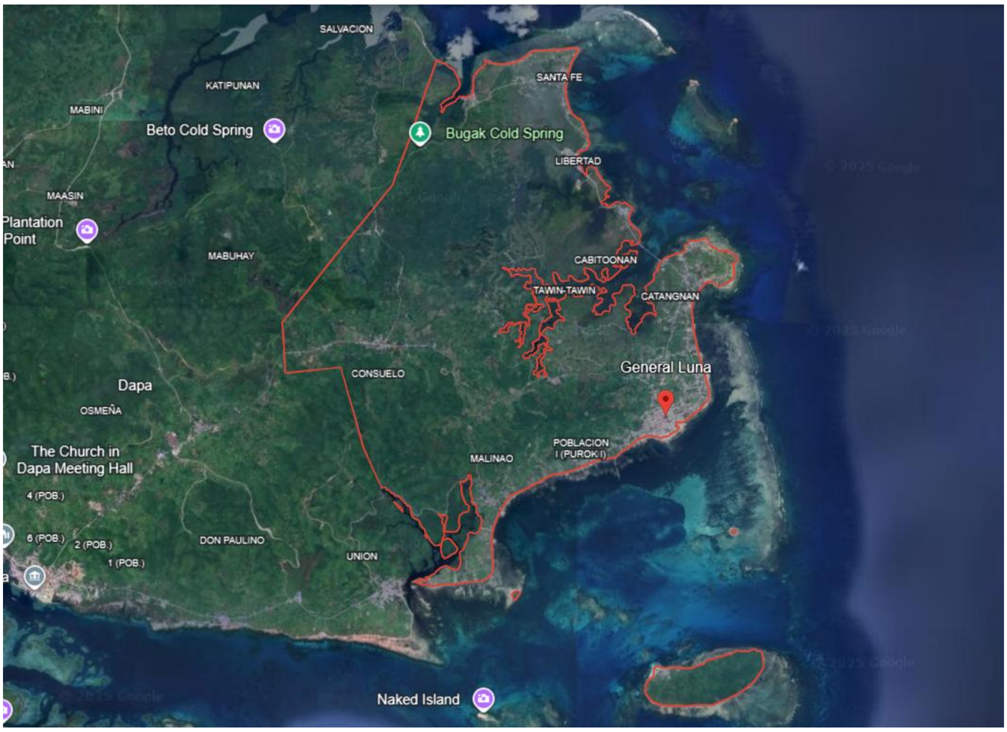


Source: PAGASA (2014)

Municipality of General Luna

The Municipality of General Luna occupies the Southern portion of the Island of Siargao, within the province of Surigao del Norte. The geographical boundaries of General Luna are: to the North, the Municipality of Pilar; to the South, the islands of Daku and La Januza; to the West, the Municipality of Dapa; while to the East, the Philippine Sea. General Luna is located within the boundaries of the Siargao Island Protected Landscapes and Seascapes (SIPLAS), a Protected Area as defined and governed through Republic Act 7586, otherwise known as the National Integrated Protected Areas System (NIPAS) Act.

Figure 7.3. Administrative Map of Municipality of General Luna



Source: Google Earth (2025)

General Luna covers a total land area of 5,998 hectares, as identified in Cadastral No. 789-09 in accordance with the DENR Memorandum dated November 19, 1998. Its municipal waters cover around 92,000 hectares. Geographically, this municipality is situated between 9°47’-9°50’ North Latitude and 126°9’-126°10’ East Longitude.

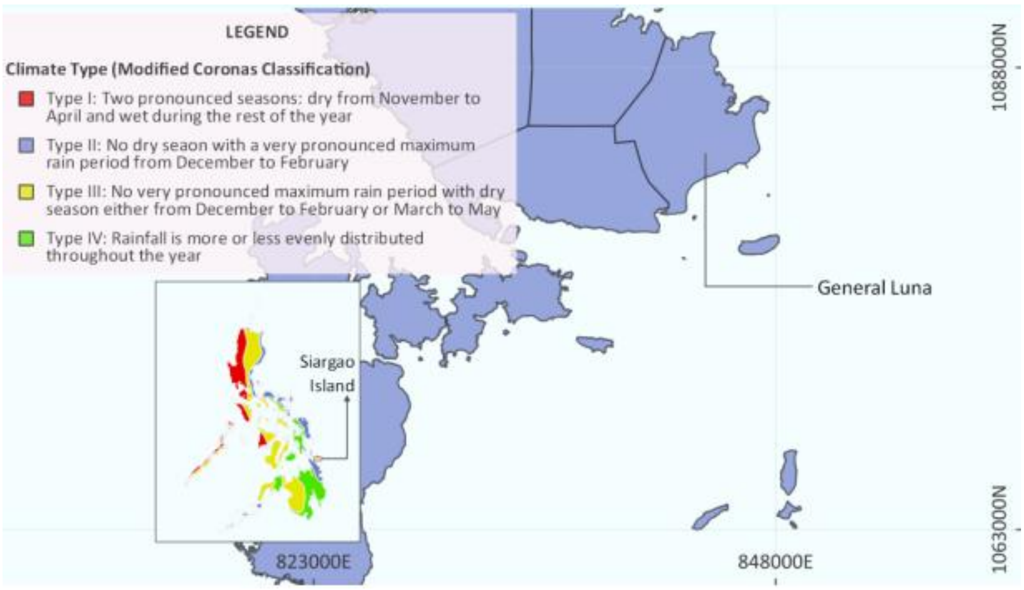
General Luna has 19 barangays, of which 15 are inland while four are island barangays. It is categorized as a 5th-class municipality and had a population of 22,853 based on the annual growth of 6.73% during the period of 2015-2020 (Philippine Statistics Authority, 2021). Its total land area is 52.21 square kilometers, giving the place an actual population density of 438 people per square kilometer. It was projected that the total population of the place as of 2024 was around 29,655, including the population projection of each barangay based on the annual growth of 6.73%.

Barangay Poblacion V has the largest population with 4,966 people, followed by Poblacion I with 3,206, while La Januza has the smallest population with 481 people.

Tourism, fishing, and agriculture primarily drives the local economy of the municipality (Province of Surigao del Norte, 2011). On the CMCI ranking, General Luna is the 6th among 316 fifth and sixth-class municipalities in the country, with an overall score of 41.48 out of a hundred. It performs particularly well in economic dynamism, ranking number 2 with a score of 7.46 out of 20.

In terms of climate, General Luna has a Type II classification according to the Modified Coronas Climate Classification. This climate type is basically without a dry season and has a very pronounced maximum rainfall from December to February (PAGASA, 2014). A rainy season coincides with the Amihan or northeast monsoon that brings cooler temperature and strong northeast trade winds to shape the municipality's weather patterns throughout the year.

Figure 7.4 Climate Map of Municipality of General Luna



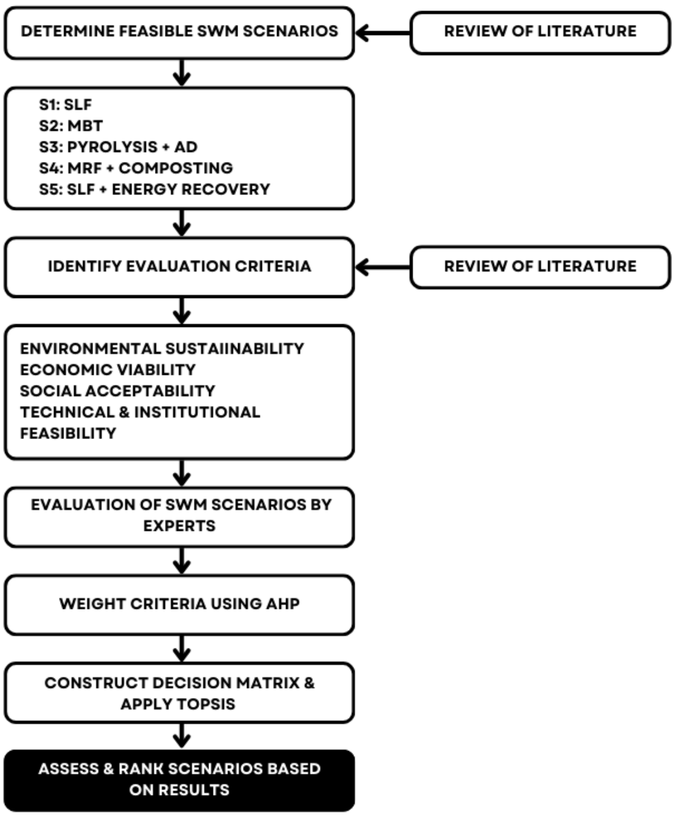
Source: PAGASA (2014)

VIII. METHODOLOGY

Research Framework

A multi-criteria decision analysis (MCDA) framework was utilized for analyzing and ranking SWM scenarios, based on an approach that integrates the Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). In this approach, expert opinions in terms of rankings of criteria and solutions, as well as solution performance measurements, are comprehensively combined for decision-making. Each of these eight iterations is presented in the flow chart of Figure 11. In this study, the words alternative and scenario are equivalent with respect to proposed processing and disposal-level technologies for municipal solid waste management.

Figure 8.1. Research Flow of the Study



Identification of proposed SWM scenarios was done through a thorough review of relevant literature. In developing the proposed scenarios, considerations were given to specific waste composition in study areas and the prevailing SWM systems to ensure that proposed alternatives are contextual and in tandem with prevailing local conditions.

S1: 100% Sanitary Landfill

A sanitary landfill is a facility for the controlled disposal of wastes by spreading in thin layers, compacting to form a dense entity with reduced volume, and then covering it with soil or other suitable material at the end of each operating day. An engineered waste management system, a sanitary landfill serves as a contained bioreactor through which anaerobic biodegradation and consolidation of compacted refuse within soil layers take place. The design requirements on SLFs vary depending on the local conditions: landfills in arid regions where the formation of leachate is minimum may be designed to nearer minimum standards while for the coastal landfills underlain by naturally saline and non-potable groundwater may use relaxed measures compared to inland sites with potentially usable groundwater (Cointreau, 2004). In the Philippines, Republic Act No. 9003 legislated the construction and operation of SLFs as the assigned final disposal site for municipal solid waste and, ultimately, residual materials generated by one or more local government units.

The main advantage of a sanitary landfill is that the wastes are only minimally manipulated and treated. Operational processes can be restricted to collecting, transportation, spreading into layers of waste, and covering with the proper material to retain sanitary and ecological criteria. This technique is generally seen as being the least complicated and least expensive to manage all kinds of different wastes against a huge collection of other waste management techniques. In this scenario, all wastes collected go to SLF.

S2: MBT and Recycling

Mechanical Biological Treatment (MBT) is a waste management system that uses a combination of both mechanical and biological processes for treatment of residual waste from municipal solid waste. In this process, the mechanical treatment is done through sorting of different waste types, such as recyclable, biodegradable waste, high calorific waste, and residues; and biodegradation of biodegradable waste (Byström, 2010). One of the advantages of MBT is that it can handle mixed waste without prior source separation. This makes MBT suitable for waste management since it is possible to have a plant that incorporates different process technologies according to strategies that have been put in place for management. Considering material recovery, another merit that MBT has is that it is applicable for production of Refused-Derived Fuel or Solid Recovered Fuel and recovery of recyclable commodities such as metals from sorted waste (Ishigaki & Lui, 2020).

Integration of recycling and composting for an MBT system is one of the most efficient ways to adopt waste management practices sustainably. Another advantage of composting is the reduction of pathogens due to the higher temperatures produced. Major gases produced here are carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and nitrous oxide (N_2O). MBT system provides support for the production of material of appropriate quality from mixed waste materials. In this context, it also helps to produce high calorific RDF mainly from plastics and organic waste. Furthermore, this type of material is further applicable to the production of energy in the cement kiln and thermal power station. In this scenario, materials such as metals, glass, plastics, and paper will be sent for recycling. On the other hand, paper/plastics mixed with other materials will be sent to produce RDF (Gombojav & Matsumoto, 2023).

S3: Pyrolysis and Anaerobic Digestion

Pyrolysis is a thermal decomposition process involving the treatment of solid waste under oxygen-deficient conditions and higher temperatures from 300°C to 900°C (Chen et al., 2014). In this process, various energy products such as char, pyrolysis oil, and gaseous fuels (syngas) are obtained. It is the only thermal method capable of the simultaneous production of energy products in the solid, liquid, and gas phases. Pyrolysis also dates back to ancient times when it was applied to produce charcoal. However, in contemporary technology, it is specifically applied to homogeneous wastes such as plastics, rubber, papers, and wood to obtain quality products. Pyrolysis of plastic waste mainly produces pyrolysis oil. In the case of wood and other biomass wastes, the products obtained are syngas and char (Chen et al., 2014). Polystyrene (PS), polypropylene (PP), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), and polyethylene terephthalate (PET) are some of the major polymers that are currently converted through pyrolysis.

There are several reactors used for pyrolysis, such as fixed-bed reactors, rotary kilns, and fluidized bed reactors. Fluidized bed reactors are particularly well-suited to plastic waste because polymers have low thermal conductivity and are viscous; rotary kilns and tube reactors are better suited to large-scale processes. Fixed-bed reactors are not generally employed at large scales because they are inefficient, but rotary kilns have been employed effectively on large scales (Dong et al., 2019). Pyrolysis can be regarded as relatively environmentally sound compared to incineration because the reduced oxygen content prevents the creation of toxic materials such as dioxins and furans and generally results in lower noise levels (Alao, Popoola, & Ayodele, 2022).

In the context of the Municipality of Del Carmen, the LGU partnered with JCA 1221 Holdings, Inc., to develop a pyrolysis facility which they target to operate within the year. In this scenario, anaerobic digestion is combined with pyrolysis.

Anaerobic Digestion (AD) refers to a sustainable biological process for the treatment of organic wastes that involves four major biochemical reactions: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Bandini et al., 2022). Although uncontrolled AD in landfills tends to produce methane gas as well as carbon dioxide, a contributor to pollution of the environment; controlled AD increases microbial productivity through controlled temperature, pH levels, nutrient composition, and retention period. AD when done properly yields useful by-products such as biogas rich in methane gas and hydrogen gases as clean fuels. Another by-product of AD is organic fertilizer rich in nutrients for agricultural use (Mahajan et al., 2020; Zamri et al., 2021). In addition, as AD does not use fuels from fossil materials (Sánchez-Bastardo, Schlögl, & Ruland, 2021).

Despite the above benefits, there are some limitations in the use of AD, such as the long recycling times, which can lead to the accumulation of ammonia, thus inhibiting the activity of microbes in the process (Malinowski, 2022). However, recent technologies in the bioreactor system have improved the efficiency of this process greatly, which can process organic waste faster with greater production of value-added chemicals (Wang, Fotidis, & Angelidaki, 2015).

S4: MRF and Composting

A Material Recovery Facility (MRF) is specific infrastructure that receives, sorts, and stores solid waste temporarily to allow for the recovery of recyclable items of value. The wastes are sorted in specific streams of paper, cardboard, glass, PET bottles, and light plastics in the MRF, which are then stored in separate containers or compartments. By managing to catch a high percentage of recyclables, MRFs maximize material recovery for resale while decreasing the volume that needs further transportation for ultimate disposal (Mertenat & Zurbrügg, 2023).

As discussed in Chapter 2, the RA 9003 provides the entire framework for the country's waste management. This law requires establishment of MRF in every barangay or cluster of barangays to promote segregation, recycling, and resource recovery at the community level (Salillas et al., 2017). However, the existing MRFs in both municipalities are still underutilized.

This scenario proposes strengthening MRF operations and improving composting facilities. This will be done through securing waste processing technologies, especially plastics using extruders and molders to create marketable products and closing gaps in SWM infrastructure. Developing partnerships with existing facilities of similar scale, exploring potential markets for recyclables, and improving technical skills of MRF personnels will also be done.

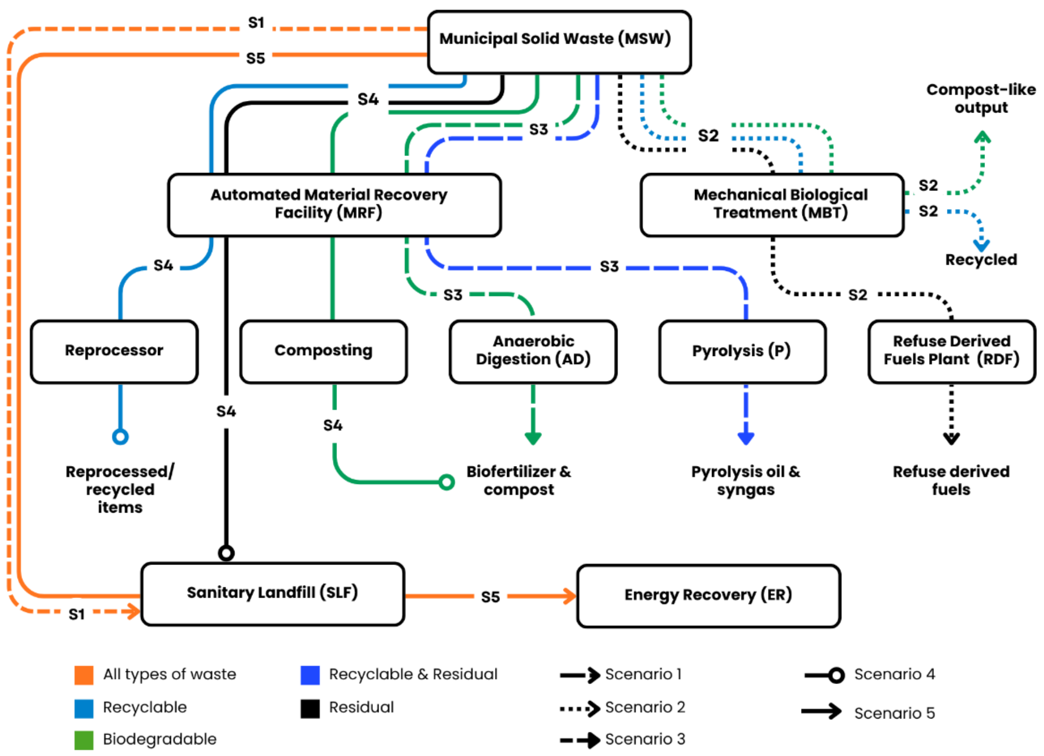
Composting refers to biochemical and heterogeneous reaction involving the degradation of the organic matter into carbon dioxide (CO_2), ammonia (NH_3), and water (H_2O) in addition to partial humification of the matter to obtain a stabilized product with less toxicity and pathogenic load (Das et al., 2011). This includes several methods that are aligned with the principle of sustainable agriculture (Adbrecht et al., 2011). Through the production of sanitized and stabilized organic materials, composting provides a proper technique for minimizing the risks of using untreated organic material for soil amendment in agricultural lands (Qian et al., 2014).

S5: SLF and Energy Recovery

This scenario is similar to Scenario 1, with the inclusion of energy recovery from waste in the landfills, mainly methane gas (Coban, Ertis, & Cavdaroglu, 2018). In most developing nations, open dumping of waste, which still occurs, can be identified as a significant factor in the emission of greenhouse gases. The landfill gases are mainly the result of the anaerobic degradation of biological materials, having methane as a significant constituent of these gases (Tian et al., 2013; Fallahizadeh et al., 2019).

Landfill gas recovery technologies try to harness these gases to produce a tangible form of energy, usually electricity or heat, using internal combustion engines. These gases are gathered using a piping system of wells that could be active or passive, using vertical or horizontal landfills driven by natural forces, suction, or pressure difference (Amini, 2011). In addition, these technologies decrease the environmental impact of landfills since the energy produced from the treatment of landfills could offer financial benefits through the creation of funds from electricity sales or carbon credits (Alao, Popoola, & Ayodele, 2022).

Figure 8.2. SWM Scenarios



These proposed scenarios were subsequently assessed and scored by ten (10) SWM experts using a set of clearly defined criteria drawn from the literature. The evaluation criteria include the following parameters:

Table 8.1

Evaluation Criteria based on Literature Review

Evaluation Criteria	Description	Reference
Environmental Sustainability		
C1. Waste Leakage Reduction	Ability to prevent plastic and other waste from leaking into rivers, seas, and open environment	Zhou et al (2022); Shanta et al (2024); Sukma et al (2024)
C2. Pollution and Health Risk Reduction	Extent to which the strategy minimizes risks from open dumping, burning, or emissions	Mujtaba et al (2023); Generowicz et al (2018); Liao & Chui (2011); Gaur et al (2020); Chung & Poon

		(1996); Zhou et al (2022); Shanta et al (2024); Sukma et al (2024)
C3. Resource Recovery Contribution	Potential to promote recycling, composting, or energy recovery	Generowicz et al (2018); Chung & Poon (1996); Zhou et al (2022); Shanta et al (2024); Sukma et al (2024)
Economic Viability		
C4. Capital Expenditure	Total investment required for establishing and operating the MSW management system	Mujtaba et al (2023); Gaur et al (2020); Chung & Poon (1996); Zhou et al (2022); Shanta et al (2024); Sukma et al (2024)
C5. Operating Expenditure	Overall expenses for managing the MSW system, including labor, equipment, and maintenance costs.	Mujtaba et al (2023); Gaur et al (2020); Shanta et al (2024); Sukma et al (2024)
C6. Cost Recovery/Revenue Potential	Ability to generate income through the sale of recyclable materials or energy recovery	Mujtaba et al (2023); Shanta et al (2024): Sukma et al (2024)
Social Acceptability		
C7. Community Acceptance & Participation	Likelihood of communities supporting and participating in the strategy	Generowicz et al (2018); Liao & Chui (2011); Chung & Poon (1996); Shanta et al (2024); Sukma et al (2024)
C8. Public Health & Sanitation Benefits	Potential of the strategy to improve local sanitation, reduce waste-related diseases, and safer waste handling	Mujtaba et al (2023); Gaur et al (2020); Chung & Poon (1996); Zhou et al (2022)
Technical & Institutional Feasibility		
C9. Ease of Implementation & Scalability	Degree to which the strategy can be rolled out with available skills, land, and infrastructure and scaled up across municipalities	Mujtaba et al (2023); Liao & Chui (2011); Gaur et al (2020); Chung & Poon (1996); Shanta et al (2024)
C10. Governance & Enforcement Compatibility	Alignment with RA 9003 requirements and LGU institutional capacity for monitoring & enforcement	Generowicz et al (2018); Chung & Poon (1996); Shanta et al (2024); Sukma et al (2024)

To determine the relative importance of each criterion, the Analytic Hierarchy Process (AHP) is applied. Experts perform pairwise comparisons using a scale of relative importance (Saaty's scale of 1–9). A pairwise comparison matrix $A = [aij]$ is constructed, where:

$$a_{ij} = \frac{w_i}{w_j}$$

Here, w_i and w_j are the relative weights of criteria i and j. The priority vector (criteria weights) is obtained by normalizing the eigenvector of the matrix:

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}}$$

Consistency is checked using the Consistency Ratio (CR):

$$CI = \frac{\lambda_{\max - n}}{n-1}, \ \ CR = \frac{CI}{RI}$$

where λ_{max} is the maximum eigenvalue of the matrix, n is the number of criteria, and RI is the Random Consistency Index. A $CR < 0.10$ indicates acceptable consistency (Saaty, 2008).

The performance of SWM scenarios are assessed based on evaluation criteria as soon as the weights of criteria are determined. The data is collected in both qualitative methods as well as quantitative data through various reports. However, to ensure data comparability in terms of scale values, the data is standardized before undergoing further analysis.

Then, TOPSIS is applied to rank the scenarios. A decision matrix is formed as:

$$X = [x_{ij}], \quad i = 1, 2, \dots, m; \;\; j = 1, 2, \dots, n$$

where x_{ij} is the performance of alternative i on criterion j.

Normalization:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$

Weighted Normalized Matrix:

$$v_{ij} = w_j \cdot r_{ij}$$

Ideal and Negative-Ideal Solutions:

$$A^+ = \{\max(v_{ij}) \mid j \in J_b; \min(v_{ij}) \mid j \in J_c\}$$

$$A^- = \{\min(v_{ij}) \mid j \in J_b; \max(v_{ij}) \mid j \in J_c\}$$

where J_b = benefit criteria and J_c = cost criteria

Separation Measures:

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij}} - v_j^+)^2, \; S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij}} - v_j^-)^2$$

Closeness Coefficient:

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

If the CC_i of a scenario is higher, this indicates that the scenario is closer to the ideal solution (Behzadian et al, 2012).

The SWM scenarios were ranked according to the respondents' preferences on the basis of the value of the closeness coefficients. The ranking of scenarios reveals the scenarios that performed best in meeting the evaluation criteria. This provide evidence on which scenarios should be considered and prioritized by the municipalities.

Sampling

To ensure that the respondents are directly relevant to the objectives, this study employed purposive sampling technique. The experts were selected as respondents to assess and evaluate the set of criteria and SWM scenarios. In this context, an expert is considered as an individual possesses specialized knowledge from formal education, training, or knowledge gained through practical exposure and experience. Six (6) to twelve (12) participants are generally sufficient for an expert group for identification processes. Beyond that, additional members make little difference in terms of incremental cost Krueger et al. (2012).

Expert's opinion is considered as reliable source of information in complex environment systems, especially when empirical evidence is limited. The expert can assist in synthesizing the best available knowledge in relation to the development of policy prior to the establishment of scientific outcomes in circumstances where urgent action is required (Leskinen & Kangas, 2005; Knol et al., 2010).

In this study, the experts were purposively selected to ensure inclusive representation in all key areas of SWM. A total of ten (10) experts in waste management from various sectors including LGUs, academic institutions, national government agencies, NGOs and private sector were engaged in the study. The table below summarizes the details of the selected experts.

Table 8.2

Selected Experts

Expert	Background	Designation	Organization
1	Engineering Consultancy	Supervising Engineer	AMH Philippines, Inc.
2	Non-Governmental Organization	UNDP Project Management Specialist	EU Green Economy Partnership with the Philippines (EUGEPP): Green LGUs Project
3	Non-Governmental Organization	Project Manager	WWF Philippines
4	National Government Agency	Environmental and Biotechnology Division Chief	Department of Science and Technology – Industrial Technology Development Institute
5	Strategic Policy Research	Policy Researcher	Institute for Global Environmental Strategies
6	National Government Agency	Environmental Management Specialist	Department of Environment and Natural Resources – Environmental Management Bureau
7	Local Government Unit	Municipal Environment and Natural Resources Officer	Municipal Environment and Natural Resources Office – Del Carmen
8	Local Government Unit	Municipal Environment and Natural Resources Officer	Municipal Environment and Natural Resources Office – General Luna
9	National Government Agency	Project Lead	Green Wave Project – DOST CARAGA
10	Academe	Assistant Professor	University of the Philippines – Institute of Civil Engineering

Data Collection

Both primary and secondary data collection methods were used in this research study.

Primary Data

A structured research questionnaire (Appendix A) is use as primary data collection tool to gather information from the selected experts (Table 8.2). The information gathered from the experts included key parameters related to waste management practices. These parameters focused on viewpoints including environment suitability, economic feasibility, social acceptability, and institutional feasibility concerning waste management.

Criteria weighting and strategy scoring were two key components of the research instrument. The scenarios were assessed using a set of criteria from literature review to highlight relevance and applicability.

Secondary Data

The secondary data collection includes thorough review and analysis of available literature such as published journals, articles, and case studies focused on solid waste management. This helped in identifying and compiling potential SWM options which were evaluated using MCDA methods.

IX. RESULTS AND DISCUSSION

This chapter presents the results of evaluating solid waste management alternatives in selected municipalities of Surigao del Norte using MCDA. Specifically, the priorities and preferences of the respondents were determined using AHP and TOPSIS methods. The findings are organized in three main sections such as respondents profile, AHP criteria weights, and TOPSIS analysis, which were followed by an overall analysis and discussion of outcomes.

Respondents Profile

A total of eleven (11) experts responded in the survey. They assessed the evaluation criteria using by rating them and evaluated the proposed SWM scenarios against the criteria. Most respondents were already familiar with the local contexts and current conditions in the selected municipalities because of their prior and current experience in working within these sites. In fact, some respondents were directly implementing SWM programs in the municipalities. This ensures that the assessments were based on actual and operational local situations. The table below outlines the key details of the respondents.

Table 9.1

Respondents Profile

Expert	Background	Designation	Organization	Years of Professional Experience in SWM
1	National Government Agency	Science Research Specialist II	Department of Science and Technology – Industrial Technology Development Institute	4-6
2	International Cooperation Agency	DPM	United Nations Development Programme	More than 10

3	National Government Agency	OIC Section Chief	Department of Environment and Natural Resources – Environmental Management Bureau - Region 12	4-6
4	National Government Agency	Senior Environmental Management Specialist	Department of Environment and Natural Resources – Environmental Management Bureau - Region 13	More than 10
5	National Government Agency	Senior Science Research Specialist	Department of Science and Technology - CARAGA Region	1-3
6	Local Government Unit	Municipal Environment and Natural Resources Officer	Municipal Environment and Natural Resources Office – Del Carmen	More than 10
7	Private Sector/ Consultancy	Supervising Engineer	AMH Philippines, Inc.	7-10
8	National Government Agency	Environmental Management Specialist II	Department of Environment and Natural Resources – Environmental Management Bureau - Region 13	7-10
9	National Government Agency	Environmental Management Researcher	Department of Environment and Natural Resources – Environmental Management Bureau - Region 13	1-3
10	Non-Government Organization	Project Manager	WWF Philippines	1-3
11	Academic/ Research Institution	Policy Researcher	Institute for Global Environmental Strategies	4-6

AHP-derived criteria weights

AHP was used to determine the relative importance of ten (10) evaluation criteria identified in this study. After reviewing the pairwise comparison matrices of each respondent, there were six (6) responses that exceeded the 0.10 Consistency Ratio (CR). These responses were rejected to improve the validity of consolidated judgments. The remaining five (5) responses with an overall CR of 0.063 were used instead, to develop the AHP matrix (Table 9.2). The overall CR is below the threshold value which implies logical consistency of the collective expert judgments. The researcher was able to determine the normalized priority weights for each criterion based on the AHP matrix, which served as sound basis for evaluation and ranking of the SWM scenarios.

Table 9.2

AHP Matrix

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
C1	1	3.21	2.18	4.83	3.74	4.21	2.72	2.18	2.18	2.18
C2	0.311	1	2.04	3.68	2.14	3.68	2.37	1.72	1.38	1.38
C3	0.459	0.491	1	3.16	2.29	2.04	2.37	1.90	1.93	1.25
C4	0.207	0.272	0.316	1	1	1.25	1	1	1.38	1.55
C5	0.238	0.467	0.437	1	1	1.72	1.55	1.55	1.72	1.25
C6	0.369	0.272	0.491	0.803	0.582	1	1.48	1.25	1.84	1.72
C7	0.459	0.422	0.422	1	0.644	0.678	1	2.37	2.63	2.37
C8	0.459	0.582	0.525	1	0.644	0.803	0.422	1	1.90	1.90
C9	0.459	0.725	0.517	0.725	0.582	0.544	0.381	0.525	1	2.37
C10	0.459	0.725	0.803	0.644	0.803	0.582	0.422	0.525	0422	1

Based on the AHP results, Waste Leakage Reduction criterion had the highest priority weight (0.23). This highlights the respondents' emphasis on reducing waste leaking into open environment, especially in coastal and marine ecosystems like Del

Carmen and General Luna. The ecological vulnerability to plastic pollution of these areas calls for urgent solutions to address plastic leakage. Gomez et al. (2023) support this concern that plastic accumulation across 56 coastal sites in the western Philippines varies with population density, oceanic transport, and habitat type. Single-use plastics dominated urbanized areas, while fishing-related plastics dominated fishing communities, and buoyant materials tend to accumulate on isolated islands, showing combined effects of human activity and ocean currents. These high-abundance plastics pose a "high exposure" risk, potentially causing serious harm to marine organisms and habitats.

Table 9.3

AHP Criteria Weights

Criterion	Weight	Rank
Waste Leakage Reduction	0.230	1
Pollution & Health Risk Reduction	0.148	2
Resource Recovery Contribution	0.125	3
Community Acceptance & Participation	0.0646	4
Operating Expenditure	0.081	5
Public Health & Sanitation Benefits	0.070	6
Cost Recovery/Revenue Potential	0.087	7
Capital Expenditure	0.072	8
Ease of Implementation & Scalability	0.064	9
Governance & Enforcement Compatibility	0.057	10

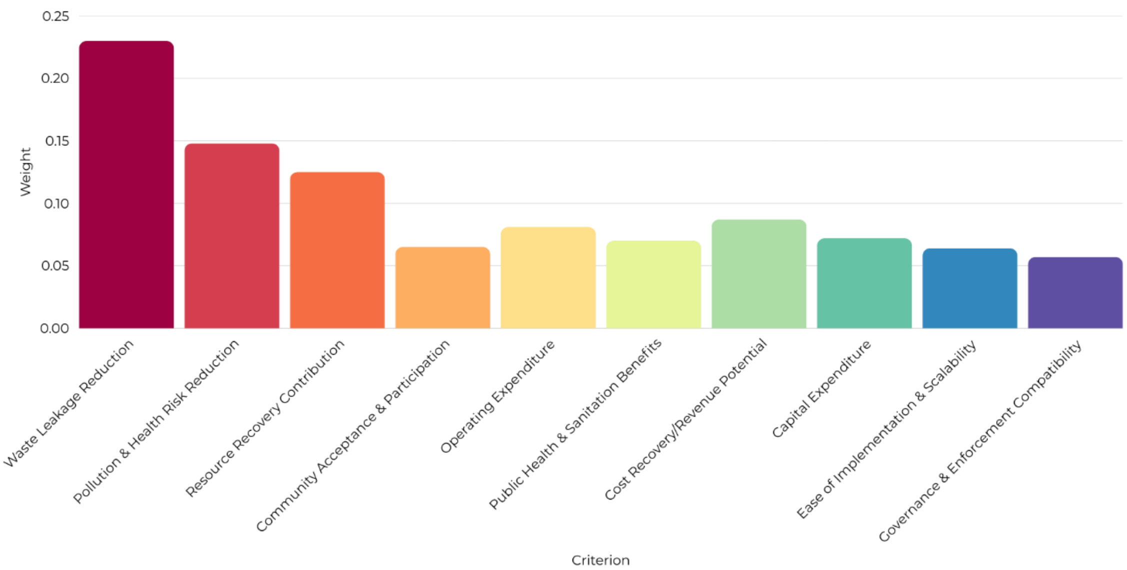
Pollution and Health Risk Reduction ranked second (0.148), emphasizing concern to avoid risks posed by toxic waste, contaminated water sources, and environmental impacts of unscientific waste disposal practices. Unsustainable waste management practices pose a direct risk of illness especially to the waste workers, as well as affecting other community members which could possibly lead to diseases like dengue, diarrhea, and malaria. Improper burning or disposal of plastics, batteries, and industrial waste releases toxic gases and chemicals which are harmful to human health. Solid waste also contributes to climate change, in which methane emissions from landfills and carbon dioxide emissions from waste burning (Alam & Ahmade, 2013; Bhardwaj & Vikram, 2023; IPCC, 2006).

Resource Recovery Contribution ranked third (0.125), indicating that stakeholders also favor interventions which maximize recycling, recovery of materials, and circular economy practices. This corresponds to the current efforts of the LGUs in enhancing MRF operations to minimize residual waste and make profits from recyclables. While there is no circular economy law in the Philippines yet, relevant waste management frameworks support key circular economy concepts implicitly, while recent policy orders promote collaboration and technological innovation. The Extended Producer Responsibility (EPR) Act of 2022 establishes a more concrete step in institutionalizing circular economy principles. The effective translation of this principle into practice, however, depends on its adaptation to local contexts, using the complementary provisions of RA 9003, and responding to the prevailing institutional and enforcement gaps (Bueta, Domingo, & Manejar, 2024).

Community Acceptance and Participation (0.0646), Operating Expenditure (0.081), Public Health and Sanitation Benefits (0.070), and Cost Recovery/Revenue Potential (0.087) were mid-rank criteria based on results. This reflects that while social involvement and economic factors are important, they are minor compared to the need for environmental protection. To make recycling and composting programs more efficient, it is essential to have a practical and viable MRFs, as well as easy access drop-off points (Camarillo & Bellotindos, 2021). Moreover, consistent door-to-door waste collection could further be boosted through awareness campaigns, incentives, penalties and fines and other interventions that can contribute in improving recycling practices and reduce waste generation.

Lowest ranking criteria include Capital Expenditure (0.072), Ease of Implementation and Scalability (0.064), and Governance and Enforcement Compatibility (0.057). This reflects that their significance is less urgent compared to environmental and public health factors. Many governance issues such as lack of stakeholders' participation, lack of coordination, and corruption have resulted to poor and ineffective management (Buenaflor, 2024). This emphasis the vital role of LGUs in implementing SWM effectively.

Figure 9.1. Respondents' Priority Criteria



TOPSIS results and ranking

TOPSIS is used to evaluate the performance of proposed SWM scenarios by applying the criteria weights derived from AHP. Each proposed scenario is measured against its similarity to positive ideal solution which captures both maximum benefits and desirability and its disparity to the negative ideal solution. This results to proximity coefficients (Pi values) that measure how well the relationship holds. A high Pi values indicate that the scenario is closer to the ideal solution, therefore a preferable option.

In addition, the judgments of eleven (11) experts are included in analysis which collectively captured the practical knowledge and realities. The Pi values for each strategy, as determined by the experts, are outlined in Table 9.4.

Table 9.4

Weighted Normalized Decision Matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
S1	0.085	0.064	0.046	0.025	0.032	0.026	0.034	0.031	0.027	0.023
S2	0.107	0.071	0.0.61	0.032	0.039	0.035	0.040	0.031	0.031	0.027
S3	0.107	0.062	0.053	0.026	0.034	0.028	0.035	0.030	0.026	0.023
S4	0.107	0.071	0.062	0.034	0.040	0.035	0.046	0.036	0.032	0.027
S5	0.107	0.064	0.056	0.026	0.034	0.032	0.038	0.033	0.027	0.027

Sanitary Landfill (S1) was revealed as the most preferred option with Pi value of 0.924 based on the evaluation of separation measures (Si^+ and Si^-) and the closeness coefficient (Pi). A very high value for Pi indicates that S1 is both the closest to the ideal solution as well as the farthest from the negative-ideal solution. The major reason could be ascribed to its advantageous scores regarding compatibility with governance, implementable nature, operating expenditure, as well as benefits to public health. When managed well, sanitary landfills are less harmful to the environment as opposed to other means of disposing of solid waste while still able to maintain the well-being of the human population. Although the ultimate goal of converting all open dumps to fully engineered sanitary landfills may not seem feasible immediately, their role in pollution control does not seem less critical. Furthermore, the efficacy of landfill management can be reinforced by strictly adhering to Reduce, Reuse, Recycle (3R) practices (Kumar, 2021).

Table 9.5

Ranks of Scenarios

SWM Scenario	Si^{+}	Si^{-}	Pi (Closeness Coefficient)	Rank
S1: Sanitary Landfill	0.003	0.035	0.924	1
S2: MBT & Recycling	0.008	0.008	0.500	2
S3: Pyrolysis & AD	0.155	0.023	0.130	3
S5: SLF + Energy Recovery	0.159	0.018	0.101	4
S4: MRF & Composting	0.172	0.001	0.005	5

The Mechanical Biological Treatment (MBT) and Recycling option (S2) came second with a Pi value of 0.500, indicating a moderate positioning between the ideal and the negative-ideal solutions. However, although S2 performed extremely well in waste reduction and material recovery, its capital and operating costs were somewhat high. Though recycling is a great opportunity for waste management on small islands, challenges include a lack of appropriate equipment for separating recyclables at the source separation level and for composting at the composting facility level. Additionally, the lack of a weighbridge to enable the measurement of waste volume complicates waste management on small islands (Singh et al., 2023). According to a study conducted by Fei et al. (2018), the highest energy efficiency for the MBT technology is achieved when combined with biogas purification systems of up to 38.5% recovery efficiency and offsets increased pollution avoidance over other competing methods. Its flexibility to changes in the composition of municipal waste further supports its suitability as a complementary technology to source separation activities, although its poor economic suitability means that they need government support.

Pyrolysis and Anaerobic Digestion (S3) came in as the third-best option, with a Pi value of 0.130. Although the environmental impact was moderate, the technology complexity and investment requirements reduced the acceptability among the stakeholders. According to a study by Manegdeg et al. (2022), the capital investment required for a 1-ton per day pyrolysis unit is around PHP 6.40 million, and for the 10-ton per day unit, it is PHP 14.64 million. For the 10-ton per day pyrolysis unit with the Brayton power cycle, it is possible to produce 800 kW electricity and an expected annual profit of PHP 83.63 million in two years for the 10-ton per day pyrolysis unit or PHP 18.06 million in three years for the 3-ton per day pyrolysis unit.

The Sanitary Landfill with Energy Recovery option (S5) follows, with a Pi value of 0.101. While this scenario presents improvements to waste reduction and resource recovery as methane capture and other uses, these requirements make it not as viable. The possibility of energy recovery from landfills may also not be as effective within the small-island scenario, given the levels of waste are insufficient to create the necessary infrastructure investment, as areas like Metro Manila, which accounts for 25% of total waste produced and lacks sufficient infrastructure to process composting, among other processes, related to waste disposal (Jao et al., 2024).

The lowest ranked scenario is MRF and Composting (S4), with a Pi of 0.005.

Although S4 has advantages in the environmental aspect, stakeholders found it to be inadequate as a standalone solution at municipal-level due to limitations in scalability.

This scenario performed poorly in criteria such as revenue potential and public health benefits. Major hurdles in effective implementation of SWM programs include limited coverage and functionality of MRFs, low public awareness, and constrained spaces, especially in urban areas (Andayal, 2025).

Though waste diversion and resource recovery has its significance, Sanitary Landfill (S1) was the top choice for waste disposal options. This can be attributed to RA 9003, which mandates the establishment of controlled and compliant disposal facilities while also emphasizing effective governance and enforcement mechanisms. Even in developing communities with moderate waste generation, SLFs are still regarded as the most feasible and viable “end-of-pipe” solution.

National trends also support this preference. According to the Department of the Interior and Local Government (DILG), there are 1,053 sanitary landfills in operation around the country, serving 63.4 million cubic meters in total capacity. While this already attests to basic compliance with RA 9003, the DILG urges LGUs to operate landfills with waste diversion efforts to lower tipping fees and create better environmental results in their pursuit of building cleaner and more climate-resilient communities (Chavez, 2025). This guidance emphasizes landfills as part of an integrated waste management approach and not the solution itself.

As suggested by Jaramillo (2003), sanitary landfills provide a comprehensive waste disposal solution, which handles variable municipal waste efficiently in relatively low-cost, capital, operating, as well as maintenance expenditures. Yet, a number of factors, like rapid urbanization, unavailability of land, lack of political will, as well as budgetary allocations, might affect landfill performance, which in turn increases the potential of unmanaged landfill sites to transform to open dumps, threatening environmental protection goals.

The respondents also mentioned essential local conditions that could affect implementing SWM in both municipalities. The two localities are geographically located within the Siargao Islands Protected Landscape and Seascape (SIPLAS) where there are restrictive environmental policies existing and some land resources are allocated for conservation and protection. This position makes it unfavorable to establish landfills and other waste management infrastructure. The island characteristics also contribute to complexity of waste transportation which require flexible and locally adaptable solutions. Institutional and social factors should also be considered such as lengthy approval processes, reliance on open dump sites and variable compliance levels and views about waste segregation and recycling. Furthermore, the low demand for recyclables and fluctuating levels of waste due to tourism are few factors that could also affect the usefulness of recovery and recycling efforts.

X. CONCLUSION

Increasing population growth, rising industries and living standards undoubtedly impacted management of MSW. Despite being a pressing issue, waste management has received little attention in terms of operations management field, even though advanced analytical tools are necessary in designing effective, context-specific solutions (Gaur, 2022).

The findings of this study are significant indications of stakeholders' preference on approaches that consider environmental sustainability and public health protection as main goals. Given that waste leakage reduction, pollution and health risk reduction, and resource recovery contribution emerged as highest priorities, among the identified criteria. The stakeholders stressed the ecological importance of Del Carmen and General Luna and its natural resources to curb the impacts of plastic pollution and waste leakage on coastal and upland ecosystems.

Sanitary landfill (S1) is the most feasible scenario for waste disposal based on TOPSIS because it is parallel to current capacities of LGUs, operational and investment costs, relative ease of implementation, and public health benefits. On the other hand, MBT and Recycling (S2) and Pyrolysis and AD (S3) are technologically advanced with crucial environmental benefits. However, their applicability is impeded by financial, technical, and logistical limitations which are evident in island municipalities. The results also show that scalability and revenue factors could affect the effectiveness of operating MRFs and composting (S4) which was proved to be inadequate as a standalone solution at municipal scale.

In addition to operating and managing sanitary landfills, initiatives such as waste reduction, recycling, and circular economy approach are crucial to achieving long-term sustainability. Strategies including enhancing MRF operations, strict enforcement of existing SWM-related policies, regulating SUPs and other materials and leveraging EPR should be implemented to reduce amount of residual waste that ends up in landfills and improve resource efficiency. Although there is no one-size-fits-all solution to address challenges in SWM, strategies that strike the balance environmental priorities with social, institutional, and economic situations are important, given the unique circumstances of the municipalities.

This study highlights the need of addressing SWM issues holistically. The importance of the environment which provide ecosystem goods and services, must be balanced with the interests of various stakeholders in a well-designed system. SLFs must adhere to operational standards, sustained investments, and combined waste diversion initiatives in order to be effective in the long run. This study offers evidence-based insights that LGUs, policymakers, and development partners should consider when designing and putting into place resilient and sustainable waste management systems.

XI. RECOMMENDATIONS

The following are recommendations to improve SWM practices in the selected municipalities of Surigao Del Norte based on the results of the study:

1. In developing and implementing of SWM strategies, LGUs must prioritize environmental sustainability. The decision-making process should consider crucial factors such as minimizing waste leakage, reducing pollution and health risks, and maximizing resource recovery.
2. Development of sanitary landfills require careful planning and regulatory compliance, particularly since Siargao Island is a protected area. Establishing clustered or centralized SLF which can serve multiple municipalities on the island is recommended. This help ensures that land usage is maximized, environmental risks are reduced, and effective operational measures are formed.
3. Waste reduction and resource recovery initiatives such as improving MRF operations, encouraging at-source segregation, supporting backyard composting and other practices that can drastically reduce residual waste while simultaneously promoting community participation and environmental stewardship should be combined with operating sanitary landfills.
4. To address gaps in enforcement, LGUs should communicate the existing policies clearly by educating the communities and utilizing social media, infographics, videos, and public discussions to enhance their awareness. Additionally, the efficacy of SWM techniques can also be improved by

creating new policy measures. LGUs can also utilize EPR to offset waste recovery expenses and encourage partnerships with manufacturers.

5. The LGUs should participate in activities that advance their waste management expertise. They can also allocate funding for the proper tools and equipment and provide waste workers with capacity-building activities.
6. LGUs should update their existing SWM plans and include monitoring and evaluation (M&E) so they can track their progress and re-direct strategies as needed. M&E can aid in decision making by providing evidence-based data. These data can also be used as foundation for developing policies and improve efficiency.
7. Updating and developing protected area management plans, integrated coastal resource management plans, and other local development plans should include solid waste management to ensure holistic approach. Additionally, future studies can investigate the unique requirements related to SWM in protected areas and island municipalities.
8. Initiatives for waste reduction and resource recovery should also involve the private sector. They can produce products and packaging using fewer resources, improve recyclability of products, and reduce the use of plastics. Manufacturing and retail businesses should collaborate with LGUs, local waste cooperatives, and other recyclers to develop market access for recycled and repurposed products, investing in infrastructure for recycling, and strengthen local collection, recycling, and recovery programs.
9. Although AHP and TOPSIS provide quantitative and systematic approaches for rating SWM options, they might not adequately account for the qualitative assessments and uncertainties inherent in practical decision-making. To

better address ambiguity and non-quantifiable issues, future research could use participatory methodologies, stakeholder deliberation tools, or fuzzy logic. The findings of this study could also be strengthened by performing supplementary analyses like LCA and CBA.

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APPENDICES

APPENDIX A

RESEARCH QUESTIONNAIRE

Evaluating Solid Waste Management Strategies in the Municipalities of Del Carmen and General Luna, Surigao del Norte using Multi-Criteria Decision Analysis (MCDA)

Research Questionnaire

This questionnaire aims to gather expert assessments to support the Multi-Criteria Decision Analysis (MCDA) using the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Your insights are highly valuable and will play a crucial role in ensuring the rigor and relevance of this study. We kindly ask that you answer the following questions thoughtfully and honestly. Thank you for your time and participation.

Instructions for Experts:

Part A: Rate the *importance (weights)* of the criteria used for decision-making in Solid Waste Management (SWM)

Part B: Evaluate the *performance* of each proposed SWM scenario against each criterion.

Consent Statement

Thank you for taking part in this study. Before proceeding, please read the following information carefully.

Your participation in this survey is voluntary, and you may choose to withdraw at any time without penalty. All responses will be kept strictly confidential and will be used solely for academic and research purposes. No personal identifiers will be disclosed in any reports or publications arising from this study.

By proceeding to answer the questionnaire, you are giving your informed consent to participate in this research.

☐ I have read and understood the information above and voluntarily agree to participate in this survey.

Respondent Information

This section gathers background information to help contextualize expert responses. All information provided will be treated with strict confidentiality and used solely for research purposes.

Full Name: ______________________________________ Designation: ______________________________

Name of Organization/Institution: ____

Type of Organization	Years of Professional Experience in SWM
☐ National Government Agency	☐ Less than 1 year
☐ Local Government Unit	☐ 1-3 years
☐ Non-Governmental Organization	☐ 4-6 years

☐ Academic/Research Institution

☐ Private Sector

☐ 7-10 years

☐ More than 10 years

Part A. AHP Pairwise Comparison of Criteria

For each pair below, please indicate how important the first criterion is compared with the second in determining the suitability of an SWM strategy for the municipalities.

Criteria Reference Table

Code	Evaluation Criteria	Description
Environmental Sustainability		
C1	Waste Leakage Reduction	Ability to prevent plastic and other waste from leaking into rivers, seas, and open environment
C2	Pollution and Health Risk Reduction	Extent to which the strategy minimizes risks from open dumping, burning, or emissions
C3	Resource Recovery Contribution	Potential to promote recycling, composting, or energy recovery
Economic Viability		
C4	Capital Expenditure	Total investment required for establishing and operating the MSW management system
C5	Operating Expenditure	Overall expenses for managing the MSW system, including labor, equipment, and maintenance costs.
C6	Cost Recovery/Revenue Potential	Ability to generate income through the sale of recyclable materials or energy recovery
Social Acceptability		
C7	Community Acceptance & Participation	Likelihood of communities supporting and participating in the strategy
C8	Public Health & Sanitation Benefits	Potential of the strategy to improve local sanitation, reduce waste-related diseases, and safer waste handling
Technical & Institutional Feasibility		
C9	Ease of Implementation & Scalability	Degree to which the strategy can be rolled out with available skills, land, and infrastructure and scaled up across municipalities
C10	Governance & Enforcement Compatibility	Alignment with RA 9003 requirements and LGU institutional capacity for monitoring & enforcement

Rating Scale

Acronym	Scale	Description
EO	Equally Importance	Both criteria contribute equally to the objective

MI	Moderate Importance	Experience and judgement slightly favor one criterion over another
SI	Strong Importance	Experience and judgement strongly favor one criterion over another
VSI	Very Strong Importance	Experience and judgement very strongly favor one criterion over another
EI	Extreme Importance	First criterion is extremely more important; its dominance is unquestionable

Criteria	**Equally Importance (EO)**	**Moderate Importance (MI)**	**Strong Importance (SI)**	**Very Strong Importance (VSI)**	**Extreme Importance (EI)**
Waste Leakage Reduction & Pollution and Health Risk Reduction					
Waste Leakage Reduction & Resource Recovery Contribution					
Waste Leakage Reduction & Capital Expenditure					
Waste Leakage Reduction & Operating Expenditure					
Waste Leakage Reduction & Cost Recovery/Revenue Potential					
Waste Leakage Reduction & Community Acceptance & Participation					
Waste Leakage Reduction & Public Health & Sanitation Benefits					
Waste Leakage Reduction & Ease of Implementation & Scalability					
Waste Leakage Reduction & Governance & Enforcement Compatibility					

Pollution and Health Risk Reduction & Resource Recovery Contribution					
Pollution and Health Risk Reduction & Capital Expenditure					
Pollution and Health Risk Reduction & Operating Expenditure					
Pollution and Health Risk Reduction & Cost Recovery/Revenue Potential					
Pollution and Health Risk Reduction & Community Acceptance & Participation					
Pollution and Health Risk Reduction & Public Health & Sanitation Benefits					
Pollution and Health Risk Reduction & Ease of Implementation & Scalability					
Pollution and Health Risk Reduction & Governance & Enforcement Compatibility					
Resource Recovery Contribution & Capital Expenditure					
Resource Recovery Contribution & Operating Expenditure					

Resource Recovery Contribution & Cost Recovery/Revenue Potential					
Resource Recovery Contribution & Community Acceptance & Participation					
Resource Recovery Contribution & Public Health & Sanitation Benefits					
Resource Recovery Contribution & Ease of Implementation & Scalability					
Resource Recovery Contribution & Governance & Enforcement Compatibility					
Capital Expenditure & Operating Expenditure					
Capital Expenditure & Cost Recovery/Revenue Potential					
Capital Expenditure & Community Acceptance & Participation					
Capital Expenditure & Public Health & Sanitation Benefits					
Capital Expenditure & Ease of Implementation & Scalability					
Capital Expenditure & Governance & Enforcement Compatibility					

Operating Expenditure & Cost Recovery/Revenue Potential					
Operating Expenditure & Community Acceptance & Participation					
Operating Expenditure & Public Health & Sanitation Benefits					
Operating Expenditure & Ease of Implementation & Scalability					
Operating Expenditure & Governance & Enforcement Compatibility					
Cost Recovery/Revenue Potential & Community Acceptance & Participation					
Cost Recovery/Revenue Potential & Public Health & Sanitation Benefits					
Cost Recovery/Revenue Potential & Ease of Implementation & Scalability					
Cost Recovery/Revenue Potential & Governance & Enforcement Compatibility					
Community Acceptance & Participation & Public Health & Sanitation Benefits					

Community Acceptance & Participation & Ease of Implementation & Scalability					
Community Acceptance & Participation & Governance & Enforcement Compatibility					
Public Health & Sanitation Benefits & Ease of Implementation & Scalability					
Public Health & Sanitation Benefits & Governance & Enforcement Compatibility					
Ease of Implementation & Scalability & Governance & Enforcement Compatibility					

Part B. Scenarios Evaluation using TOPSIS

This section evaluates how well each proposed SWM scenarios performs against each of the ten criteria.

Rating Scale

Score	**Qualitative Rating**	**Description**
1	Very Poor	The scenario performs very poorly on this criterion
2	Poor	The scenario performs below average or has limited effect
3	Fair	The scenario has a moderate contribution or mixed performance
4	Good	The scenario performs well and contributes positively
5	Excellent	The scenario performs very well and fully satisfies the criterion

SWM Scenarios

Scenario		**Description**
1	Sanitary Landfill	All collected waste goes to landfill
2	MBT and Recycling	Recyclable materials such as metal, glass, plastic, and paper are segregated for recycling. Meanwhile, residual paper and plastic contaminated with other waste are utilized as RDF

3	Pyrolysis and Anaerobic Digestion	Given that the LGU through partnership with JCA 1221 Holdings, Inc. is currently setting up a pyrolysis facility which is expected to operate by October 2025, this scenario combines pyrolysis with anaerobic digestion
4	MRF and Composting	Given that both municipalities have underutilized Material Recovery Facilities (MRFs), this scenario proposes the establishment of composting facilities alongside the strengthening of MRF operations
5	SLF and Energy Recovery	All collected waste goes to landfill but it includes energy recovery from landfill gas, primarily methane

Scenario 1: Sanitary Landfill					
Evaluation Criteria	**1**	**2**	**3**	**4**	**5**
C1. Waste Leakage Reduction	☐	☐	☐	☐	☐
C2. Pollution and Health Risk Reduction	☐	☐	☐	☐	☐
C3. Resource Recovery Contribution	☐	☐	☐	☐	☐
C4. Capital Expenditure	☐	☐	☐	☐	☐
C5. Operating Expenditure	☐	☐	☐	☐	☐
C6. Cost Recovery/Revenue Potential	☐	☐	☐	☐	☐
C7. Community Acceptance & Participation	☐	☐	☐	☐	☐
C8. Public Health & Sanitation Benefits	☐	☐	☐	☐	☐
C9. Ease of Implementation & Scalability	☐	☐	☐	☐	☐
C10. Governance & Enforcement Compatibility	☐	☐	☐	☐	☐

Scenario 2: MBT and Recycling					
Evaluation Criteria	**1**	**2**	**3**	**4**	**5**
C1. Waste Leakage Reduction	☐	☐	☐	☐	☐
C2. Pollution and Health Risk Reduction	☐	☐	☐	☐	☐
C3. Resource Recovery Contribution	☐	☐	☐	☐	☐
C4. Capital Expenditure	☐	☐	☐	☐	☐
C5. Operating Expenditure	☐	☐	☐	☐	☐
C6. Cost Recovery/Revenue Potential	☐	☐	☐	☐	☐
C7. Community Acceptance & Participation	☐	☐	☐	☐	☐
C8. Public Health & Sanitation Benefits	☐	☐	☐	☐	☐
C9. Ease of Implementation & Scalability	☐	☐	☐	☐	☐
C10. Governance & Enforcement Compatibility	☐	☐	☐	☐	☐

Scenario 3: Pyrolysis and Anaerobic Digestion					
Evaluation Criteria	**1**	**2**	**3**	**4**	**5**
C1. Waste Leakage Reduction	☐	☐	☐	☐	☐
C2. Pollution and Health Risk Reduction	☐	☐	☐	☐	☐

C3. Resource Recovery Contribution	☐	☐	☐	☐	☐
C4. Capital Expenditure	☐	☐	☐	☐	☐
C5. Operating Expenditure	☐	☐	☐	☐	☐
C6. Cost Recovery/Revenue Potential	☐	☐	☐	☐	☐
C7. Community Acceptance & Participation	☐	☐	☐	☐	☐
C8. Public Health & Sanitation Benefits	☐	☐	☐	☐	☐
C9. Ease of Implementation & Scalability	☐	☐	☐	☐	☐
C10. Governance & Enforcement Compatibility	☐	☐	☐	☐	☐

Scenario 4: MRF and Composting					
Evaluation Criteria	**1**	**2**	**3**	**4**	**5**
C1. Waste Leakage Reduction	☐	☐	☐	☐	☐
C2. Pollution and Health Risk Reduction	☐	☐	☐	☐	☐
C3. Resource Recovery Contribution	☐	☐	☐	☐	☐
C4. Capital Expenditure	☐	☐	☐	☐	☐
C5. Operating Expenditure	☐	☐	☐	☐	☐
C6. Cost Recovery/Revenue Potential	☐	☐	☐	☐	☐
C7. Community Acceptance & Participation	☐	☐	☐	☐	☐
C8. Public Health & Sanitation Benefits	☐	☐	☐	☐	☐
C9. Ease of Implementation & Scalability	☐	☐	☐	☐	☐
C10. Governance & Enforcement Compatibility	☐	☐	☐	☐	☐

Scenario 5: SLF and Energy Recovery					
Evaluation Criteria	**1**	**2**	**3**	**4**	**5**
C1. Waste Leakage Reduction	☐	☐	☐	☐	☐
C2. Pollution and Health Risk Reduction	☐	☐	☐	☐	☐
C3. Resource Recovery Contribution	☐	☐	☐	☐	☐
C4. Capital Expenditure	☐	☐	☐	☐	☐

C5. Operating Expenditure	☐	☐	☐	☐	☐
C6. Cost Recovery/Revenue Potential	☐	☐	☐	☐	☐
C7. Community Acceptance & Participation	☐	☐	☐	☐	☐
C8. Public Health & Sanitation Benefits	☐	☐	☐	☐	☐
C9. Ease of Implementation & Scalability	☐	☐	☐	☐	☐
C10. Governance & Enforcement Compatibility	☐	☐	☐	☐	☐

Additional Comments

Are there local factors or conditions in Del Carmen or General Luna that may influence the performance of these strategies?

Do you have any recommendations or insights for improving waste management implementation in these municipalities?

APPENDIX B

LETTER TO RESPONDENTS

UNIVERSITY OF THE PHILIPPINES
OPEN UNIVERSITY

06 November 2025

ENGR. DENNIS O. CELESTIAL, MM
Regional Director
DENR Environmental Management Bureau Region XIII

Dear Director,

Good day! I am Gelli Jamaica Felices, a graduate student under the Master of Environment and Natural Resources Management program at the University of the Philippines Open University. I am currently conducting a study entitled "Evaluating Solid Waste Management Strategies in the Municipalities of Del Carmen and General Luna, Surigao del Norte using Multi-Criteria Decision Analysis (MCDA)."

The primary objective of this study is to evaluate the solid waste management (SWM) strategies of the two municipalities using the Multi-Criteria Decision Analysis approach. Specifically, it aims to:

- Assess the performance of proposed SWM strategies based on environmental sustainability, economic viability, social acceptability, and technical and institutional feasibility;
- Determine expert preferences and priorities regarding SWM strategies through the Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods; and
- Develop evidence-based recommendations for local governments and stakeholders on the most viable and sustainable SWM strategies.

The study seeks to contribute to addressing SWM challenges by providing local government units (LGUs) with a structured and evidence-based framework for evaluating and prioritizing solid waste management strategies, thereby supporting sound policymaking and planning in coastal municipalities.

In line with this, I would like to invite you to participate in the survey. Your expertise and professional insights in solid waste management, environmental governance, or related fields are essential to ensure the accuracy, credibility, and practical relevance of the study's findings. Your participation will help validate the proposed criteria, assess the feasibility of different SWM strategies, and ensure that the results are reflective of real-world contexts and decision-making considerations.

You use this link to access the survey questionnaire: https://forms.gle/bjiTh1Lhw6ZW9iwMA

Attached is a reference document providing an overview of the current SWM systems in the study sites, along with further information on the proposed scenarios for evaluation.

I would deeply appreciate it if you could complete the survey between November 7-10, 2025.

Should you have any questions or concerns, please feel free to contact me at gfelices@up.edu.ph or +63915 308 1690.

Thank you very much for your time and kind consideration. I look forward to your positive response.

Sincerely,

Gelli Jamaica Felices
Graduate Student
Master of Environment and Natural Resources Management
Faculty of Management and Development Studies
University of the Philippines – Open University

APPENDIX C

AHP ANALYSIS

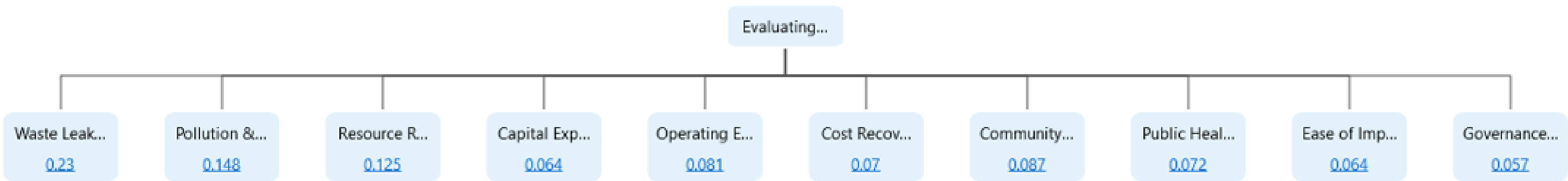
Analytic Hierarchy Process - Evaluating SWM Strategies in the Municipalities of Del Carmen and General Luna using MCDA

AIJ (Aggregation of individual judgements)

Weighted geometric mean

Members	Relative Priority
Expert 1	0.2
Expert 2	0.2
Expert 3	0.2
Expert 4	0.2
Expert 5	0.2

Criteria



Priority Trade-offs

	Waste Leakage Reduction	Pollution & Health Risk Reduction	Resource Recovery Contribution	Capital Expenditure	Operating Expenditure	Cost Recovery/Revenue Potential	Community Acceptance & Participation	Public Health & Sanitation Benefits	Ease of Implementation & Scalability	Governance & Enforcement Compatibility	Priorities
Waste Leakage Reduction	1	3.21409585	2.177906424	4.828651495	3.743324423	4.210289595	2.713085417	2.177906424	2.177906424	2.177906424	0.22987838
Pollution & Health Risk Reduction	0.311129489	1	2.036168005	3.680109614	2.141127368	3.680109614	2.37144061	1.718771928	1.379729661	1.379729661	0.14793035
Resource Recovery Contribution	0.45915655	0.49111861	1	3.159818306	2.290172049	2.036168005	2.37144061	1.903653939	1.933182045	1.24573094	0.12546268
Capital Expenditure	0.207097158	0.271731037	0.316473893	1	1	1.24573094	1	1	1.379729661	1.551845574	0.06445219
Operating Expenditure	0.267142221	0.467043677	0.436648417	1	1	1.718771928	1.551845574	1.551845574	1.718771928	1.24573094	0.08073561
Cost Recovery/Revenue Potential	0.237513353	0.271731037	0.49111861	0.802741562	0.581810759	1	1.475773162	1.24573094	1.838416287	1.718771928	0.07047184
Community Acceptance & Participation	0.368584046	0.421684606	0.421684606	1	0.644394015	0.677610913	1	2.37144061	2.626527804	2.37144061	0.08744612
Public Health & Sanitation Benefits	0.45915655	0.581810759	0.525305561	1	0.644394015	0.802741562	0.421684606	1	1.903653939	1.903653939	0.0723232
Ease of Implementation & Scalability	0.45915655	0.724779664	0.517281858	0.724779664	0.581810759	0.543946443	0.380730788	0.525305561	1	2.37144061	0.06395963
Governance & Enforcement Compatibility	0.45915655	0.724779664	0.802741562	0.644394015	0.802741562	0.581810759	0.421684606	0.525305561	0.421684606	1	0.05733999

* Consistency Ratio calculated as 0.063

Pairwise Comparisons of Options for Criteria

- Multi-Criteria Utility Function = 0.23 * [Waste Leakage Reduction] + 0.15 * [Pollution & Health Risk Reduction] + 0.13 * [Resource Recovery Contribution] + 0.06 * [Capital Expenditure] + 0.08 * [Operating Expenditure] + 0.07 * [Cost Recovery/Revenue Potential] + 0.09 * [Community Acceptance & Participation] + 0.07 * [Public Health & Sanitation Benefits] + 0.06 * [Ease of Implementation & Scalability] + 0.06 * [Governance & Enforcement

Metrics

APPENDIX D

TOPSIS ANALYSIS

Solving MCDM problem using TOPSIS Method

S1: Sanitary Landfill

	Barcelo	Acosta	Ampatin	Rivera	Prisco	Barquilla	Requejo	Bantilan	Mondejar	Biyo	Osorio	Average
weightage	0.23	0.148	0.125	0.064	0.081	0.07	0.087	0.072	0.064	0.057		
Waste Leakage Reduction	1	1	5	2	3	4	3	5	5	4	1	3.090909
Pollution and health risk reduction	2	3	4	2	2	4	5	5	4	4	2	3.363636
resource recovery contribution	2	2	3	3	2	4	3	3	5	4	3	3.090909
Capital expenditure	2	1	5	2	2	3	2	2	4	4	3	2.727273
Operating expediture	2	2	5	2	3	3	2	3	4	3	3	2.909091
Cost Recovery/Revenue potential	2	1	2	1	2	3	4	4	5	3	3	2.727273
Community acceptance and Participation	2	2	3	1	4	5	3	3	4	3	2	2.909091
Public health and Sanitation benefits	2	3	4	2	3	4	4	5	5	4	1	3.363636
Ease of implementation & Scalability	2	2	4	2	2	5	3	2	4	4	3	3
Governance & Enforcement Compatibility	2	3	5	2	3	3	4	3	4	4	2	3.181818

	Barcelo	Acosta	Ampatin	Rivera	Prisco	Barquilla	Requejo	Bantilan	Mondejar	Biyo	Osorio
Waste Leakage Reduction	0.164399	0.147442	0.383482	0.320256	0.353553	0.326599	0.27735	0.430331	0.357143	0.339276	0.130189
Pollution and health risk reduction	0.328798	0.442326	0.306786	0.320256	0.235702	0.326599	0.46225	0.430331	0.285714	0.339276	0.260378
resource recovery contribution	0.328798	0.294884	0.230089	0.480384	0.235702	0.326599	0.27735	0.258199	0.357143	0.339276	0.390567
Capital expenditure	0.328798	0.147442	0.383482	0.320256	0.235702	0.244949	0.1849	0.172133	0.285714	0.339276	0.390567
Operating expediture	0.328798	0.294884	0.383482	0.320256	0.353553	0.244949	0.1849	0.258199	0.285714	0.254457	0.390567
Cost Recovery/Revenue potential	0.328798	0.147442	0.153393	0.160128	0.235702	0.244949	0.3698	0.344265	0.357143	0.254457	0.390567
Community acceptance and Participation	0.328798	0.294884	0.230089	0.160128	0.471405	0.408248	0.27735	0.258199	0.285714	0.254457	0.260378
Public health and Sanitation benefits	0.328798	0.442326	0.306786	0.320256	0.353553	0.326599	0.3698	0.430331	0.357143	0.339276	0.130189
Ease of implementation & Scalability	0.328798	0.294884	0.306786	0.320256	0.235702	0.408248	0.27735	0.172133	0.285714	0.339276	0.390567
Governance & Enforcement Compatibility	0.328798	0.442326	0.383482	0.320256	0.353553	0.244949	0.3698	0.258199	0.285714	0.339276	0.260378

	Barcelo	Acosta	Ampatin	Rivera	Prisco	Barquilla	Requejo	Bantilan	Mondejar	Biyo	Osorio	Si+	Si-	Pi	Rank
Waste Leakage Reduction	0.037812	0.033912	0.088201	0.073659	0.081317	0.075118	0.063791	0.098976	0.082143	0.078033	0.029943	0.194457	0.03368	0.14765	10
Pollution and health risk reduction	0.048662	0.065464	0.045404	0.047398	0.034884	0.048337	0.068413	0.063689	0.042286	0.050213	0.038536	0.129117	0.09488	0.42358	9
resource recovery contribution	0.0411	0.03686	0.028761	0.060048	0.029463	0.040825	0.034669	0.032275	0.044643	0.042409	0.048821	0.093963	0.12931	0.57916	8
Capital expenditure	0.021043	0.009436	0.024543	0.020496	0.015085	0.015677	0.011834	0.011016	0.018286	0.021714	0.024996	0.023417	0.19206	0.89132	1
Operating expediture	0.026633	0.023886	0.031062	0.025941	0.028638	0.019841	0.014977	0.020914	0.023143	0.020611	0.031636	0.042163	0.17121	0.8024	5
Cost Recovery/Revenue potential	0.023016	0.010321	0.010738	0.011209	0.016499	0.017146	0.025886	0.024099	0.025	0.017812	0.02734	0.028258	0.18833	0.86953	4
Community acceptance and Participation	0.028605	0.025655	0.020018	0.013931	0.041012	0.035518	0.024129	0.022463	0.024857	0.022138	0.022653	0.046276	0.16618	0.78219	7
Public health and Sanitation benefits	0.023673	0.031847	0.022089	0.023058	0.025456	0.023515	0.026626	0.030984	0.025714	0.024428	0.009374	0.041771	0.164	0.797	6
Ease of implementation & Scalability	0.021043	0.018873	0.019634	0.020496	0.015085	0.026128	0.01775	0.011016	0.018286	0.021714	0.024996	0.026572	0.18655	0.87532	3
Governance & Enforcement Compatibility	0.018741	0.025213	0.021859	0.018255	0.020153	0.013962	0.021079	0.014717	0.016286	0.019339	0.014842	0.024068	0.18598	0.88542	2

V+	0.018741	0.009436	0.010738	0.011209	0.015085	0.013962	0.011834	0.011016	0.016286	0.017812	0.009374
V-	0.048662	0.065464	0.088201	0.073659	0.081317	0.075118	0.068413	0.098976	0.082143	0.078033	0.048821

Step-1 Normalised Matrix

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}}$$

Step-2 Calculate weighted Normalised Matrix

$$V_{ij} = \bar{X}_{ij} \times W_j$$

Step-3 best and ideal worst value

Step-4 Calculate the Euclidean distance from the ideal best

$$S_i^+ = \left[\sum_{j=1}^{m} (V_{ij} - V_j^+)^2\right]^{0.5}$$

Step-4 ı distance from the ideal worst

$$S_i^- = \left[\sum_{j=1}^{m} (V_{ij} - V_j^-)^2\right]^{0.5}$$

Step-6 'erformance Score

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

Solving MCDM problem using TOPSIS Method

S2: MBT & Recycling

weightage	0.23	0.148	0.125	0.064	0.081	0.07	0.087	0.072	0.064	0.057		
	Barcelo	**Acosta**	**Ampatin**	**Rivera**	**Prisco**	**Barquilla**	**Requejo**	**Bantilan**	**Mondejar**	**Biyo**	**Osorio**	**Average**
Waste Leakage Reduction	3	5	4	2	4	4	4	5	4	4	4	3.909091
Pollution and health risk reduction	3	3	5	2	4	4	4	5	4	3	4	3.727273
resource recovery contribution	4	5	4	2	4	5	4	5	5	3	4	4.090909
Capital expenditure	3	4	4	2	4	4	2	4	5	3	3	3.454545
Operating expediture	3	5	4	2	4	5	2	3	5	4	3	3.636364
Cost Recovery/Revenue potential	3	4	3	2	5	5	4	2	5	5	3	3.727273
Community acceptance and Participation	3	3	3	2	3	5	4	3	4	4	3	3.363636
Public health and Sanitation benefits	3	2	4	1	4	4	4	4	4	4	3	3.363636
Ease of implementation & Scalability	3	4	4	2	2	4	3	4	4	4	3	3.363636
Governance & Enforcement Compatibility	3	3	5	2	2	5	5	5	4	3	3	3.636364

Step-1 Normalised Matrix

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}}$$

Step-2 Calculate weighted Normalised Matrix

$$V_{ij} = \bar{X}_{ij} \times W_j$$

Step-3 best and ideal worst value

Step-4 Calculate the Euclidean distance from the ideal best

$$S_i^+ = \left[\sum_{j=1}^{m} (V_{ij} - V_j^+)^2 \right]^{0.5}$$

Step-4 ı distance from the ideal worst

$$S_i^- = \left[\sum_{j=1}^{m} (V_{ij} - V_j^-)^2 \right]^{0.5}$$

Step-6 'erformance Score

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

	Barcelo	Acosta	Ampatin	Rivera	Prisco	Barquilla	Requejo	Bantilan	Mondejar	Biyo	Osorio
Waste Leakage Reduction	0.304604	0.402911	0.312348	0.328798	0.340503	0.279372	0.340503	0.383482	0.285714	0.336861	0.379663
Pollution and health risk reduction	0.304604	0.241747	0.390434	0.328798	0.340503	0.279372	0.340503	0.383482	0.285714	0.252646	0.379663
resource recovery contribution	0.406138	0.402911	0.312348	0.328798	0.340503	0.349215	0.340503	0.383482	0.357143	0.252646	0.379663
Capital expenditure	0.304604	0.322329	0.312348	0.328798	0.340503	0.279372	0.170251	0.306786	0.357143	0.252646	0.284747
Operating expediture	0.304604	0.402911	0.312348	0.328798	0.340503	0.349215	0.170251	0.230089	0.357143	0.336861	0.284747
Cost Recovery/Revenue potential	0.304604	0.322329	0.234261	0.328798	0.425628	0.349215	0.340503	0.153393	0.357143	0.421076	0.284747
Community acceptance and Participation	0.304604	0.241747	0.234261	0.328798	0.255377	0.349215	0.340503	0.230089	0.285714	0.336861	0.284747
Public health and Sanitation benefits	0.304604	0.161165	0.312348	0.164399	0.340503	0.279372	0.340503	0.306786	0.285714	0.336861	0.284747
Ease of implementation & Scalability	0.304604	0.322329	0.312348	0.328798	0.170251	0.279372	0.255377	0.306786	0.285714	0.336861	0.284747
Governance & Enforcement Compatibility	0.304604	0.241747	0.390434	0.328798	0.170251	0.349215	0.425628	0.383482	0.285714	0.252646	0.284747

	Barcelo	Acosta	Ampatin	Rivera	Prisco	Barquilla	Requejo	Bantilan	Mondejar	Biyo	Osorio	Si+	Si-	Pi	Rank
Waste Leakage Reduction	0.070059	0.09267	0.07184	0.075624	0.078316	0.064256	0.078316	0.088201	0.065714	0.077478	0.087323	0.213005	0	0	10
Pollution and health risk reduction	0.045081	0.035779	0.057784	0.048662	0.050394	0.041347	0.050394	0.056755	0.042286	0.037392	0.05619	0.114487	0.10007	0.4664	9
resource recovery contribution	0.050767	0.050364	0.039043	0.0411	0.042563	0.043652	0.042563	0.047935	0.044643	0.031581	0.047458	0.100956	0.10762	0.51598	8
Capital expenditure	0.019495	0.020629	0.01999	0.021043	0.021792	0.01788	0.010896	0.019634	0.022857	0.016169	0.018224	0.021429	0.18331	0.89533	3
Operating expediture	0.024673	0.032636	0.0253	0.026633	0.027581	0.028286	0.01379	0.018637	0.028929	0.027286	0.023065	0.040806	0.16423	0.80098	7
Cost Recovery/Revenue potential	0.021322	0.022563	0.016398	0.023016	0.029794	0.024445	0.023835	0.010738	0.025	0.029475	0.019932	0.034522	0.17321	0.83381	5
Community acceptance and Participation	0.026501	0.021032	0.020381	0.028605	0.022218	0.030382	0.029624	0.020018	0.024857	0.029307	0.024773	0.039847	0.1649	0.80538	6
Public health and Sanitation benefits	0.021931	0.011604	0.022489	0.011837	0.024516	0.020115	0.024516	0.022089	0.020571	0.024254	0.020502	0.027026	0.17992	0.8694	4
Ease of implementation & Scalability	0.019495	0.020629	0.01999	0.021043	0.010896	0.01788	0.016344	0.019634	0.018286	0.021559	0.018224	0.018792	0.18447	0.90755	1
Governance & Enforcement Compatibility	0.017362	0.01378	0.022255	0.018741	0.009704	0.019905	0.024261	0.021859	0.016286	0.014401	0.016231	0.019827	0.18739	0.90432	2

V+	0.017362	0.011604	0.016398	0.011837	0.009704	0.01788	0.010896	0.010738	0.016286	0.014401	0.016231
V-	0.070059	0.09267	0.07184	0.075624	0.078316	0.064256	0.078316	0.088201	0.065714	0.077478	0.087323

Solving MCDM problem using TOPSIS Method

S3: Pyrolysis & AD

weightage	0.23	0.148	0.125	0.064	0.081	0.07	0.087	0.072	0.064	0.057		
	Barcelo	Acosta	Ampatin	Rivera	Prisco	Barquilla	Requejo	Bantilan	Mondejar	Biyo	Osorio	Average
Waste Leakage Reduction	3	4	4	3	3	4	5	5	5	3	4	3.909091
Pollution and health risk reduction	3	2	4	3	3	3	4	4	4	2	4	3.272727
resource recovery contribution	3	4	3	2	4	4	4	3	5	3	4	3.545455
Capital expenditure	2	2	5	3	4	3	1	3	3	3	2	2.818182
Operating expediture	2	3	5	3	4	4	2	5	3	2	2	3.181818
Cost Recovery/Revenue potential	3	1	3	3	3	4	4	2	5	2	2	2.909091
Community acceptance and Participation	3	2	3	2	4	4	3	5	3	1	3	3
Public health and Sanitation benefits	4	2	3	3	3	3	4	4	4	1	4	3.181818
Ease of implementation & Scalability	3	1	3	3	3	4	2	2	4	2	4	2.818182
Governance & Enforcement Compatibility	3	2	4	3	4	3	5	3	4	2	2	3.181818

Step-1 Normalised Matrix

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}}$$

Step-2 Calculate weighted Normalised Matrix

$$V_{ij} = \bar{X}_{ij} \times W_j$$

Step-3 best and ideal worst value

Step-4 Calculate the Euclidean distance from the ideal best

$$S_i^+ = \left[\sum_{j=1}^{m} (V_{ij} - V_j^+)^2 \right]^{0.5}$$

Step-4 ı distance from the ideal worst

$$S_i^- = \left[\sum_{j=1}^{m} (V_{ij} - V_j^-)^2 \right]^{0.5}$$

Step-6 ᵓerformance Score

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

	Barcelo	Acosta	Ampatin	Rivera	Prisco	Barquilla	Requejo	Bantilan	Mondejar	Biyo	Osorio
Waste Leakage Reduction	0.321634	0.503953	0.334497	0.33541	0.268328	0.348155	0.435194	0.419591	0.388075	0.428571	0.39036
Pollution and health risk reduction	0.321634	0.251976	0.334497	0.33541	0.268328	0.261116	0.348155	0.335673	0.31046	0.285714	0.39036
resource recovery contribution	0.321634	0.503953	0.250873	0.223607	0.357771	0.348155	0.348155	0.251754	0.388075	0.428571	0.39036
Capital expenditure	0.214423	0.251976	0.418121	0.33541	0.357771	0.261116	0.087039	0.251754	0.232845	0.428571	0.19518
Operating expediture	0.214423	0.377964	0.418121	0.33541	0.357771	0.348155	0.174078	0.419591	0.232845	0.285714	0.19518
Cost Recovery/Revenue potential	0.321634	0.125988	0.250873	0.33541	0.268328	0.348155	0.348155	0.167836	0.388075	0.285714	0.19518
Community acceptance and Participation	0.321634	0.251976	0.250873	0.223607	0.357771	0.348155	0.261116	0.419591	0.232845	0.142857	0.29277
Public health and Sanitation benefits	0.428845	0.251976	0.250873	0.33541	0.268328	0.261116	0.348155	0.335673	0.31046	0.142857	0.39036
Ease of implementation & Scalability	0.321634	0.125988	0.250873	0.33541	0.268328	0.348155	0.174078	0.167836	0.31046	0.285714	0.39036
Governance & Enforcement Compatibility	0.321634	0.251976	0.334497	0.33541	0.357771	0.261116	0.435194	0.251754	0.31046	0.285714	0.19518

	Barcelo	Acosta	Ampatin	Rivera	Prisco	Barquilla	Requejo	Bantilan	Mondejar	Biyo	Osorio	Si+	Si-	Pi	Rank
Waste Leakage Reduction	0.073976	0.115909	0.076934	0.077144	0.061715	0.080076	0.100095	0.096506	0.089257	0.098571	0.089783	0.25371	0	0	10
Pollution and health risk reduction	0.047602	0.037292	0.049506	0.049641	0.039713	0.038645	0.051527	0.04968	0.045948	0.042286	0.057773	0.113654	0.14206	0.55554	9
resource recovery contribution	0.040204	0.062994	0.031359	0.027951	0.044721	0.043519	0.043519	0.031469	0.048509	0.053571	0.048795	0.109095	0.14553	0.57155	8
Capital expenditure	0.013723	0.016126	0.02676	0.021466	0.022897	0.016711	0.00557	0.016112	0.014902	0.027429	0.012492	0.023362	0.2252	0.90601	3
Operating expediture	0.017368	0.030615	0.033868	0.027168	0.028979	0.028201	0.0141	0.033987	0.01886	0.023143	0.01581	0.04513	0.20135	0.81691	7
Cost Recovery/Revenue potential	0.022514	0.008819	0.017561	0.023479	0.018783	0.024371	0.024371	0.011749	0.027165	0.02	0.013663	0.028238	0.22003	0.88626	4
Community acceptance and Participation	0.027982	0.021922	0.021826	0.019454	0.031126	0.03029	0.022717	0.036504	0.020258	0.012429	0.025471	0.045361	0.20615	0.81965	6
Public health and Sanitation benefits	0.030877	0.018142	0.018063	0.02415	0.01932	0.0188	0.025067	0.024168	0.022353	0.010286	0.028106	0.036734	0.21535	0.85428	5
Ease of implementation & Scalability	0.020585	0.008063	0.016056	0.021466	0.017173	0.022282	0.011141	0.010742	0.019869	0.018286	0.024983	0.020471	0.23052	0.91844	1
Governance & Enforcement Compatibility	0.018333	0.014363	0.019066	0.019118	0.020393	0.014884	0.024806	0.01435	0.017696	0.016286	0.011125	0.022521	0.22448	0.90882	2

V+	0.013723	0.008063	0.016056	0.019118	0.017173	0.014884	0.00557	0.010742	0.014902	0.010286	0.011125
V-	0.073976	0.115909	0.076934	0.077144	0.061715	0.080076	0.100095	0.096506	0.089257	0.098571	0.089783

Solving MCDM problem using TOPSIS Method

S4: MRF & Composting

weightage	0.23	0.148	0.125	0.064	0.081	0.07	0.087	0.072	0.064	0.057		
	Barcelo	**Acosta**	**Ampatin**	**Rivera**	**Prisco**	**Barquilla**	**Requejo**	**Bantilan**	**Mondejar**	**Biyo**	**Osorio**	**Average**
Waste Leakage Reduction	4	5	5	2	3	4	4	5	4	4	3	3.90909
Pollution and health risk reduction	3	3	5	3	2	5	4	5	4	4	3	3.72727
resource recovery contribution	3	5	5	3	4	5	4	5	5	3	4	4.18182
Capital expenditure	4	5	3	3	4	4	4	3	4	3	4	3.72727
Operating expediture	4	5	3	3	4	4	4	3	4	3	4	3.72727
Cost Recovery/Revenue potential	4	3	3	3	3	4	4	4	5	3	4	3.63636
Community acceptance and Participation	4	4	4	3	2	5	4	5	5	3	4	3.90909
Public health and Sanitation benefits	3	3	5	3	3	5	4	5	4	3	4	3.81818
Ease of implementation & Scalability	3	5	5	2	2	3	4	5	4	2	4	3.54545
Governance & Enforcement Compatibility	4	3	5	3	2	3	5	5	4	2	4	3.63636

	Barcelo	**Acosta**	**Ampatin**	**Rivera**	**Prisco**	**Barquilla**	**Requejo**	**Bantilan**	**Mondejar**	**Biyo**	**Osorio**
Waste Leakage Reduction	0.34816	0.37582	0.35991	0.22361	0.31449	0.2965	0.30769	0.34586	0.29251	0.41257	0.24828
Pollution and health risk reduction	0.26112	0.22549	0.35991	0.33541	0.20966	0.37062	0.30769	0.34586	0.29251	0.41257	0.24828
resource recovery contribution	0.26112	0.37582	0.35991	0.33541	0.41931	0.37062	0.30769	0.34586	0.36564	0.30943	0.33104
Capital expenditure	0.34816	0.37582	0.21594	0.33541	0.41931	0.2965	0.30769	0.20751	0.29251	0.30943	0.33104
Operating expediture	0.34816	0.37582	0.21594	0.33541	0.41931	0.2965	0.30769	0.20751	0.29251	0.30943	0.33104
Cost Recovery/Revenue potential	0.34816	0.22549	0.21594	0.33541	0.31449	0.2965	0.30769	0.27669	0.36564	0.30943	0.33104
Community acceptance and Participation	0.34816	0.30066	0.28793	0.33541	0.20966	0.37062	0.30769	0.34586	0.36564	0.30943	0.33104
Public health and Sanitation benefits	0.26112	0.22549	0.35991	0.33541	0.31449	0.37062	0.30769	0.34586	0.29251	0.30943	0.33104
Ease of implementation & Scalability	0.26112	0.37582	0.35991	0.22361	0.20966	0.22237	0.30769	0.34586	0.29251	0.20628	0.33104
Governance & Enforcement Compatibility	0.34816	0.22549	0.35991	0.33541	0.20966	0.22237	0.38462	0.34586	0.29251	0.20628	0.33104

	Barcelo	**Acosta**	**Ampatin**	**Rivera**	**Prisco**	**Barquilla**	**Requejo**	**Bantilan**	**Mondejar**	**Biyo**	**Osorio**	**Si+**	**Si-**	**Pi**	**Rank**
Waste Leakage Reduction	0.08008	0.08644	0.08278	0.05143	0.07233	0.06819	0.07077	0.07955	0.06728	0.09489	0.0571	0.20056	0	0	**10**
Pollution and health risk reduction	0.03865	0.03337	0.05327	0.04964	0.03103	0.05485	0.04554	0.05119	0.04329	0.06106	0.03675	0.10683	0.1022	0.489	**9**
resource recovery contribution	0.03264	0.04698	0.04499	0.04193	0.05241	0.04633	0.03846	0.04323	0.0457	0.03868	0.04138	0.09615	0.1104	0.5345	**8**
Capital expenditure	0.02228	0.02405	0.01382	0.02147	0.02684	0.01898	0.01969	0.01328	0.01872	0.0198	0.02119	0.02331	0.1799	0.8853	**3**
Operating expediture	0.0282	0.03044	0.01749	0.02717	0.03396	0.02402	0.02492	0.01681	0.02369	0.02506	0.02681	0.03953	0.1641	0.8058	**6**
Cost Recovery/Revenue potential	0.02437	0.01578	0.01512	0.02348	0.02201	0.02075	0.02154	0.01937	0.02559	0.02166	0.02317	0.02358	0.1772	0.8825	**4**
Community acceptance and Participation	0.03029	0.02616	0.02505	0.02918	0.01824	0.03224	0.02677	0.03009	0.03181	0.02692	0.0288	0.04496	0.1563	0.7766	**7**
Public health and Sanitation benefits	0.0188	0.01624	0.02591	0.02415	0.02264	0.02668	0.02215	0.0249	0.02106	0.02228	0.02384	0.02941	0.1721	0.854	**5**
Ease of implementation & Scalability	0.01671	0.02405	0.02303	0.01431	0.01342	0.01423	0.01969	0.02213	0.01872	0.0132	0.02119	0.01746	0.1849	0.9137	**2**
Governance & Enforcement Compatibility	0.01984	0.01285	0.02051	0.01912	0.01195	0.01268	0.02192	0.01971	0.01667	0.01176	0.01887	0.01114	0.1901	0.9446	**1**

V+	0.01671	0.01285	0.01382	0.01431	0.01195	0.01268	0.01969	0.01328	0.01667	0.01176	0.01887
V-	0.08008	0.08644	0.08278	0.05143	0.07233	0.06819	0.07077	0.07955	0.06728	0.09489	0.0571

Step-1 Normalised Matrix

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}}$$

Step-2 Calculate weighted Normalised Matrix

$$V_{ij} = \bar{X}_{ij} \times W_j$$

Step-3 best and ideal worst value

Step-4 Calculate the Euclidean distance from the ideal best

$$S_i^{+} = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^{+} \right)^2 \right]^{0.5}$$

Step-4 ı distance from the ideal worst

$$S_i^{-} = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^{-} \right)^2 \right]^{0.5}$$

Step-6 ›erformance Score

$$P_i = \frac{S_i^{-}}{S_i^{+} + S_i^{-}}$$

Solving MCDM problem using TOPSIS Method

S5: SLF & Energy Recovery

	Barcelo	Acosta	Ampatin	Rivera	Prisco	Barquilla	Requejo	Bantilan	Mondejar	Biyo	Osorio	Average
weightage	0.23	0.148	0.125	0.064	0.081	0.07	0.087	0.072	0.064	0.057		
Waste Leakage Reduction	4	2	5	5	3	3	4	5	5	4	3	3.909091
Pollution and health risk reduction	2	4	4	3	2	3	5	4	4	3	3	3.363636
resource recovery contribution	4	3	4	3	3	4	4	4	5	3	4	3.727273
Capital expenditure	2	1	5	3	3	4	1	2	4	4	2	2.818182
Operating expediture	2	4	5	3	3	4	1	3	4	4	2	3.181818
Cost Recovery/Revenue potential	2	3	3	3	4	4	4	3	4	3	4	3.363636
Community acceptance and Participation	2	3	4	3	4	4	2	3	4	3	3	3.181818
Public health and Sanitation benefits	3	3	4	3	4	4	4	5	4	2	3	3.545455
Ease of implementation & Scalability	3	2	4	3	3	4	2	3	4	2	2	2.909091
Governance & Enforcement Compatibility	3	3	5	3	3	4	5	5	4	2	3	3.636364

	Barcelo	Acosta	Ampatin	Rivera	Prisco	Barquilla	Requejo	Bantilan	Mondejar	Biyo	Osorio
Waste Leakage Reduction	0.450035	0.215666	0.363696	0.485643	0.291386	0.248282	0.359211	0.412393	0.374766	0.408248	0.317999
Pollution and health risk reduction	0.225018	0.431331	0.290957	0.291386	0.194257	0.248282	0.449013	0.329914	0.299813	0.306186	0.317999
resource recovery contribution	0.450035	0.323498	0.290957	0.291386	0.291386	0.331042	0.359211	0.329914	0.374766	0.306186	0.423999
Capital expenditure	0.225018	0.107833	0.363696	0.291386	0.291386	0.331042	0.089803	0.164957	0.299813	0.408248	0.212
Operating expediture	0.225018	0.431331	0.363696	0.291386	0.291386	0.331042	0.089803	0.247436	0.299813	0.408248	0.212
Cost Recovery/Revenue potential	0.225018	0.323498	0.218218	0.291386	0.388514	0.331042	0.359211	0.247436	0.299813	0.306186	0.423999
Community acceptance and Participation	0.225018	0.323498	0.290957	0.291386	0.388514	0.331042	0.179605	0.247436	0.299813	0.306186	0.317999
Public health and Sanitation benefits	0.337526	0.323498	0.290957	0.291386	0.388514	0.331042	0.359211	0.412393	0.299813	0.204124	0.317999
Ease of implementation & Scalability	0.337526	0.215666	0.290957	0.291386	0.291386	0.331042	0.179605	0.247436	0.299813	0.204124	0.212
Governance & Enforcement Compatibility	0.337526	0.323498	0.363696	0.291386	0.291386	0.331042	0.449013	0.412393	0.299813	0.204124	0.317999

	Barcelo	Acosta	Ampatin	Rivera	Prisco	Barquilla	Requejo	Bantilan	Mondejar	Biyo	Osorio	Si+	Si-	Pi	Rank
Waste Leakage Reduction	0.103508	0.049603	0.08365	0.111698	0.067019	0.057105	0.082618	0.09485	0.086196	0.093897	0.07314	0.235775	0.01423	0.05693	10
Pollution and health risk reduction	0.033303	0.063837	0.043062	0.043125	0.02875	0.036746	0.066454	0.048827	0.044372	0.045316	0.047064	0.117012	0.14017	0.54501	9
resource recovery contribution	0.056254	0.040437	0.03637	0.036423	0.036423	0.04138	0.044901	0.041239	0.046846	0.038273	0.053	0.101181	0.14424	0.58772	8
Capital expenditure	0.014401	0.006901	0.023277	0.018649	0.018649	0.021187	0.005747	0.010557	0.019188	0.026128	0.013568	0.017093	0.22184	0.92846	2
Operating expediture	0.018226	0.034938	0.029459	0.023602	0.023602	0.026814	0.007274	0.020042	0.024285	0.033068	0.017172	0.042181	0.20103	0.82657	6
Cost Recovery/Revenue potential	0.015751	0.022645	0.015275	0.020397	0.027196	0.023173	0.025145	0.017321	0.020987	0.021433	0.02968	0.034459	0.20968	0.85885	4
Community acceptance and Participation	0.019577	0.028144	0.025313	0.025351	0.033801	0.028801	0.015626	0.021527	0.026084	0.026638	0.027666	0.042096	0.1977	0.82445	7
Public health and Sanitation benefits	0.024302	0.023292	0.020949	0.02098	0.027973	0.023835	0.025863	0.029692	0.021587	0.014697	0.022896	0.038199	0.20155	0.84067	5
Ease of implementation & Scalability	0.021602	0.013803	0.018621	0.018649	0.018649	0.021187	0.011495	0.015836	0.019188	0.013064	0.013568	0.013846	0.21921	0.94059	1
Governance & Enforcement Compatibility	0.019239	0.018439	0.020731	0.016609	0.016609	0.018869	0.025594	0.023506	0.017089	0.011635	0.018126	0.027724	0.21459	0.88559	3
V+	0.014401	0.006901	0.015275	0.016609	0.016609	0.018869	0.005747	0.010557	0.017089	0.011635	0.013568				
V-	0.103508	0.063837	0.08365	0.111698	0.067019	0.057105	0.082618	0.09485	0.086196	0.093897	0.07314				

Step-1 Normalised Matrix

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}}$$

Step-2 Calculate weighted Normalised Matrix

$$V_{ij} = \bar{X}_{ij} \times W_j$$

Step-3 best and ideal worst value

Step-4 Calculate the Euclidean distance from the ideal best

$$S_i^+ = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^+ \right)^2 \right]^{0.5}$$

Step-4 ı distance from the ideal worst

$$S_i^- = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^- \right)^2 \right]^{0.5}$$

Step-6 ᐣerformance Score

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

Solving MCDM problem using TOPSIS Method

	Waste Leakage Reduction	Pollution and health risk reduction	resource recovery contribution	Capital expenditure	Operating expediture	Cost Recovery/Revenue potential	Community acceptance and Participation	Public health and Sanitation benefits	Ease of implementation & Scalability	Governance & Enforcement Compatibility
weightage	0.23	0.148	0.125	0.064	0.081	0.07	0.087	0.072	0.064	0.057
S1: Sanitary Landfill	3.090909091	3.363636364	3.090909091	2.727272727	2.909090909	2.727272727	2.909090909	3.363636364	3	3.181818182
S2: MBT & Recycling	3.909090909	3.727272727	4.090909091	3.454545455	3.636363636	3.727272727	3.363636364	3.363636364	3.363636364	3.636363636
S3: Pyrolysis & AD	3.909090909	3.272727273	3.545454545	2.818181818	3.181818182	2.909090909	3	3.181818182	2.818181818	3.181818182
S4: MRF & Composting	3.909090909	3.727272727	4.181818182	3.727272727	3.727272727	3.636363636	3.909090909	3.818181818	3.545454545	3.636363636
S5: SLF & Energy Recovery	3.909090909	3.363636364	3.727272727	2.818181818	3.181818182	3.363636364	3.181818182	3.545454545	2.909090909	3.636363636

	Waste Leakage Reduction	Pollution and health risk reduction	resource recovery contribution	Capital expenditure	Operating expediture	Cost Recovery/Revenue potential	Community acceptance and Participation	Public health and Sanitation benefits	Ease of implementation & Scalability	Governance & Enforcement Compatibility
S1: Sanitary Landfill	0.367658889	0.430232558	0.368803473	0.389020319	0.38934742	0.370003988	0.395212349	0.434602912	0.427312033	0.411054154
S2: MBT & Recycling	0.46498036	0.476744186	0.488122244	0.492759071	0.486684275	0.505672117	0.456964278	0.434602912	0.479107431	0.469776176
S3: Pyrolysis & AD	0.46498036	0.418604651	0.423039278	0.401987663	0.425848741	0.39467092	0.407562734	0.411110863	0.401414334	0.411054154
S4: MRF & Composting	0.46498036	0.476744186	0.498969405	0.531661102	0.498851382	0.49333865	0.531066593	0.493333035	0.50500513	0.469776176
S5: SLF & Energy Recovery	0.46498036	0.430232558	0.4447336	0.401987663	0.425848741	0.456338252	0.432263506	0.458094961	0.414363183	0.469776176

	Waste Leakage Reduction	Pollution & health risk reduction	Resource Recovery Contribution	Capital expenditure	Operating expediture	Cost Recovery/Revenue potential	Community acceptance and Participation	Public health and Sanitation benefits	Ease of implementation & Scalability	Governance & Enforcement Compatibility	Si+	Si-	Pi	Rank
S1: Sanitary Landfill	0.084561545	0.063674419	0.046100434	0.0248973	0.031537141	0.025900279	0.034383474	0.03129141	0.02734797	0.023430087	0.0029274	0.03548055	0.92378	1
S2: MBT & Recycling	0.106945483	0.07055814	0.061015281	0.031536581	0.039421426	0.035397048	0.039755892	0.03129141	0.030662876	0.026777242	0.00843795	0.008437948	0.5	2
S3: Pyrolysis & AD	0.106945483	0.061953488	0.05287991	0.02572721	0.034493748	0.027626964	0.035457958	0.029599982	0.025690517	0.023430087	0.15501358	0.023108336	0.12973	3
S4: MRF & Composting	0.106945483	0.07055814	0.062371176	0.034026311	0.040406962	0.034533706	0.046202794	0.035519979	0.032320328	0.026777242	0.17160137	0.000863343	0.00501	5
S5: SLF & Energy Recovery	0.106945483	0.063674419	0.0555917	0.02572721	0.034493748	0.031943678	0.037606925	0.032982837	0.026519244	0.026777242	0.15930082	0.017974773	0.10139	4