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Sustainable Municipal Solid Waste Management Strategies and Practices: A review

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Abstract

Purpose: This paper introduces a multi-period, multi-objective model for creating an integrated, sustainable municipal solid waste management supply chain. The model includes source separation and a reward-penalty mechanism, aiming to minimize total system costs, greenhouse gas emissions, and environmental impacts on residential areas. Many countries strive to develop efficient solid waste management systems (SWMS) that handle and dispose of daily waste cost-effectively while maintaining sustainability. These systems include waste sources, collection stations, landfills, incinerators, recycling plants, and a transportation network.

Methodology: A systematic literature review was conducted on existing literature from various studies. Recent studies were used for this systematic review of sustainable municipal solid waste management strategies and practices.

Findings: Decision-makers must design or reconfigure a sustainable MSWM to determine the optimal supply chain network for treating and disposing of daily waste effectively. This paper suggests sustainable waste management strategies and practices from various countries, aiming to determine the best number and locations for facilities and optimal waste flow within the system to minimize daily costs. The primary contribution of this review is the theoretical development of sustainable MSWM practices applicable worldwide.

Unique contribution to theory, policy and practice: Cooperation between the private and public sectors involved in solid waste management and the circular economy is imperative to ensure the technical, financial, and social sustainability of waste management systems. Large-scale awareness programs on solid waste management and the circular economy should be implemented, focusing on fostering environmentally responsible behaviors and attitudes, promoting sorting, selective collection, and the recovery of materials and energy from waste.

Keywords: *Sustainable, Municipal Solid Waste, Reduction, Recycling, Recovery*

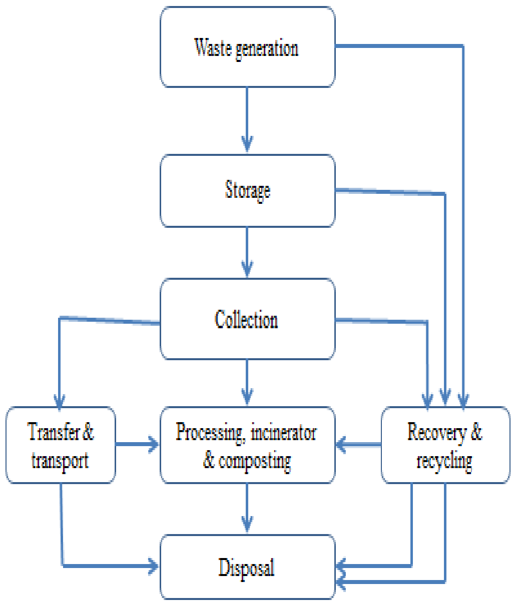
1. Introduction

Globally, communities are producing and discarding increasing amounts of solid waste, including municipal, industrial, and agricultural waste. Without sustainable management, these wastes pose significant public health risks, environmental damage, and socio-economic issues. (Abu-Qdais & Kurbatova, 2022) Therefore, regulations should promote sustainable practices such as reducing, reusing, and recycling solid waste. Effective solid waste management is essential for creating sustainable, healthy, and eco-friendly cities and societies. (Shaban et al., 2022) In developing countries, a small percentage of municipal solid waste is safely disposed of, with the majority left in the streets or dumped in open landfills. The rise in municipal solid waste (MSW) generation presents a serious challenge, particularly for emerging nations. Improper MSW management also contributes to increased greenhouse gas (GHG) emissions. (Li et al., 2015)

Municipal Solid Waste Management (MSWM) is particularly challenging in metropolitan areas where rapidly growing populations, expanding infrastructure, and evolving lifestyles generate increasing amounts of solid waste. This issue is exacerbated by poor government policy implementation. (Bhaskar, 2023) Consequently, MSWM has become a significant burden not only due to health and environmental concerns but also because of the sheer volume of waste produced. Sustainable MSWM remains a major challenge in Africa and other resource-constrained regions. (Ansori et al., 2022) To achieve sustainability, the gaps in waste management governance must be swiftly addressed, as population growth is rapidly outpacing available infrastructure and resources. Additionally, credit expansion contributes to increased MSW generation, highlighting financial development as a negative indicator for sustainable waste management. In contrast, human development and energy efficiency play crucial roles in mitigating MSW, making them essential for sustainable MSW management. (Kocak & Baglitas, 2022)

Municipalities are responsible for managing the generated municipal solid waste (MSW), including food and biodegradable waste, which constitutes the largest portion by weight nationwide. (MEJILLÓN GONZÁLEZ YURI LISBETH TUTOR:, 2022a) Smart cities in India are on the verge of becoming a reality, transforming challenges into opportunities for society. However, the rapid increase in population, fast urbanization, and the growing demand for advanced services in these smart cities have led to a rise in per capita MSW. Additionally, the COVID-19 pandemic has further strained the MSWM system with the influx of infectious waste from households, quarantine centers, healthcare facilities, and vaccination centers. (*Thakur V, Parida DJ, Raj V.*, 2022)

Achieving good governance in Sustainable Municipal Solid Waste Management (MSWM) requires involvement from the government, waste generators, and the private sector. Clear laws and regulations, coupled with proper financial planning through public-private partnerships and privatization, are essential. (Ansori et al., 2022) Generating revenue from the MSW system, raising awareness, and empowering the community can foster a sense of ownership and responsibility. Beyond landfills, options like recycling and incineration can convert MSW into valuable products or energy. (Li et al., 2015) This paper aims to highlight effective strategies and practices for sustainable MSWM through a systematic review of recent studies.



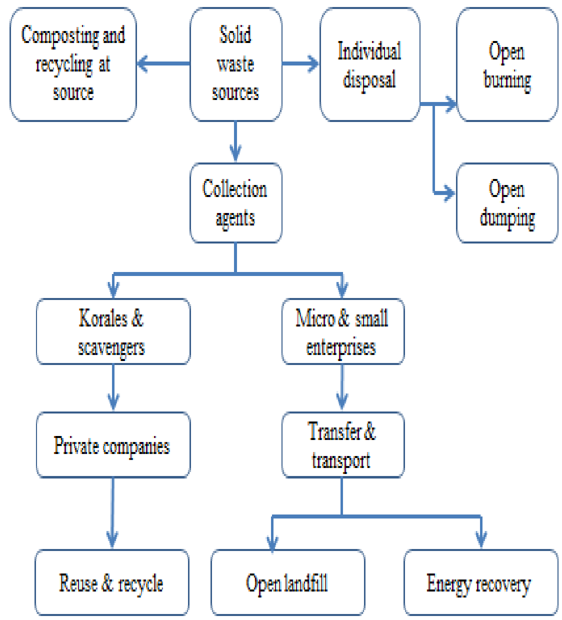


Figure 1. Components of a typical solid waste management system (Shaban et al., 2022)

Figure 2. Flow of municipal solid waste management practice in Ethiopia (Hirpe & Yeom, 2021)

2. Objectives

2.1. Main objective

To review and highlight effective sustainable municipal solid waste management (MSWM) strategies and practices from various countries, aiming to determine the optimal number and locations for facilities and optimal waste flow within the system to minimize daily costs, greenhouse gas emissions, and environmental impacts.

2.2. Specific Objectives

1. **Examine reduction strategies**: Investigate and analyze sustainable MSWM strategies and practices focused on reducing waste generation. This includes studying integrated planning, capacity building, financial support, and the implementation of life cycle assessment and waste categorization to effectively manage and reduce municipal solid waste.
2. **Evaluate recycling practices**: Assess the current recycling practices and methodologies used in different regions. This involves exploring the integration of recycling with other waste management strategies, the role of community and private sector collaboration, and the impact of advanced technologies and systems on improving recycling rates and efficiency.

3. **Assess recovery techniques:** Review and evaluate various recovery techniques such as waste-to-energy (WTE) and landfill gas recovery. This includes analyzing the technical, economic, environmental, and social aspects of different recovery methods and their effectiveness in reducing greenhouse gas emissions and converting waste into valuable resources or energy.

3. Materials and Methods

A systematic literature review was conducted on existing literature from various studies. Recent studies were used for this systematic review of sustainable municipal solid waste management strategies and practices.

3.1. Study eligibility criteria

Studies published in English from January 2019 to December 2023 were included. Additionally, government policies, legislation, and regulations on sustainable municipal solid waste management from various countries' official websites in English were also considered.

3.2. Search Strategy and data collection

Based on the review's eligibility criteria, electronic searches on Google Scholar and other databases were conducted from February 2024 to March 2024. The search strategy included the exact phrase "sustainable municipal solid waste management" in the titles and abstracts of articles.

3.3. Study Selection and data Collection process

Following the initial screening, we have reviewed the studies with two other co-authors by titles and abstracts and discussed the final records. The entire contents of the selected papers were then examined for the eligibility criteria by a single reviewer, me.

4. Results

Sustainable municipal solid waste management strategies and practices of different countries based on systematic review of selected articles according to reduction, recycling, recovery, pollution control technology and innovation technology will be discussed.

4.1. Components and generation rate of municipal solid waste

Waste generation is calculated as the total amount of waste from different sources at a specific time and place. Sub-Saharan African countries generated approximately 174 million tons of solid waste in 2016 at a rate of 0.46 kilograms per capita per day, which is expected to triple by 2050 (Hirpe & Yeom, 2021). Low waste collection efficiency and financial constraints along with poor planning and lack of study on changing complexities of municipal waste lead to worsening of municipal solid waste related problem, which results in masking the goal of sustainable management of municipal solid waste (MSW). (Jha et al., 2011)

Table 1: Municipal solid waste generation (MSWG) rates in different towns and cities of Ethiopia (Hirpe & Yeom, 2021)

Town/City	MSWG (Kg/capita/day)
Dilla	0.457
Chiro	0.30
Burayu	0.29
Robe	0.26
Addis Ababa	0.45
Mekele	0.27
Bahir dar	0.45
Wolaita Sodo	0.47
Jimma	0.34
Lega Tafo	0.41
Debire Birhan	0.25
Jigjiga	0.49
Hawasa	0.43
Dessie	0.45

The above table 1 shows municipal solid waste generation (MSWG) rates in different towns and cities of Ethiopia in which Jigjiga, Wolaita Sodo and Dilla higher generation rate and Debire Birhan, Robe and Mekele with lower generation rate respectively.

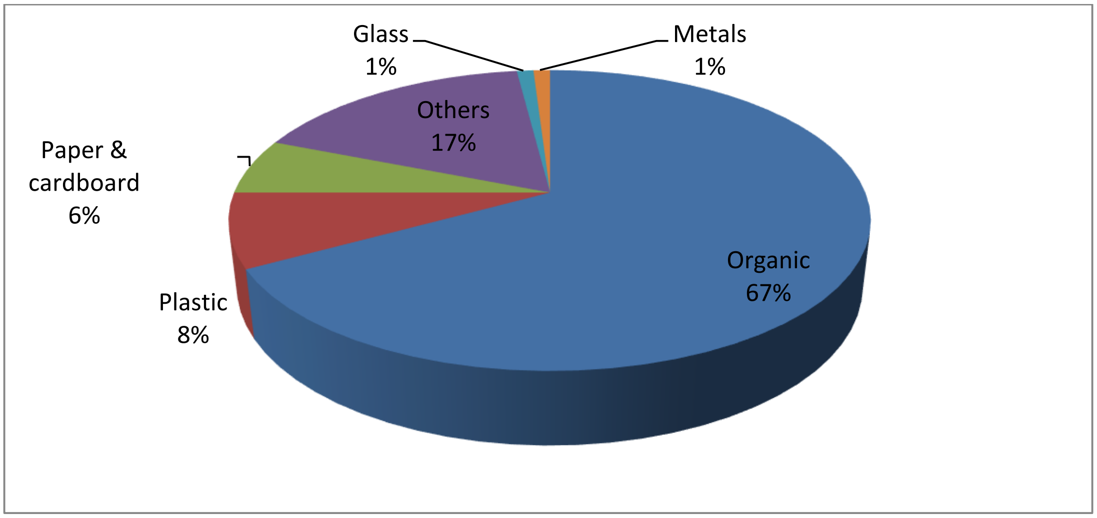


Figure 3: Composition of municipal solid waste in Ethiopia (Hirpe & Yeom, 2021)

Solid waste management in most Middle East and North Africa (MENA) countries is characterized by lack of planning, improper disposal, and inadequate collection services,

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inappropriate technologies that suit the local conditions and technical requirements, and insufficient funding. Therefore, waste management is mainly limited to collection, transportation, and disposal. As the circular economy has recently been given high priority on the MENA region's political agenda, all MENA member states are seeking to move away from old-fashioned waste disposal, "waste management", towards a more intelligent waste treatment, "resource efficiency". (Hemidat et al., 2022)

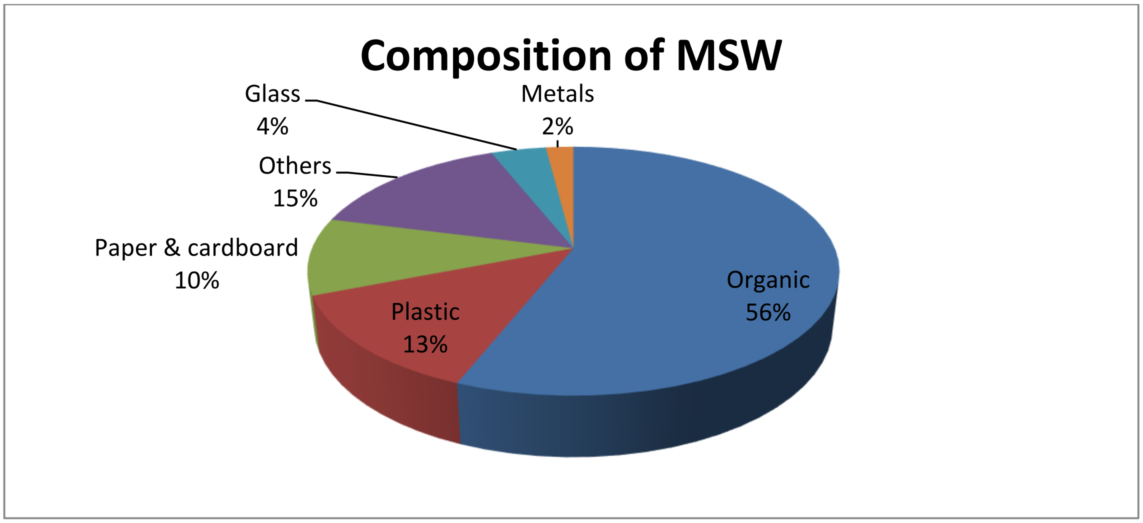

Figure 4: Composition of municipal solid waste in Egypt (Hemidat et al., 2022)

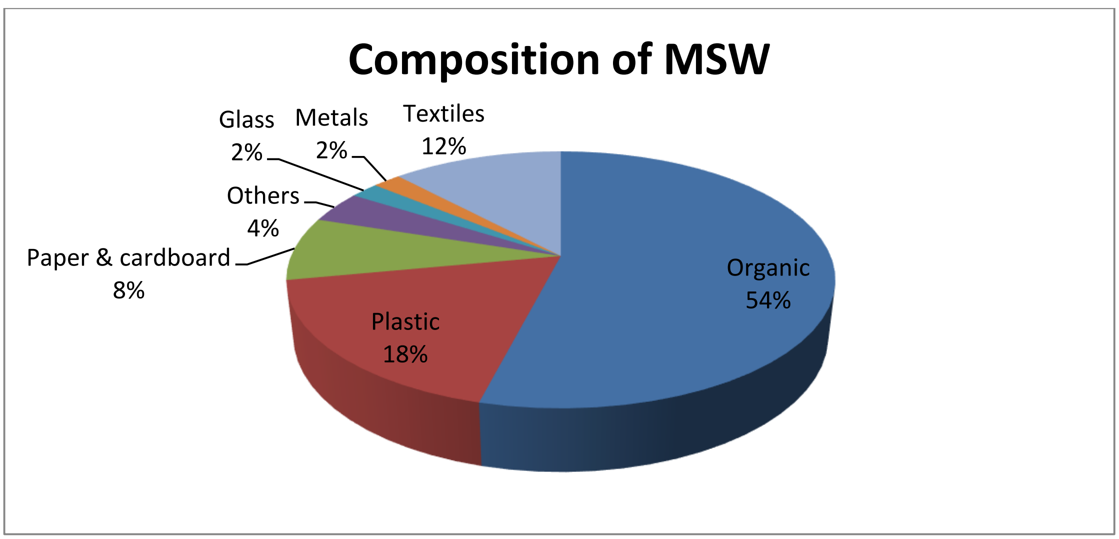

Figure 5: Composition of municipal solid waste in Algeria (Hemidat et al., 2022)

4.2. Municipal solid waste reduction

Low waste collection efficiency, financial constraints, poor planning, and a lack of study on the changing complexities of municipal waste exacerbate municipal solid waste (MSW) problems, hindering sustainable management goals. Integrated planning, capacity building, and financial support are essential to address these issues. Effective MSW management requires life cycle assessment, waste categorization, recycling, reduction, and proper landfilling. The severity of MSW management problems varies widely between cities with similar income levels; well-managed cities with medium or low income differ significantly from those with poor urban MSW management. (DERDRIED ATHANASIO JOHANN, 2011)

Major cities in transitional and developing countries face growing challenges in managing solid waste sustainably. Despite various treatment options, these cities need an integrated municipal solid waste management (MSWM) system to select and invest in appropriate treatments based on waste composition and quantity. (ElSaid & Aghezzaf, 2020) Landfill and incineration as traditional waste management strategies due to their cost-effectiveness and simplicity, though they require high management levels to mitigate negative impacts. Modern sustainable municipal solid waste (MSW) management now encompasses environmental protection, social equity, economic stability, and sustainability. Pollutant partitioning to understand the movement of hydrophobic colloids in different environments such as marine, groundwater, and soil, which is crucial for selecting sustainable MSW management options and incorporating cleaner production methods in waste management significantly enhances environmental sustainability and cleaner bio-resources by addressing potential environmental depletion. (*Bello, A. S., Al - Ghouti, M. A., & Abu - Dieyeh, M. H. (2022).*

India generates over sixty million metric tons of municipal solid waste (MSW) annually, leading to environmental degradation and public health issues. Additionally, about 1,200 hectares of landfill space are required each year. Proper handling and management of MSW, involving collection, segregation, and treatment, are essential. Strategic planning is necessary for a sustainable MSW management system for future development. ((ÖCAL, 2021) Transitioning to a circular economy can significantly reduce waste disposal. Key strategies in circular economy models, such as source reduction, source separation, and recycling, align with the United Nations Sustainable Development Goals (SDGs). Municipalities should invest in infrastructure, techniques, and programs supporting the circular economy to promote sustainability. While recycling activities are currently present, especially in the private sector, increased efforts across all sectors are needed to reduce waste entering landfills and mitigate environmental impacts. (Ansori et al., 2022)

The most environmentally sustainable MSW plan for CU canteens involves reducing waste, separating it at the source, and reusing materials instead of landfilling mixed waste. (Ansori et al., 2022) According to Rafew SM's investigation, several policy scenarios focused on the collection and separate industrial-scale treatment of food and biodegradable MSW in the city. The results indicated that the developed SD model can serve as an effective simulation platform for evaluating MSW management systems and determining methods to achieve sustainable conditions in the long run. (MEJILLÓN GONZÁLEZ YURI LISBETH TUTOR:, 2022a)

Amsterdam is one of the most eco-conscious cities globally. Aiming to reduce CO_2 emissions by 95% by 2050, the Dutch capital began upgrading its public waste collection system with smart technology. In 2014, the city equipped some collection trucks with weighing mechanisms and installed fill-level sensors in public trash bins. The data collected from these innovations enabled the city to develop more efficient and cost-effective waste collection schedules. (*Liam Stannard Innovative Smart Waste Management Technologies.Pdf*, n.d.)

4.3. Municipal solid waste recycling

As the world's population and living standards rise, waste generation in emerging nations is expected to quadruple in the next ten years. The urban poor often recycle a significant portion of waste, earning income while benefiting the environment. A cohesive methodology is needed, where the community, commercial, and private sectors collaborate to create local solutions that promote sustainable solid waste management (SWM). (MEJILLÓN GONZÁLEZ YURI LISBETH TUTOR:, 2022b)

Apart from landfilling, options for converting municipal solid waste (MSW) into valuable products or energy include recycling and incineration crisp and fuzzy optimization models have been developed for designing optimal supply chain networks for sustainable MSW management, considering both economic (cost minimization) and environmental (emissions reduction) objectives. The crisp model is based on a superstructure that includes material balances, capacity limits, and planning constraints for MSW transfer stations, disposal sites, and treatment technologies. Fuzzy optimization with max-min aggregation is then used to address conflicting economic and environmental objectives, as well as uncertainties in GHG emission factors and cost coefficients for MSW treatment. (Ansori et al., 2022)

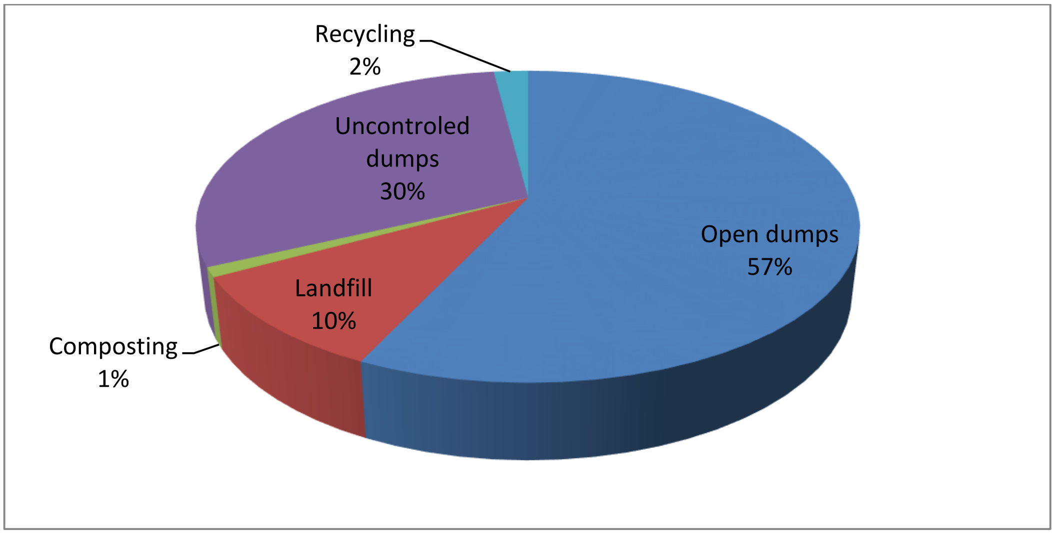

Figure 6: Methods of waste disposal in Algeria (Hemidat et al., 2022)

Municipal solid waste (MSW) management is a significant global environmental issue. The shift towards sustainability and the circular economy has advanced MSW management from basic disposal to recycling and resource recovery. The most appropriate strategy involves integrating recycling, treatment, and disposal technologies, with choices depending on the region's technological and socio-economic context. (*Iqbal, A., Liu, X., & Chen, G. H. (2020)*)

If a municipality implements an efficient waste material separation system, the focus of waste management is likely to shift more towards recycling. (Ansori et al., 2022) This could reduce the use of recyclables as a source of income for underprivileged communities. According to the Environmental Protection Agency (EPA), roughly 75% of the waste stream in the United States is recyclable, yet only about 30% of recyclable materials are actually recycled. Given that humans produce over 2 billion tons of waste annually, a substantial amount of unnecessary trash ends up in landfills and waterways. (*Liam Stannard Innovative Smart Waste Management Technologies.Pdf*, n.d.)The global trash problem persists, and traditional waste management systems are ill-equipped to handle the extra waste from growing populations. To bridge this gap, communities need to adopt smart waste management technologies that increase efficiency, lower collection costs, and divert more trash away from landfills. San Francisco, for example, diverts about 80% of its waste from landfills annually, boasting one of the highest recycling rates in the U.S. The city achieved this partly through its partnership with recology, a waste collection company. Recology invested $20 million in upgrading its facilities and installed a fleet of sorting robots to quickly and accurately sort recyclables.

4.4. Municipal solid waste recovery

In a circular economy, municipal solid waste will be used as a resource, making the design of a product-oriented waste management network essential. According to *Liam*, a sustainable waste management network was designed to optimally extract various bio energies, considering economic, environmental, and social sustainability under uncertain conditions. The proposed model for sustainable municipal solid waste network is a multi-objective, mixed-integer non-linear programming approach. The results of the proposed solution method included the quantities of bio energies generated by different treatment technologies and the technologies implemented over the defined time interval. (*Liam Stannard Innovative Smart Waste Management Technologies.Pdf*, n.d.)

Waste management in urban areas is a major concern for municipalities due to massive waste production from population growth, leading to increased greenhouse gas emissions. Common energy recovery techniques include Waste-to-Energy (WTE) and landfill gas plants. A research in Tehran investigated four waste management scenarios, analyzing emitted GHGs using IPCC guidelines and calculating the total cost of each scenario. Various parameters, such as plant usage, methane recovery factor, and MSW heating value, were evaluated. Results showed that 50% waste burned in WTE, 30% landfilled, and 20% recycled had the lowest GHG emissions. Cost comparison indicated that landfilling with recovery is the most economical option. (*Liam Stannard Innovative Smart Waste Management Technologies.Pdf*, n.d.)

According to Abu-Qdais, the number and diversity of studies from different regions worldwide highlighted the growing importance of sustainable solid waste management. The Sustainable Development Goals (SDGs) play a crucial role, emphasizing responsible resource use, production, and consumption, including waste management. (Abu-Qdais & Kurbatova, 2022)

The figure below indicates the percentage of energy from total solid waste in different countries.

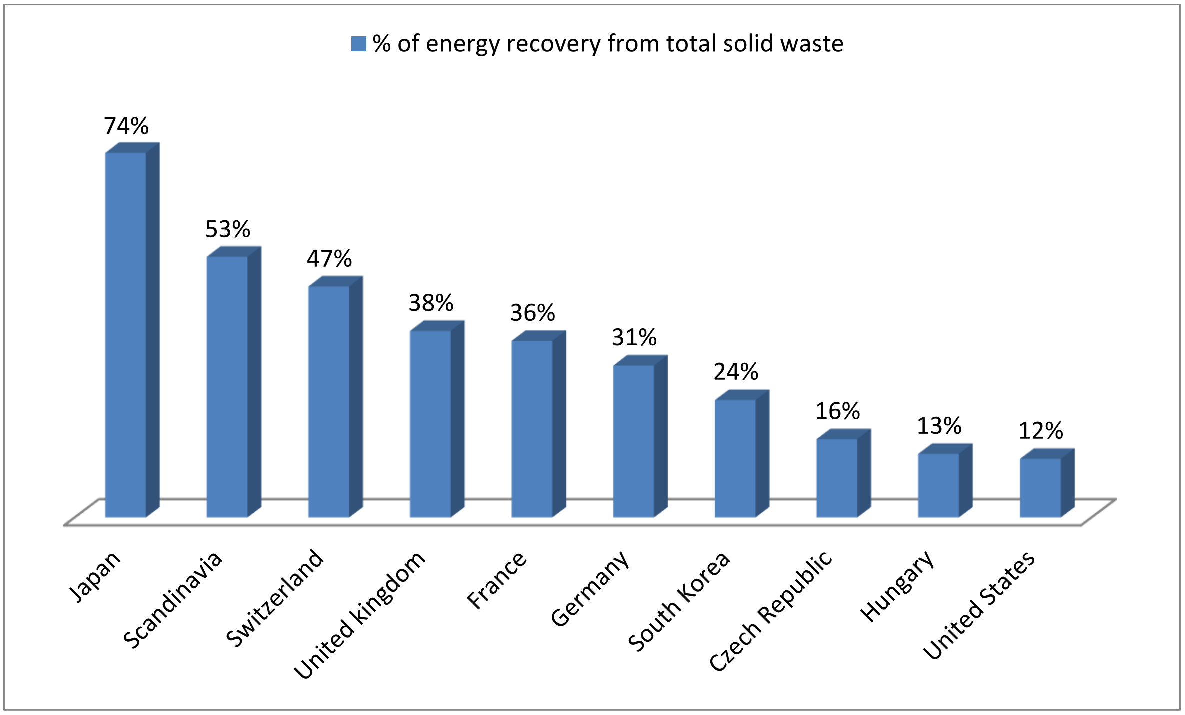

Figure 7. Percent of energy recovery from total solid waste. (ÖCAL, 2021)

In addition, SDGs 3, 7, 11, 12, and 13 are directly or indirectly related to waste management. Anaerobic digestion, gasification, incineration, and landfill gas (LFG) recovery are considered viable alternatives. Technical, economic, environmental, and social issues are essential criteria for evaluation. Using the analytical hierarchy process to rank these technologies based on stakeholders' perceptions, anaerobic digestion (AD) ranked first with 38% of the overall weight. The second preferred technology is LFG at 27%, followed by gasification and incineration at 21% and 14%, respectively. According to a sensitivity study, the decision is only sensitive to economic factors. If the economy is prioritized above 38%, landfill gas recovery will become the most favored solution for waste-to-energy conversion. (MEJILLÓN GONZÁLEZ YURI LISBETH TUTOR:, 2022c)

4.5. Municipal solid waste strategies and practices of pollution control

Solid waste management (SWM) issues remain a significant focus of global environmental policy in alignment with the UN Sustainable Development Goals 2030. Despite being over two and a half years since the original COVID-19 outbreak, the world continues to grapple with the ongoing impact of the coronavirus pandemic. Consequently, the composition of waste generated by households, businesses, and medical institutions has evolved. The widespread use of personal protective equipment (PPE) such as masks, gloves, and hand sanitizers by frontline workers in various sectors, as well as by the general public, has altered waste generation patterns and presented new challenges. To ensure improved health and human security, an effective and sustainable SWM system is essential for the long term. (Shah et al., 2022)

The world's finite resources face threats from various factors like population growth, climate change, and waste and pollution from municipal and industrial processes. While human advancements and technologies drive economic growth and enhance quality of life, it's crucial to utilize these developments sustainably; ensuring future generations have access to the same resources. Moreover, the loss and collapse of biodiversity and ecosystems can lead to irreversible consequences, severely depleting resources and harming both humanity and industry. Sustainability is thus a vital concept, and sustainable waste management not only addresses local impacts but also minimizes the environmental burden on the planet. Municipal Solid Waste (MSW) management is recognized as a public service and should adhere to legal requirements, employing various technologies. Sustainable waste management options, particularly through initiatives like the "Zero Waste Regulation," play a crucial role in reducing or eliminating harmful environmental effects, starting with proper initial municipal waste management practices. (*Öztaş S*, 2022)

Globally, communities are producing and disposing of increasing volumes of solid waste, encompassing categories such as municipal, industrial, and agricultural waste. Without sustainable management practices, such waste poses risks to public health, the environment, and socio-economic well-being. Therefore, regulations should be enforced to promote sustainable practices like waste reduction, reuse, and recycling. (Abu-Qdais & Kurbatova, 2022)

4.6. MSWM strategies and practices of innovation technology

The increasing generation of municipal solid waste (MSW) and growing environmental concerns have led to global interest in waste valorization through various waste-to-energy (WtE) technologies. These technologies aim to generate renewable energy sources and reduce reliance on fossil-derived fuels and chemicals, contributing to the envisioned global "bio-economy" through bio-refineries. In developing countries, the most feasible MSW management solutions include anaerobic digestion for organic wastes, incineration for mixed MSW (excluding bio-waste), pyrolysis, and gasification for specific wastes such as electronic devices and woody biomass, along with landfilling for inert wastes. However, the characteristics and composition of MSW are critical factors to consider. (*Iqbal, A., Liu, X., & Chen, G. H. (2020)*

Smart MSW bins, integrated with systems, networks, and technology providers utilizing innovative technology-based intelligent devices, play a crucial role in MSW segregation from the initial stage. This includes qualitative and quantitative segregation of biodegradable and non-biodegradable waste. Incorporating this technology provides municipal corporations with a feasible and cost-effective alternative for the disposal and treatment of MSW. (*Liam Stannard Innovative Smart Waste Management Technologies.Pdf*, n.d.)

In India, as in many rising economies, solid waste management (SWM) poses a significant challenge, attributable to factors such as inadequate information and facilities for source segregation, lack of sound and feasible technology, insufficient funds, and delayed implementation of legislation and policies at the grassroots level. Addressing these challenges requires improved procedures, training, and skill development, along with proper site resource management and planning to bridge gaps in implementing a sustainable MSWM system in India.

Additionally, issues related to the adoption and application of emerging technologies needs to be considered. The role of both state and central governments is crucial, necessitating robust policies to intervene effectively in the country's SWM landscape. (MEJILLÓN GONZÁLEZ YURI LISBETH TUTOR:, 2022b)

In the era of the Fourth Industrial Revolution, achieving sustainability in waste management is increasingly feasible through the utilization of Internet of Things (IoT), Geographic Information Systems (GIS), and Information and Communication Technology (ICT). These technologies offer benefits such as increased realism, reliability, transparency, efficiency, and optimization. Recommendations for futuristic Solid Waste Management (SWM) technologies that could be adapted in Nepal to improve the efficiency and effectiveness of SWM in to the changes brought about by the COVID-19 pandemic could be explored. (Shah et al., 2022) According to a study by Kocak E, the turning point income level, where technological and structural effects occur in waste management, falls within the range of $20,000–$34,000. Human development and energy efficiency have mitigating effects on Municipal Solid Waste (MSW) issues. Therefore, prioritizing energy efficiency and human development is crucial for sustainable MSW management practices. (Kocak & Baglitas, 2022)

5. Analysis and discussion of sustainable municipal solid waste management strategies and practice

This systematic literature review examines studies published from 2019 to 2023, focusing on sustainable municipal solid waste management (MSWM) strategies and practices across various countries. The review includes 28 studies identified through Google Scholar, addressing the rising global concern over increasing volumes of municipal solid waste (MSW) due to urbanization, market dynamics, and environmental impacts. Effective MSWM begins with the collection and transportation (C&T) of waste, crucial for initiating sustainability efforts and maintaining environmentally friendly, economically sustainable, and socially supportive systems over the long term.

According to Pati and Agrawal (2023), integrating sustainability into the C&T phase is vital. They emphasize the importance of systematic waste collection from various sources and efficient transportation to different disposal options. The role of governance in MSWM is highlighted by Ansori et al. (2022), who stress the participation of government, waste generators, and the private sector. Governments are pivotal in promoting equity and inclusiveness through clear laws, regulations, and proper financial planning. This can be facilitated via public-private partnerships, privatization, and revenue generation mechanisms, such as collection and disposal fees and MSW taxes. Raising community awareness and empowering individuals in MSW management fosters a sense of ownership and responsibility towards sustainability goals, environmental protection, and conservation. The contributions of organizations like the Environmental Public Interest Litigation Network (EPIL Network) in resolving political conflicts related to municipal waste management in China are also noteworthy.

In the realm of decision-making, Kaur and Yadav (2022) identify limitations in current multicriteria decision-making procedures, which often rely on basic scoring methods. These methods struggle to incorporate both physical and intangible criteria, necessitating advanced techniques like fuzzy sets. The study finds that the spherical fuzzy Analytic Hierarchy Process (AHP)-Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is highly effective in prioritizing performance indicators for sustainable MSWM.

Innovative models and technologies play a crucial role in enhancing MSWM. Mejillón González (2022) proposes a mixed-integer linear programming (MILP) model for configuring solid waste management systems, integrating waste generation sources, collection/transfer stations, recycling plants, incinerators, and landfills. This model optimizes facility locations and waste flow to minimize daily costs. Similarly, Alidoosti (2023) presents a model for sustainable bioenergy supply chains using Multi-Objective Programming Mixed-Integer Nonlinear Programming (MOPMINLP). This model emphasizes evaluating social and environmental sustainability dimensions and incorporates fuzzy logic to handle data uncertainties.

Technological advancements are further illustrated by Liam, who discusses the use of waste level sensors in bins or dumpsters to enhance collection efficiency. These sensors, coupled with data analytics, predict optimal collection times, preventing overflow and contamination. Apps like Recycle Nation and I Recycle aid in improving recycling rates by providing users with comprehensive recycling information. Additionally, Ecube Labs' solar-powered trash compactor compresses waste to increase bin capacity and transmits data on fill levels and collection times, streamlining the waste collection process.

These sustainable waste management practices not only minimize environmental impact but also promote social equity and economic benefits. They create employment opportunities, improve public health, and enhance the overall quality of life. Economically, these practices can lead to cost savings through resource recovery, reduced disposal costs, and the development of green technologies and industries. Through integrated planning, technological innovation, and community involvement, sustainable MSWM can significantly contribute to a healthier, cleaner, and more equitable society.

6. Conclusion and recommendations

6.1. Conclusion

To achieve sustainability in MSWM, a multifaceted approach involving integrated planning, technological innovation, financial support, and community involvement is essential. Governments, private sectors, and waste generators must collaborate to implement clear regulations and financial strategies, fostering a sense of ownership and responsibility towards waste management. Sustainable practices such as reduction, recycling, recovery, pollution control, and the adoption of innovative technologies are vital for addressing the growing challenge of municipal solid waste and ensuring a sustainable future.

6.2. Recommendations

Efforts should be directed towards enhancing coordination and collaboration among governmental bodies, institutions, and services at administrative and legislative levels to enhance waste management practices encompassing collection, treatment, and disposal. Establishing a network dedicated to waste management, including a platform for sharing experiences, is essential at the national level. Cooperation between the private and public sectors involved in solid waste management and the circular economy is imperative to ensure the technical, financial, and social sustainability of waste management systems. Large-scale awareness programs on solid waste management and the circular economy should be implemented, focusing on fostering environmentally responsible behaviors and attitudes, promoting sorting, selective collection, and the recovery of materials and energy from waste.

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