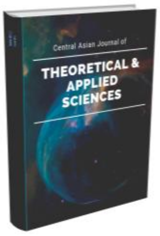

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Article

Industrial Waste-to-Energy Prioritization: A GIS–MCDM Approach to Conversion Process Design and Environmental Implications under Energy Security Constraints

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Abstract: Industrial waste-to-energy (WtE) systems have emerged as a strategic solution for addressing the dual challenges of increasing waste generation and rising energy demand. This study presents an integrated framework based on Geographic Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) for the prioritization and siting of WtE facilities under energy security constraints. The proposed approach combines spatial analysis with structured decision-making techniques to evaluate technical, environmental, economic, and social criteria in a unified framework. GIS is utilized to process and visualize spatial variables such as land use, transportation networks, population density, waste generation patterns, and environmental sensitivity, enabling the identification of suitable locations for WtE development. MCDM methods, particularly the Analytical Hierarchy Process (AHP) and Fuzzy Analytical Hierarchy Process (FAHP), are employed to assign relative weights to evaluation criteria based on expert judgment while addressing uncertainty and inconsistency in decision making. The integration of these methodologies allows for the development of suitability maps that classify potential sites based on their feasibility and sustainability performance. Environmental considerations, including soil characteristics, proximity to water bodies, and topographical conditions, are incorporated alongside socioeconomic and economic factors such as land use compatibility, cost effectiveness, energy recovery potential, and community acceptance. The framework also emphasizes supply chain optimization and logistics efficiency, reducing transportation costs and associated emissions. GIS MCDM improves transparency, accuracy, and reliability of WtE site selection while supporting circular economy goals through landfill reduction, resource recovery, and renewable energy generation for sustainable development.

Keywords: Waste-to-energy, GIS, Multi-Criteria Decision Making, AHP, Sustainable Energy Systems

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1. Introduction

An innovative concept to encounter the challenges of industrial waste management and energy security is the application of a GIS-based Multicriteria decision-making (MCDM) approach for prioritization for Industrial Waste-to-Energy (WtE) [1]. This framework unifies spatial analysis with structured decision making to improve the selection, prioritization, and design of WtE facilities that can transform unrecyclable waste into renewable energy while minimizing environmental impacts. The rising burden of waste production, especially in industrialized and developing regions, has highlighted the need for advanced waste treatment technologies that aim to improve environmental sustainability while generating valuable energy by-products [2]. GIS and multi-criteria decision-making (MCDM) techniques can assist in evaluating various technical, environmental, economic, and social criteria when determining planning for WtE. GIS acts as a spatial tool for evaluating land suitability, distance to transportation networks, waste generation, population distribution, and vulnerability models [3]. Meanwhile, MCDM approaches provide a structured framework for the evaluation of competing alternatives based on multiple weighted criteria. The interconnected model aids decision makers in identifying suitable locations for WtE where they can operate optimally while reducing transport costs and greenhouse gases emitted during conventional waste treatment, such as landfilling [4]. Due to their potential to convert municipal and industrial waste into valuable energy forms like electricity and heat, waste-to-energy technologies have become an important part of modern integrated waste management systems. WtE facilities can drastically reduce the volume of waste, which minimizes dependence on landfills and contributes to generating renewable energy. In terms of GHG emissions, modern facilities utilize state-of-the-art emissions controls and filters that enhance environmental performance and mitigate air pollution concerns [5]. Additionally, the incorporation of CHP systems into WtE plants increases energy efficiency and reduces costs by recovering more energy from waste. Through the employment of high-level approaches, particularly Fuzzy Analytical Hierarchy Process (FAHP), which will enhance the process GIS MCDM model, this uncertainty and subjective judgement elements in site selection by the removal of ambiguity and fuzziness [6]. The proposed FAHP model used in this study provides higher flexibility and accuracy to stakeholders in evaluating criteria such as soil stability, closeness to water bodies, transportation infrastructure, environmental risks associated with the operation of a waste facility, availability of industrial waste, and investigation into socio-economic impact [7]. These all-inclusive evaluations enhance the viability, durability, and societal acceptance of WtE programs.

2. GIS and MCDM in Industrial Waste-to-Energy Prioritization

Geographic Information Systems (GIS) are indispensable for industrial waste-to-energy (WtE) prioritization by allowing spatial analysis and optimization to address environmental, technical, and economic parameters that underpin energy security through sustainable waste management [8]. GIS is an excellent decision support system that integrates geographic, demographic, and infrastructural data to find the best locations for WtE centres. With spatial mapping and analysis, GIS aids decision makers in assessing the suitability of land for various purposes (including waste generation), transportation routes, population density, environmental sensitivity, and more to support efficient and environmentally responsible state planning [9]. For industrial waste-to-energy systems, GIS is especially useful for enhancing supply chain management and logistics. GIS promotes efficiency by analyzing transportation paths/geographic accessibility to enable organizations to minimize the distances traveled for waste collection and disposal, leading to enhanced fuel management [10]. It succeeds in cutting operational costs, whilst simultaneously curbing emissions from the waste transport. Efficient route planning also contributes to improved industrial productivity and resource utilization, making GIS an essential tool of sustainable industrial operations. It is also very helpful for the site selection of renewable energy and WtE projects. This involves a mapping of the sites within GIS, through which technical, environment and socio-economic variables are integrated to show possible site locations [11]. With this process, stakeholders can systematically compare alternative sites to identify sites that maximize the potential for energy generation while limiting ecological and social impacts. The incorporation of GIS with improved187 decision tactics more supports the dependability and accuracy188 of the outcomes for site selection [12]. It incorporates both quantitative data and subjective expert information in an MCDM framework, providing a holistic evaluation of all relevant criteria. Due to the flexibility in evaluation criteria and stakeholder preferences, this method is often used in urban planning, environmental management, land suitability assessment, and renewable energy development. Analytic Hierarchy Process (AHP) and Weighted Sum Model (WSM) are some of the common MCDM methods that have been applied to assess factors like waste availability, transport accessibility, land suitability, safety from the environment (Figure 1) [13]. For industrial WtE project development, along with the evaluation of the proximity of population centers to the specific capacity of economic feasibility. Among the most popularly applied techniques in MCDM is the Analytical Hierarchy Process (AHP) method, which organizes decision criteria into a hierarchical structure to allow for pair-wise comparisons among alternatives [14]. The AHP methodology usually contains a hierarchy to each decision factor, pairwise comparisons between criteria, relative weightings based on the importance of criteria, aggregation of evaluation scores, and finally the identification of the best alternative. The decision framework provides a formalized process to make more consistent decisions, which improves the credibility of site prioritization results.

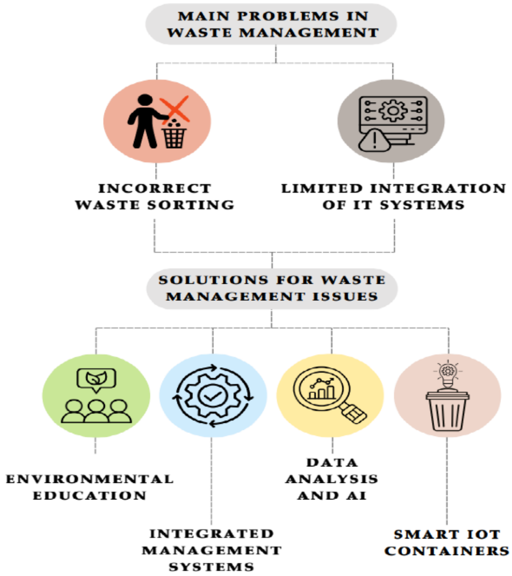

Figure 1. Flowchart mapping core waste management problems (Incorrect Sorting and Limited IT Integration) to behavioral, systemic, and digital solutions [48].

3. GIS Integration and Prioritization Framework in Waste-to-Energy Projects

One of the important directions in the area of Multi-Criteria Decision Making(MCDM) is integration with Geographic Information System (GIS), which considerably improves the spatial dimension of the decision-making process [15]. GIS-based MCDM integrates spatial analysis with multi-criteria decision making, allowing experts to obtain a comprehensive simultaneous assessment of multiple geo-referenced layers that originate from environmental (natural hazards), technical (technology development), and socio-economic aspects of the land. This integration also enhances the process of planning by transforming complex datasets into graphical and interpretable forms that improve accuracy and effectiveness [16]. A significant advantage of utilising GIS-based MCDM is to produce appropriate maps that successfully support what type of project can be implemented in an area selected for site planning (Table 1). Using spatial visualization, identifying places where infrastructure can be built, new renewable energy systems installed, or industrial projects developed becomes simple for the decision-makers. These mapping methods typically contribute to WtE planning with useful information about land availability, infrastructure access, industrial waste source, environmental sensitivity, and community proximity, which enable fact-based decision making [17]. MCDM is crucial in waste-to-energy projects for assessing the viability and sustainability of various waste conversion technologies and facility sites. Due to the fact that WtE systems are strategic decisions involving multiple technical, economic, environmental, and societal factors, a structured decision-making framework is necessary to select appropriate alternatives [18]. It provides a systematic assessment of competing options by striking a balance among conflicting priorities that assists stakeholders in making sure selected solutions are aligned with long-term sustainability goals. MCDM applies to identify various important parameters for the assessment of WtE planning, such as economic feasibility, energy production, environment, solid waste management, and social acceptance [19]. Economic studies concentrate on whether capital expenditures, operating costs, and long-term financial gains can offset the outlay, environmental investigations line up greenhouse gas emissions, risk of pollution, and the saving of natural resources.

Table 1. Key GIS–MCDM Criteria for Industrial Waste-to-Energy (WtE) Site Selection

Criteria Category	Key Parameters	Importance in WtE Planning	Reference
Environmental Criteria	Soil texture, slope, proximity to water bodies, environmental sensitivity	Minimizes ecological degradation, groundwater contamination, and pollution risks	[23–25]
Technical Criteria	Transportation access, infrastructure availability, waste generation patterns	Improves logistics efficiency, waste collection, and energy conversion feasibility	[9–11]
Economic Criteria	Cost-effectiveness, energy recovery potential, operational efficiency	Enhances project sustainability and long-term economic benefits	[19, 32–35]
Socioeconomic Criteria	Population density, land-use compatibility, community acceptance	Reduces social conflict and improves public acceptance	[26, 41]
Decision-Making Criteria	AHP, FAHP weighting, consistency ratio (CR)	Ensures transparent and reliable prioritization process	[20–22]

4. Criteria Selection, Environmental and Socioeconomic Considerations, and Policy Alignment

A systematic selection and weighting of decision criteria is a key component of the prioritization framework for waste-to-energy (WtE) that targets accurate, transparent, and scientifically robust site evaluation. Central to this framework, the Analytical Hierarchy Process (AHP) provides a structured, systematic mathematical process that quantifies subjective expert judgments [20]. The process involves experts from a multitude of disciplines – waste management, environmental science, urban planning, hydrology, and engineering – who conduct pairwise comparisons in order to assign weights to site selection criteria. This process integrates diverse clinical and nonclinical perspectives into a single, evidence-informed analytic system that increases the rigor of decision-making [21]. The Calculation in AHP to assign weight is done using the method of eigenvector, which allows you to distribute importance consistently among the criteria that have been selected. CR is computed here as a validation measure for reliability and logical continuity in expert assessments. The CR values are considered satisfactory if it is decided below 0.1, which shows better agreement among the expert opinions and strengthens framework credibility in prioritization [22]. This approach, with a quantifying weight system in place, allows stakeholders to compare alternatives more objectively and hopes to eliminate bias. One of the most important aspects included in the WtE prioritization process is environmental considerations, as incorrect siting of facilities may cause serious and long-term ecological damage. Soil texture, which is the proportion of sand, silt, and clay in soil, is one such criterion that was found to significantly affect the risk of leachate infiltration into groundwater systems [23]. More permeable soil types could increase contamination risk and deteriorate drinking water quality and ecosystems in the area. Likewise, proximity to rivers, lakes, groundwater extraction points, and other water bodies is rigorously scrutinized so as not to give rise to the risk of water pollution due to leachate or run-off. Land topography and slope are also critical environmental elements for site selection because they are indicators of soil stability, susceptibility to erosion, and structural feasibility [24]. There is a higher risk of soil erosion and environmental degradation on steeper slopes, while flatter terrains generally provide safer and more stable conditions for the construction and operation of facilities. In addition, the framework incorporates hydrogeological conditions, environmental sensitivity, and long-term ecological effects to enable planning that is sustainable as well as environmentally sound [25]. Following environmental criteria, socioeconomic aspects are equally essential to a feasible and acceptable WtE project. Compatibility with land use — Preservation of lands where residential, agricultural, and commercial areas are already situated near pitfalls, avoiding conflicts with industrial development. Waste treatment facilities are generally not wanted in built-up areas and productive agricultural lands, seen as a risk to public health, an increased burden on agricultural productivity (the scarce land needed for food production), and social resistance [26]. It also prioritizes community health to minimize adverse impacts from pollution, odors, or transportation activity.

5. Case Studies and Practical Applications

The environmental, social, and technical implications of waste management strategies from industrial WtE prioritization case studies are a concern for today's world [27]. These review methods of converting waste to energy and evaluate their performance for waste minimization, renewable energy production, sustainability, and energy independence or self-sufficiency. Case studies of real-world situations provide best practice examples and identify common challenges to WtE implementation to support evidence-based planning and policy development [28]. A strong emphasis within these case studies is placed on the evaluation of environmental consequences arising from alternative waste management approaches. Environmental Impact of Different Waste Treatment Approaches — Comparison between Landfilling, Incineration, Recycling, and Energy Recovery Systems Findings overwhelmingly indicate that methods need to be selected with mitigation of greenhouse gas emissions, avoidance of landfilling, conservation of natural resources, and minimization of environmental impacts in mind (Figure 2) [29]. Modern WtE technologies, which are characterized by their ability to not only reduce waste volumes significantly but also produce useful energy from the residual materials generated most sustainably, are increasingly promoted as leading options for more resilient circular economy strategies. One of the major developments mentioned in several case studies is the combination of GIS and MCDM (Multi-Criteria Decision Making) techniques [30]. This integration contributes to decision-making, including spatial analysis coupled with multicriteria evaluation for siting waste management and renewable energy projects. The use of a GIS-based suitability map allows planners to review potential site options that have been subjected to a range of environmental and technical criteria, while MCDM methods allow structured means of arriving at priorities among the alternatives [31]. The studies validated that the usage of selected evaluation criteria, degree of standardization, and weights assigned to each criterion greatly affect the final form sheet site suitability scores assigned and thus project implementation.

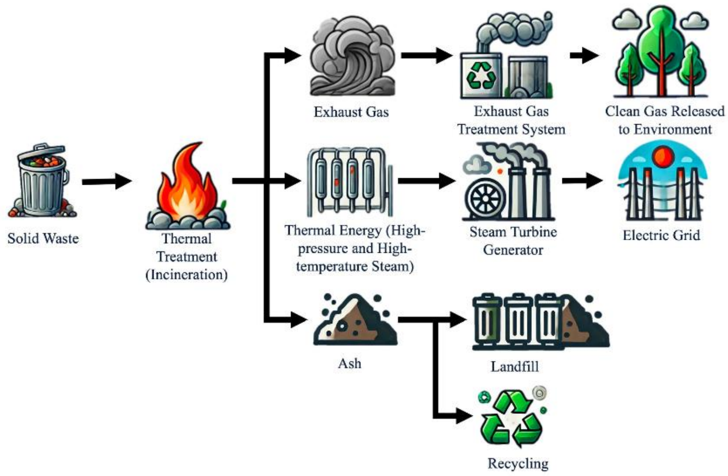

Figure 2. Process diagram illustrating the practical application of solid waste incineration, tracking its conversion into treated exhaust gas, grid electricity via steam turbines, and managed ash byproduct [49].

6. Economic Implications of Waste-to-Energy Projects

Waste-to-Energy (WtE) projects matrix is not limited to impacting the economy, local economies, industrial development, and energy markets. WtE systems provide a sustainable waste disposal solution by converting solid waste material into renewable energy resources, resulting in lower dependence on imported fossil fuels and strengthening the energy security of nations [32]. These projects use waste as a resource, which helps to support economic resiliency and provide for more energy independence. In addition to minimizing the use of landfills, WtE facilities promote recovery, allowing valuable materials to be extracted from waste and providing levers for circular economy principles by converting leftover trash into productive inputs instead of sending it directly to landfills. One of the key economic benefits of WtE projects is that they are capable of generating jobs in various types of industries [33]. Waste-to-energy (WtE) plants create positions in waste collection, transportation, plant construction and engineering, as well as monitoring the environment (construction), maintenance, supervision of employees, and ensuring compliance with regulations (Table 2). These projects also provide indirect job stimulation through support industries and supply chains. Additionally, WtE projects often create job training and vocational education opportunities that can strengthen the local workforce for managing modern waste processing and clean energy systems. This job creation promotes regional economic and social development. The economic feasibility of WtE projects is determined by government policies and financial mechanisms [34]. The foundation for incentive programs acts as an encouragement for lucrative investment in WtE technologies by reducing financial risk and offsetting operating expenses. An extra financial stream of income comes from waste management service fees, such as tipping fees or gate entry charges for waste disposal. These economic incentives bolster investor confidence and reinforce the long-term sustainability of WtE plants [35]. Successful WtE projects facilitate better waste management and pave the way for innovation, sustainable industry practices, and new economic activities. Advanced technologies allow the emergence of secondary resources such as recyclable materials, biobased products, nutrients, and alternative fuels. This diversifies the economy and relieves environmental pressure as traditional waste management practices are notorious for being environmentally damaging.

Table 2. Comparison of Waste Management Approaches and Their Implications

Waste Management Approach	Energy Recovery	Environmental Impact	Economic Benefit	Sustainability Contribution	Reference
Landfilling	Very low	High greenhouse gas emissions and land degradation	Low	Poor	[29]
Recycling	Moderate	Reduces resource depletion and waste generation	Moderate	High	[29, 35]
Incineration	High	Emission concerns but reduced waste volume	Moderate to High	Moderate	[5, 29]
Waste-to-Energy (WtE)	High	Lower landfill dependency and improved emission control	High through energy generation and job creation	Very High	[32–35, 43]

7. Discussion

The integration of Geographic Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) approaches in the prioritisation of Industrial waste to energy (WtE) represents a fundamental paradigm shift methodology regarding one or two dilemmas between waste management, renewable energy generation, and energy security [36]. Based on these findings, this study has shown that spatial analysis combined with systematic decision support can enhance WtE planning effectiveness in terms of allowing decision makers to simultaneously evaluate multiple competing technical, environmental, economic, and social criteria. This integrated framework is instrumental in sustainable development by optimizing resource use and limiting environmental impacts [37]. The GIS MCDM approach can enhance the accuracy of site selection for WtE facilities, highlighting one of its strong points. Solid waste disposal has been linked to greenhouse gas emissions, leaching of solid waste contaminants into groundwater, and degradation of land in traditional landfill practices. These concerns can be addressed through possible challenges and risks in GIS-based suitability mapping, which allows spatial visualization of land use, transportation accessibility, industrial waste availability, topography, population density, and environmental sensitivity [38]. This spatial feature enables planners to market appropriate places to their end users, while also preventing the occupation of ecologically sensitive areas as well as densely populated ones, where competition for land is more prone to foster conflict on both ecological and social levels. The production of the suitability maps classifying sites as unsuitable, moderately suitable, and highly suitable areas facilitates not only efficient decision-making but also ensures transparency in planning [39]. The contributions of MCDM, particularly the Analytical Hierarchy Process (AHP) and Fuzzy Analytical Hierarchy Process (FAHP), seem to be just as important for reinforcing the robustness of WtE prioritization models. Since planning Waste to Energy (WtE) also faces multiple conflicting goals in the presence of uncertainty, decision makers should not rely on technical feasibility alone for decision making [40]. AHP and FAHP facilitate structuring and comparing different criteria in a pairwise manner, allowing weighting of these alternatives according to their importance. The involvement of disciplinary expertise from environmental science, hydrology, urban planning, and engineering makes the decisions multidisciplinary and scientifically based [41]. Furthermore, the consistency check enhances the confidence in the prioritization results, making it more transparent and reliable. The environmental aspects are still the primary condition for a successful WtE implementation. The discussion emphasises that improper site selection leads to severe environmental degradation, including leachate pollution of groundwater, air pollution, soil deterioration, and disruption of the ecosystem. Some factors need to be considered for environmental breathing of the site, including soil permeability, distance to water bodies, stability of slopes, and hydrogeological conditions [42]. Contemporary WtE technologies, particularly those that utilize sophisticated emission control systems, have shown a significant ability to mitigate environmental impacts by offering a more environmentally friendly alternative than the conventional waste disposal methods. WtE systems can reduce the waste volume by 90% while recycling materials and producing renewable energy, thus strengthening their environmental relevance in a transition to low-carbon development [43]. GIS-MCDM also helps improve operational efficiency via optimized supply chain management. Waste collection and distribution transportation routing helps you to cut back on gasoline consumption, carbon emissions, and operations bill. Besides the economic impact, this also has an environmental sustainability role through minimizing the footprint of waste management systems. Linked with GIS, location allocation models will optimize efficiency by locating facilities such that the optimal distance to provide service is maximized while transportation burden is minimized [44]. Findings from the case studies further strengthen the need for adaptive and context-sensitive planning in WtE projects. The success of WtE programmes is highly dependent on the local environmental conditions, waste generation patterns and capabilities, as well as technological and regulatory environments. Hence, region-wise herding may not apply as a one-size-fits-all solution. GIS-based multicriteria frameworks provide flexibility, which allows the adaptation of evaluation criteria to local needs and sustainability aims [45]. As novel technologies, new policies, and climate-related challenges reshape waste management systems worldwide, this flexibility becomes all the more relevant. The growing inclination from the linear economy to the circular economy strongly reinforces the relevance of WtE technologies as a strategic infrastructure [46]. These systems turn waste from cities and industrial companies into energy and secondary resources, generating directional benefits of resource efficiency, landfill reduction, and therefore sustainable industrial development [47]. The WtE facilities with advanced technologies are now being connected to their possible economic outputs, not only as energy production but also recycled materials, alternative fuels, and bio-based products. These developments are in line with the global sustainability strategy of decreasing resource waste and fostering green economic growth.

8. Conclusion

Industrial waste-to-energy (WtE) prioritization using GIS and MCDM provides an effective framework for addressing waste management challenges while enhancing energy security and environmental sustainability. The integration of spatial analysis with systematic decision-making improves site selection, resource efficiency, and operational planning. Consideration of environmental, socioeconomic, and economic factors ensures balanced and sustainable outcomes for WtE implementation. Advanced approaches such as AHP and FAHP strengthen decision accuracy by incorporating expert judgment and uncertainty analysis. Overall, GIS-based MCDM frameworks support resilient waste management systems, renewable energy generation, and the transition toward a sustainable circular economy.

REFERENCES

[1] K. A. Rambo, D. M. Warsinger, S. J. Shanbhogue, and A. F. Ghoniem, "Water-energy nexus in Saudi Arabia," *Energy Procedia*, vol. 105, pp. 3837–3843, 2017. Available: https://doi.org/10.1016/j.egypro.2017.03.899

[2] I. Albaik, R. Al-Dadah, S. Mahmoud, M. K. Almesfer, M. A. Ismail, E. Elsayed, and M. Saleh, "A comparison between the packed and coated finned tube for adsorption system using aluminium fumarate: Numerical study," *Therm. Sci. Eng. Prog.*, vol. 22, p. 100859, 2021. Available: https://doi.org/10.1016/j.tsep.2021.100859

[3] D. Dajnak and F. Lockwood, "Use of thermal energy from waste for seawater desalination," *Desalination*, vol. 130, pp. 137–146, 2000. Available: https://doi.org/10.1016/S0011-9164(00)00081-3

[4] S. Udomsri, A. R. Martin, and V. Martin, "Thermally driven cooling coupled with municipal solid waste-fired power plant: Application of combined heat, cooling and power in tropical urban areas," *Appl. Energy*, vol. 88, pp. 1532–1542, 2011. Available: https://doi.org/10.1016/j.apenergy.2010.10.040

[5] Y. Shao, J. Wang, F. Preto, J. Zhu, and X. Fu, "Ash Deposition in Biomass Combustion or Co-Firing for Power/Heat Generation," *Energies*, vol. 5, pp. 5171–5189, 2012. Available: https://doi.org/10.3390/en5125171

[6] M. Bolhàr-Nordenkampf, T. Nummelin, T. Luomaharju, and J. Viljanen, "Operating Experience from the Worlds Largest Waste Fired Circulating Fluidized Bed Reactor in Västerås," *Waste Manag.*, vol. 5, pp. 168–178, 2015.

[7] G. Fitzgerald, "Pre-processing and treatment of municipal solid waste (MSW) prior to incineration," in *Waste to Energy Conversion Technology*, Amsterdam, The Netherlands: Elsevier, 2013, pp. 55–71.

[8] A. Tozlu, A. Abusoglu, E. Ozahi, and A. Anvari-Moghaddam, "Municipal solid waste-based district heating and electricity production: A case study," *J. Clean. Prod.*, vol. 297, p. 126495, 2021. Available: https://doi.org/10.1016/j.jclepro.2021.126495

[9] M. Fabricius, D. Tarp, T. W. Rasmussen, and A. Arabkoohsar, "Utilization of Excess Production of Waste-Fired CHP Plants for District Cooling Supply, an Effective Solution for a Serious Challenge," *Energies*, vol. 13, p. 3319, 2020. Available: https://doi.org/10.3390/en13133319

[10] W. Köppen and R. Geiger, *Handbuch der Klimatologie*, vol. 1, Berlin, Germany: Gebrüder Borntraeger, 1930.

[11] B. Leckner and F. Lind, "Combustion of municipal solid waste in fluidized bed or on grate—A comparison," *Waste Manag.*, vol. 109, pp. 94–108, 2020. Available: https://doi.org/10.1016/j.wasman.2020.04.050

[12] S. S. AlRwashdeh and H. Ammari, "Life cycle cost analysis of two different refrigeration systems powered by solar energy," *Case Stud. Therm. Eng.*, vol. 16, p. 100559, 2019. Available: https://doi.org/10.1016/j.csite.2019.100559

[13] H. Chen, "Forward Osmosis of Water Across Ionic Membranes for Desalination," University of Delaware, Newark, DE, USA, 2020.

[14] Y. S. H. Najjar and A. Abu-Shamleh, "Performance evaluation of a large-scale thermal power plant based on the best industrial practices," *Sci. Rep.*, vol. 10, p. 20661, 2020. Available: https://doi.org/10.1038/s41598-020-77561-1

[15] R. Ibikunle, I. Titiladunayo, B. Akinnuli, S. Dahunsi, and T. Olayanju, "Estimation of power generation from municipal solid wastes: A case Study of Ilorin metropolis, Nigeria," *Energy Rep.*, vol. 5, pp. 126–135, 2019. Available: https://doi.org/10.1016/j.egyr.2018.11.005

[16] *Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste*, ASTM D5231-92, West Conshohocken, PA, USA, 2016.

[17] O. K. M. Ouda, "Assessment of the Environmental Values of Waste-to-Energy in the Gaza Strip," *Curr. World Environ. J.*, vol. 8, pp. 355–364, 2013. Available: https://doi.org/10.12944/CWE.8.3.04

[18] K. M. N. Islam, "Municipal Solid Waste to Energy Generation in Bangladesh: Possible Scenarios to Generate Renewable Electricity in Dhaka and Chittagong City," *J. Renew. Energy*, vol. 2016, p. 1712370, 2016. Available: https://doi.org/10.1155/2016/1712370

[19] D. Konwar and T. Gogoi, "Performance of double effect H2O–LiCl absorption refrigeration systems and comparison with H2O–LiBr systems, Part 1: Energy analysis," *Therm. Sci. Eng. Prog.*, vol. 8, pp. 184–203, 2018. Available: https://doi.org/10.1016/j.tsep.2018.08.013

[20] M. Ameri, S. S. Mohammadi, M. Hosseini, and M. Seifi, "Effect of design parameters on multi-effect desalination system specifications," *Desalination*, vol. 245, pp. 266–283, 2009. Available: https://doi.org/10.1016/j.desal.2008.07.013

[21] B. Ortega-Delgado, L. García-Rodríguez, and D.-C. Alarcón-Padilla, "Opportunities of improvement of the MED seawater desalination process by pretreatments allowing high-temperature operation," *Desalination Water Treat.*, vol. 97, pp. 94–108, 2017. Available: https://doi.org/10.5004/dwt.2017.21665

[22] N. Ghaffour, T. M. Missimer, and G. L. Amy, "Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability," *Desalination*, vol. 309, pp. 197–207, 2013. Available: https://doi.org/10.1016/j.desal.2012.10.015

[23]R. E. Dos Santos, I. F. S. Dos Santos, R. M. Barros, A. P. Bernal, G. L. Tiago Filho, and F. D. G. B. da Silva, "Generating electrical energy through urban solid waste in Brazil: An economic and energy comparative analysis," *J. Environ. Manag.*, vol. 231, pp. 198–206, 2019. Available: https://doi.org/10.1016/j.jenvman.2018.10.015

[24] M. W. Shahzad, M. Burhan, G. Ghaffour, and K. C. Ng, "A multi evaporator desalination system operated with thermocline energy for future sustainability," *Desalination*, vol. 435, pp. 268–277, 2018. Available: https://doi.org/10.1016/j.desal.2017.05.020

[25]I. M. Costa and M. Ferreira Dias, "Evolution on the solid urban waste management in Brazil: A portrait of the Northeast Region," *Energy Rep.*, vol. 6, pp. 878–884, 2020. Available: https://doi.org/10.1016/j.egyr.2019.11.020

[26]N. Ferronato and V. Torretta, "Waste Mismanagement in Developing Countries: A Review of Global Issues," *Int. J. Environ. Res. Public Health*, vol. 16, no. 6, p. 1060, 2019. Available: https://doi.org/10.3390/ijerph16061060

[27]A. Kamran, M. N. Chaudhry, and S. A. Batool, "Effects of socio-economic status and seasonal variation on municipal solid waste composition: A baseline study for future planning and development," *Environ. Sci. Eur.*, vol. 27, p. 16, 2015. Available: https://doi.org/10.1186/s12302-015-0049-5

[28]R. F. Rego, L. R. S. Moraes, and I. Dourado, "Diarrhoea and garbage disposal in Salvador, Brazil," *Trans. R. Soc. Trop. Med. Hyg.*, vol. 99, no. 1, pp. 48–54, 2005. Available: https://doi.org/10.1016/j.trstmh.2004.03.007

[29]M. Liikanen, J. Havukainen, E. Viana, and M. Horttanainen, "Steps towards more environmentally sustainable municipal solid waste management—A life cycle assessment study of São Paulo, Brazil," *J. Clean. Prod.*, vol. 196, pp. 150–162, 2018. Available: https://doi.org/10.1016/j.jclepro.2018.06.022

[30]T. N. Silva, F. S. N. Freitas, and G. Candiani, "Evaluation of surface emissions of gas from large landfills," *Eng. Sanitária Ambient.*, vol. 18, no. 1, pp. 95–104, 2013. Available: https://doi.org/10.1590/S1413-41522013000100011

[31]J. Malinauskaite, H. Jouhara, D. Czajczyńska, P. Stanchev, E. Katsou, P. Rostkowski, R. J. Thorne, J. Colón, S. Ponsá, and F. Al-Mansour, "Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe," *Energy*, vol. 141, pp. 2013–2044, 2017. Available: https://doi.org/10.1016/j.energy.2017.11.128

[32]G. Candiani and E. Viana, "Emissões fugitivas de metano em aterros sanitários," *GEOUSP Espaço Tempo*, vol. 21, no. 3, p. 845, 2018. Available: https://doi.org/10.11606/ext.v21i3.142826

[33]W. Gu, D. Liu, and C. Wang, "Energy recovery potential from incineration using municipal solid waste based on multi-scenario analysis in Beijing," *Environ. Sci. Pollut. Res.*, vol. 28, pp. 27119–27131, 2021. Available: https://doi.org/10.1007/s11356-021-12543-9

[34]H. Hettiarachchi, J. N. Meegoda, and S. Ryu, "Organic Waste Buyback as a Viable Method to Enhance Sustainable Municipal Solid Waste Management in Developing Countries," *Int. J. Environ. Res. Public Health*, vol. 15, no. 11, p. 2483, 2018. Available: https://doi.org/10.3390/ijerph15112483

[35]T. Matheson, "Disposal Is Not Free: Fiscal Instruments to Internalize the Environmental Costs of Solid Waste," IMF, Washington, DC, USA, Working Paper No. 2019/283, 2019. Available: https://doi.org/10.5089/9781513519807.001

[36]S. C. Barman, "Heterogeneous Catalysis for Industrial Waste to Energy Conversion Process Design and Environmental Implications," *Journal of Primeasia*, vol. 2, no. 1, pp. 1–9, 2021, Art. no. 10678, doi: 10.25163/primeasia.2110678.

[37]F. C. Eboh, B.-Å. Andersson, and T. Richards, "Economic evaluation of improvements in a waste-to-energy combined heat and power plant," *Waste Manag.*, vol. 100, pp. 75–83, 2019. Available: https://doi.org/10.1016/j.wasman.2019.09.006

[38]M. Krnávek, V. Freisleben, and Z. Jegla, "Advanced Modular and Integrated Equipment Design for Small-capacity Waste-to-Energy Units," *Chem. Eng. Trans.*, vol. 88, pp. 937–942, 2021. Available: https://doi.org/10.3303/CET2188156

[39]N. Scarlat, V. Motola, J. F. Dallemand, F. Monforti-Ferrario, and L. Mofor, "Evaluation of energy potential of Municipal Solid Waste from African urban areas," *Renew. Sustain. Energy Rev.*, vol. 50, pp. 1269–1286, 2015. Available: https://doi.org/10.1016/j.rser.2015.05.067

[40]R. G. de Souza Marotta Alfaia, A. M. Costa, and J. C. Campos, "Municipal solid waste in Brazil: A review," *Waste Manag. Res. J. Sustain. Circ. Econ.*, vol. 35, no. 12, pp. 1195–1209, 2017. Available: https://doi.org/10.1177/0734242X17735375

[41]S. N. de Souza, M. Horttanainen, J. Antonelli, O. Klaus, C. A. Lindino, and C. E. Nogueira, "Technical potential of electricity production from municipal solid waste disposed in the biggest cities in Brazil: Landfill gas, biogas and thermal treatment," *Waste Manag. Res. J. Sustain. Circ. Econ.*, vol. 32, no. 10, pp. 1015–1023, 2014. Available: https://doi.org/10.1177/0734242X14544352

[42]H. K. Jeswani and A. Azapagic, "Assessing the environmental sustainability of energy recovery from municipal solid waste in the UK," *Waste Manag.*, vol. 50, pp. 346–363, 2016. Available: https://doi.org/10.1016/j.wasman.2016.02.010

[43]S. Evangelisti, P. Lettieri, D. Borello, and R. Clift, "Life cycle assessment of energy from waste via anaerobic digestion: A UK case study," *Waste Manag.*, vol. 34, no. 1, pp. 226–237, 2014. Available: https://doi.org/10.1016/j.wasman.2013.09.013

[44]S. L. Nordahl, J. P. Devkota, J. Amirebrahimi, Smith, H. M. Breunig, C. V. Preble, A. J. Satchwell, L. Jin, N. Journal. Brown, and T. W. Kirchstetter, "Life-Cycle Greenhouse Gas Emissions and Human Health Trade-Offs of Organic Waste Management Strategies," *Environ. Sci. Technol.*, vol. 54, no. 15, pp. 9200–9209, 2020. Available: https://doi.org/10.1021/acs.est.0c00364

[45]R. M. S. Dutra, L. Harue Yamane, and R. Ribeiro Siman, "Influence of the expansion of the selective collection in the sorting infrastructure of waste pickers' organizations: A case study of 16 Brazilian cities," *Waste Manag.*, vol. 77, pp. 50–58, 2018. Available: https://doi.org/10.1016/j.wasman.2018.05.003

[46]I. T. P. Miranda, R. Fidelis, D. A. de Souza Fidelis, L. A. Pilatti, and C. T. Picinin, "The Integration of Recycling Cooperatives in the Formal Management of Municipal Solid Waste as a Strategy for the Circular Economy—The Case of Londrina, Brazil," *Sustainability*, vol. 12, no. 24, p. 10513, 2020. Available: https://doi.org/10.3390/su122410513

[47]Z. J. L. Nogueira, C. Jacobsen Leopoldino, L. H. Yamane, and R. Ribeiro Siman, "Waste pickers organizations and municipal selective waste collection: Sustainability indicators," *Waste Manag.*, vol. 118, pp. 219–231, 2020. Available: https://doi.org/10.1016/j.wasman.2020.08.031

[48]A. S. A. Fernandes, L. S. Pinheiro, and A. B. F. M. do Nascimento, "An analysis of intermunicipal consortia to provide waste services based on institutional collective action," *Rev. Adm. Pública*, vol. 54, no. 3, pp. 501–523, 2020. Available: https://doi.org/10.1590/0034-761220190288x

[49]D. P. da Silva, H. C. Silvestre, and A. A. Embalo, "Inter-municipal cooperation in Brazil: The case of solid waste consortia," *Rev. Adm. Pública*, vol. 54, no. 5, pp. 1239–1259, 2020. Available: https://doi.org/10.1590/0034-761220190333x