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Environmental Impact Assessment Report of Waste to Energy Projects

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Abstract

The circular economy (CE) and waste-to-energy (WtE) projects represent complementary strategies for transitioning from linear "take-make-dispose" systems to sustainable resource management. The CE prioritizes waste prevention, reuse, and recycling to close material loops, while WtE technologies convert non-recyclable waste into energy, mitigating landfill reliance and fossil fuel dependence. This synergy addresses two critical challenges: escalating global waste volumes and the urgent need for renewable energy sources.

Modern WtE systems, including incineration, gasification, pyrolysis, and anaerobic digestion, align with CE principles by recovering energy and materials (e.g., metals from ash) from end-of-life waste streams. For instance, advanced incinerators achieve 80–90% landfill diversion rates and generate electricity or heat, while anaerobic digestion transforms organic waste into biogas and nutrient-rich fertilizers. However, WtE's role remains contentious, as critics argue it may disincentivize waste reduction and recycling—core tenets of the CE.

Key benefits of integrating WtE into CE frameworks include:

1. Resource Efficiency: Valorizing non-recyclable waste into energy and secondary raw materials.
2. Climate Mitigation: Reducing methane emissions from landfills and displacing fossil fuel energy.
3. Economic Resilience: Creating jobs in waste management and energy sectors.

Challenges persist, such as emissions control (e.g., dioxins, CO_2), public opposition due to health concerns, and equitable siting of facilities. Successful integration requires stringent regulations, technological innovation (e.g., carbon capture), and policies that prioritize waste hierarchy compliance.

Case studies from Europe and Asia demonstrate that WtE projects, when coupled with robust recycling infrastructure and stakeholder engagement, can enhance circularity. For example, Denmark's Amager Bakke plant combines energy recovery with public amenities and carbon capture, while Singapore's Tuas Nexus integrates WtE with material recovery facilities.

In conclusion, WtE is not a standalone solution but a transitional tool within broader CE strategies. Its sustainability hinges on balancing energy recovery with waste minimization, ensuring it complements—rather than competes with—recycling and reuse efforts. Future advancements must prioritize low-carbon technologies, circular design, and inclusive governance to realize a zero-waste, energy-secure future.

Keywords: Circular economy, waste-to-energy, resource recovery, renewable energy, sustainability, carbon neutrality.

Preface or Acknowledgements

The global imperative to transition from a linear "take-make-dispose" model to a circular economy has never been more urgent. As societies grapple with mounting waste crises, resource scarcity, and climate change, waste-to-energy (WtE) projects emerge as a critical bridge between waste management and sustainable energy production. This work explores the symbiotic relationship between circular economy principles and WtE systems, emphasizing their potential to transform waste into value while reducing environmental degradation.

This project was born from a recognition of two intertwined challenges: the unsustainable volume of waste overwhelming landfills and the pressing need to decarbonize energy systems. By interrogating how WtE technologies—such as incineration, gasification, and anaerobic digestion—can align with circular economy goals, this study seeks to contribute actionable insights for policymakers, industry leaders, and communities striving to balance economic growth with planetary boundaries.

The following chapters synthesize technological innovations, environmental trade-offs, and socioeconomic considerations, drawing on global case studies to highlight successes and pitfalls. It is my hope that this work sparks dialogue on integrating WtE into holistic circular strategies, ensuring that energy recovery complements—rather than undermines—waste reduction and recycling efforts.

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KHALDO ALDARRAJI
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Chapter One: Introduction and Aim of Study

The circular economy represents a transformative shift from the traditional linear "take-make-dispose" model, emphasizing resource efficiency through reduction, reuse, recycling, and regeneration. By closing material loops, it aims to minimize waste and extend product lifecycles, fostering sustainable growth and reducing environmental impact. Central to this model is the principle of valuing waste as a resource, thereby unlocking opportunities for innovation and sustainability.

Waste-to-Energy (WtE) projects emerge as a strategic component within the circular economy framework, particularly in the "recover" phase. These technologies, including incineration, gasification, pyrolysis, and anaerobic digestion—convert non-recyclable waste into electricity, heat, or fuels. By diverting waste from landfills, WtE reduces methane emissions and harnesses energy that might otherwise be lost, aligning with circular goals by extracting residual value from materials at their end-of-life.

However, WtE's role is nuanced. While it offers benefits such as renewable energy generation, reduced landfill dependence, and greenhouse gas mitigation, it must complement—not replace—reduction, reuse, and recycling efforts. Critics highlight challenges like potential emissions, toxic byproducts, and the risk of disincentivizing waste prevention if prioritized over higher circular strategies. Sustainable integration of WtE requires stringent pollution controls, advanced sorting to avoid burning recyclables, and public engagement to address health concerns.

In conclusion, WtE projects, when thoughtfully implemented within a holistic waste management hierarchy, can enhance circular economies by managing non-recyclable waste responsibly. Balancing innovation with environmental and social considerations ensures that energy recovery supports, rather than undermines, the broader vision of a resource-efficient future.

Chapter Two: Literature Review

Waste-to-Energy (WtE) technologies have garnered significant attention in recent decades as sustainable solutions to manage growing waste volumes while addressing energy demands. This review synthesizes key findings from academic research, policy analyses, and case studies to explore the technological, environmental, economic, and social dimensions of WtE projects.

2.1. Technological Advancements in WtE

WtE encompasses diverse technologies that convert waste into energy, including:

- Incineration: The most established method, involving combustion of municipal solid waste (MSW) to generate heat and electricity. Studies highlight its high energy recovery efficiency (~20–25%) but criticize its emissions of dioxins, particulate matter, and CO_2 (Astrup et al., 2015).
- Gasification and Pyrolysis: Thermochemical processes that decompose waste at high temperatures in oxygen-limited environments. These methods produce syngas ($CO + H_2$) or bio-oil, with lower emissions than incineration but higher operational complexity and costs (Kumar & Samadder, 2020).
- Anaerobic Digestion (AD): Biological decomposition of organic waste to produce biogas (methane). AD is lauded for its suitability for food and agricultural waste but faces challenges in scalability and feedstock contamination (Appels et al., 2011).
- Plasma Arc Gasification: Emerging technology using ionized gas to break down waste into syngas and inert slag. While promising for hazardous waste treatment, high energy input and capital costs limit adoption (Materazzi et al., 2019).

Technological innovation is central to optimizing Waste-to-Energy (WtE) systems, balancing energy recovery with environmental and economic sustainability. This review focuses on advancements in key WtE technologies, their efficiency improvements, and emerging trends that address historical limitations.

2.1.1 Incineration: Modernization and Emission Control

Incineration remains the most widely adopted WtE technology globally, but recent advancements have targeted efficiency and emissions reduction:

- High-Efficiency Systems: Modern moving grate incinerators achieve energy recovery rates of 25–30%, up from 15–20% in older models, by optimizing combustion temperatures (1,200–1,500°C) and steam cycle integration (Astrup et al., 2019).

- Emission Mitigation: Advanced flue gas treatment systems, such as selective catalytic reduction (SCR) for NO_x, activated carbon injection for dioxins, and electrostatic precipitators for particulate matter, reduce pollutants to near-zero levels (Chen et al., 2022).
- Waste-to-Combined Heat and Power (CHP): Plants in Scandinavia and Japan now prioritize district heating alongside electricity, achieving 80–90% total energy efficiency (Eurostat, 2023).

Critique: Despite improvements, concerns persist over CO_2 emissions and ash management. Carbon capture and storage (CCS) retrofits are being piloted in the EU to address this (Hansen et al., 2023).

2.1.2 Gasification and Pyrolysis: Scaling Thermochemical Processes

Gasification and pyrolysis are gaining traction as flexible, low-emission alternatives:

- Plasma Gasification: Ionized gas torches (up to 5,000°C) convert waste into syngas and vitrified slag (non-leachable). Japan's Utashinai plant processes 300 tons/day with 99% landfill diversion, though high energy costs remain a barrier (Materazzi et al., 2021).
- Fluidized Bed Gasifiers: Improved designs handle heterogeneous waste streams, including plastics and biomass, with 70–80% syngas purity (Kumar et al., 2022).
- Catalytic Pyrolysis: Novel catalysts (e.g., zeolites) enhance bio-oil yield from organic waste by 30%, enabling drop-in fuel production (Zhang et al., 2023).

Challenges: High capital costs (~200–200–500 million for large plants) and feedstock pre-treatment requirements limit scalability in developing regions (World Bank, 2022).

2.1.3 Anaerobic Digestion (AD): Biogas Optimization

AD has evolved to address organic waste management and energy needs:

- Co-Digestion: Mixing food waste, agricultural residues, and sewage sludge boosts biogas yields by 40–60% (Li et al., 2021).
- Microbial Consortia Engineering: Genetically modified microbes enhance methane production rates, with lab-scale trials showing 25% efficiency gains (Appels et al., 2023).

- Small-Scale Modular Systems: Containerized digesters in India and Kenya process 1–5 tons/day of organic waste, providing off-grid energy to rural communities (Gupta et al., 2022).

Limitations: Contamination (e.g., plastics in feedstock) and slow digestion rates hinder large-scale adoption.

2.1.4 Emerging Technologies: Beyond Conventional Methods

Emerging technologies in waste-to-energy (WtE) projects are moving beyond conventional methods by focusing on enhanced efficiency, reduced emissions, and the potential for resource recovery. These advancements include improved thermochemical processes like pyrolysis and gasification, biochemical methods like anaerobic digestion, and the integration of AI and robotics for optimized waste sorting and management. Additionally, carbon capture technologies are being explored to further minimize the environmental impact of WtE facilities. By embracing these emerging technologies, waste-to-energy projects can become more sustainable, efficient, and contribute to a circular economy.

- Hydrothermal Carbonization (HTC): Converts high-moisture organic waste (e.g., sewage sludge) into hydrochar (solid fuel) at 180–250°C, avoiding energy-intensive drying (Berge et al., 2021).
- Enzymatic Waste Conversion: Designer enzymes break down complex polymers (e.g., PET plastics) into fermentable sugars for biofuel production, though commercialization is nascent (Ellis et al., 2023).
- Solar-Driven WtE: Pilot projects in the UAE use concentrated solar power to augment gasification temperatures, reducing fossil fuel reliance (Almasoud & Gandayh, 2023).

2.1. 5 Digital Integration and AI

In the current era, waste management activities, including energy and material recycling, may create indirect environmental impacts beyond waste management systems. Energy waste is used to reproduce different products, such as electricity, heat, compost, and biofuels. Effective environmental protection depends on the quality of the information available for a proper decision. Reliable data collection is essential to facilitate planning processes in the effective planning of waste management. Firstly, with a neural network, the amount of waste is predicted. An enhanced machine learning algorithm further improves waste collection on energy costs based on volatile sustainable energy markets.

Findings showed that proposed algorithms based on machine learning have been used successfully to generate efficient waste models. The simulation analysis shows that the analysis of waste quantity reduced by 90% using the proposed method, landfill analysis as 40%, and transportation reduced by 15%. (Artificial intelligence for planning of energy and waste management Author links open overlay panel Jueru Huang, Dmitry D. Koroteev).

- Smart Sorting with AI: Machine learning algorithms optimize waste segregation, increasing calorific value of feedstock for incinerators by 15–20% (IBM, 2022).
- Predictive Maintenance: IoT sensors monitor plant equipment in real time, reducing downtime by 30% in EU WtE facilities (Siemens, 2023).
- Blockchain for Circularity: Platforms like "Waste Ledger" track waste streams and energy outputs, ensuring transparency in resource recovery (Jiang et al., 2023).

2.1.6 Regional Trends and Case Studies

Waste-to-energy (WtE) projects are gaining traction globally as a sustainable solution for managing waste and generating energy. Several regional trends and case studies highlight the growing interest and implementation of WtE technologies. Overall, WtE is a rapidly evolving field with regional variations in adoption and implementation. Successful WtE projects require careful consideration of local context, technology selection, public engagement, and economic viability.

- Europe: Denmark's Amager Bakke plant incinerates waste with CCS and doubles as a ski slope, showcasing multifunctional design (Copenhagen Municipality, 2023).
- Asia: Singapore's Tuas Nexus integrates gasification with AD, achieving 100% energy self-sufficiency (NEA, 2023).
- Africa: South Africa's Bio2Watt employs AD to convert dairy farm waste into 4.6 MW of electricity, addressing energy poverty (IRENA, 2022).

2.1.7 Challenges and Future Directions

Waste-to-energy (WtE) projects face challenges related to waste composition variability, high initial investment costs, and the need for robust regulatory frameworks. Future directions include integrating WtE with other renewable energy sources, leveraging digital technologies for optimization, and expanding into new markets, particularly in developing countries.

- Cost Reduction: Modular, prefabricated WtE systems could lower capital costs by 30–50% (IRENA, 2023).
- Circular Synergies: Integrating WtE with material recovery facilities (MRFs) to salvage metals and minerals from ash (e.g., Sweden's 99% metal recovery rate).
- Policy Alignment: Stricter emissions standards and subsidies for R&D (e.g., EU's Green Deal funding for CCS-WtE hybrids).

This review highlights the transformative potential of WtE technologies while underscoring the need for context-specific solutions and cross-sector collaboration.

2.2. Environmental Impacts

Environmental impact assessment (EIA) is a formal process used to predict environmental consequences, which may be positive or negative, of a plan, policy, program, or project prior to approval. The International Association for Impact Assessment (IAIA) defines an environmental impact assessment as "*…the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made.*" EIAs should contain proposals for scheme design or operation to reduce these impacts to acceptable levels or to address different technical solutions. "Acceptable levels" is a contested and political concept, though the purpose of an EIA is to inform better decision-making by bringing wider environmental concerns into consideration alongside economic, social, and political concerns.

Environmental Impact Assessment (EIA) is a process that evaluates the potential environmental effects of a planned project or development. The goal is to identify, predict, and evaluate the likely consequences that the planned project could have on the environment, and suggest actions to reduce or avoid any negative effects. The EIA process usually consists of various stages such as scoping, collecting baseline data, identifying impacts, assessing impacts, planning for mitigation and management, consulting the public, and making decisions. The EIA report offers decision-makers detailed information about the probable environmental effects of the proposed project and suggests methods to mitigate or prevent these impacts.

Benefits:

- Landfill Diversion: WtE reduces landfill use by 80–90%, mitigating methane emissions (a potent GHG) (Brunner & Rechberger, 2015).
- Renewable Energy: WtE offsets fossil fuel consumption. For example, EU WtE plants supply ~2% of electricity and 14% of district heating (CEWEP, 2021).

- Material Recovery: Modern plants recover metals from ash, aligning with circular economy goals (Jiang et al., 2022).

Criticisms:

- Air Pollution: Older incinerators emit NO_x, SO_2, and heavy metals, though advanced filtration systems (e.g., activated carbon, scrubbers) reduce risks (Chen et al., 2020).
- Carbon Footprint: Incineration emits CO_2, but lifecycle assessments (LCAs) suggest net benefits when displacing fossil fuels and avoiding methane from landfills (Psomopoulos et al., 2009).

Waste-to-Energy (WtE) technologies offer a dual solution to waste management and energy generation, but their environmental implications remain a focal point of academic and policy debates. This review synthesizes recent research to evaluate the multifaceted environmental impacts of WtE systems, balancing their benefits against ecological risks and contextualizing their role in sustainable waste management.

2.2.1 Greenhouse Gas (GHG) Emissions and Climate Impact

Greenhouse gas (GHG) emissions, primarily from human activities, are the main driver of climate change. These gases trap heat in the atmosphere, leading to a warming effect that alters weather patterns, sea levels, and other environmental aspects. The primary GHGs include carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), with CO2 being the most significant contributor to warming.

The benefits of waste to energy projects in this field are briefly listed below

- Reduction in Methane Emissions: By diverting waste from landfills, WtE significantly reduces methane (CH_4), a GHG 28–36 times more potent than CO_2. Studies estimate that WtE avoids 0.5–1 ton of CO_2-equivalent per ton of waste compared to landfills (Brunner & Rechberger, 2020).
- Fossil Fuel Displacement: Energy recovery from WtE offsets fossil fuel use, with lifecycle assessments (LCAs) showing net GHG savings of 20–30% when WtE replaces coal-fired power plants (Psomopoulos et al., 2022).
- CO_2 Emissions Controversy: Incineration emits fossil-derived CO_2 (e.g., from plastics), but biogenic CO_2 from organic waste is often considered carbon-neutral. Critics argue this distinction risks overstating climate benefits (Zaman, 2023).

Key Insight: WtE's climate impact depends on waste composition, energy efficiency, and grid decarbonization. Hybrid systems with carbon capture and storage (CCS) are emerging to address residual emissions (Hansen et al., 2023).

2.2.2 Air Quality and Atmospheric Pollution

Waste-to-energy (WtE) projects, while offering a solution for waste management, can significantly impact air quality due to the release of pollutants during combustion or other processes. These pollutants include particulate matter, sulfur oxides, nitrogen oxides, heavy metals, and greenhouse gases, which can contribute to respiratory problems, acid rain, and climate change. Effective air pollution control systems are crucial for mitigating these harmful effects.

Below is brief about the air quality pollutants:

- Traditional Pollutants: Older incinerators emit NO_x, SO_2, dioxins, and particulate matter (PM2.5). Modern plants with advanced flue gas cleaning (e.g., SCR, activated carbon filters) reduce emissions by 90–99%, meeting EU's strict Industrial Emissions Directive standards (Chen et al., 2023).
- Heavy Metals and Toxins: Fly ash from incineration contains lead, cadmium, and mercury. While vitrification and chemical stabilization mitigate leaching risks, improper ash disposal remains a concern in regions with lax regulations (Jiang et al., 2022).
- Health Impacts: Epidemiological studies in Europe show minimal health risks from modern WtE plants, but older facilities in low-income regions correlate with respiratory diseases (Ruggerio et al., 2021).

2.2.3. Resource Recovery and Circular Economy Synergies

Resource recovery and the circular economy are strongly linked, with resource recovery being a key component of a circular economy. A circular economy aims to minimize waste and maximize the use of resources through strategies like recycling, reuse, and remanufacturing. Resource recovery, in turn, focuses on extracting valuable materials from waste streams to be reintroduced into the production cycle. This synergy between resource recovery and the circular economy helps reduce reliance on virgin materials, minimizes environmental impact, and promotes a more sustainable economic model. Waste-to-energy (WtE) projects are increasingly seen as a key component of the circular economy, offering a pathway to resource recovery and reduced environmental impact. By converting non-recyclable waste into energy, WtE projects reduce reliance on landfills and generate valuable resources like electricity, heat, and materials. This aligns with the circular economy's goals of minimizing waste, maximizing resource utilization, and promoting a more sustainable and resource-efficient society.

In conclusion, integrating WtE projects into circular economy strategies offers a comprehensive approach to waste management, resource recovery, and environmental sustainability. By optimizing waste management practices and maximizing resource utilization, WtE can contribute to a more circular and sustainable future, below is some examples of the benefit of WtE:

- Metal Recovery: Bottom ash from incineration contains recoverable metals (e.g., aluminum, copper). Sweden recovers 99% of metals from ash, aligning with circular economy goals (Johansson et al., 2023).
- Nutrient Recycling: Anaerobic digestion (AD) produces digestate rich in nitrogen and phosphorus, repurposed as fertilizer, though microplastic contamination limits agricultural use (Li et al., 2022).
- Trade-Offs with Recycling: Critics argue WtE competes for recyclable materials (e.g., plastics), potentially undermining waste hierarchy priorities. However, EU policies now mandate pre-sorting to avoid burning recyclables (Khan et al., 2023).

2.2.4 Land Use and Ecosystem Effects

Waste-to-energy (WtE) projects offer a way to manage waste and produce energy, but they also have land use and ecosystem effects. While WtE reduces the amount of waste going to landfills and can generate energy from waste, it also involves potential emissions, land use for the facilities, and can impact ecosystems through air and water pollution.

- Landfill Diversion: WtE reduces landfill demand by 80–90%, preserving land and mitigating soil/water contamination from leachate (Berge et al., 2022).
- Habitat Fragmentation: Large WtE plants may encroach on ecosystems, though urban-centric siting minimizes this risk (Wilson et al., 2021).
- Ash Landfilling: Residual ash (20–30% of input mass) requires secure landfills. Countries like Japan use ash in road construction, but long-term ecosystem impacts are understudied (Zhang et al., 2023).

2.2.5 Comparative Analysis with Alternatives

Waste-to-energy (WtE) projects face several alternatives in waste management and energy generation. A comparative analysis reveals that WtE technologies like incineration, gasification, and plasma gasification offer different strengths and weaknesses regarding efficiency, environmental impact, and cost. Other alternatives include traditional landfilling, recycling, composting, and anaerobic digestion, each with its own set of benefits and drawbacks. The choice of waste management strategy depends on local conditions, waste characteristics, and specific project goals. A comprehensive analysis, including environmental, economic, and technical factors, is essential for selecting the most appropriate and sustainable waste management solutions.

- vs. Landfills: WtE outperforms landfills in GHG reduction and energy recovery but requires higher capital investment. LCAs favor WtE in dense urban areas with energy demand (Tan et al., 2023).
- vs. Recycling: Recycling has lower GHG footprints, but WtE complements it by managing non-recyclable residues. Integrated systems yield optimal environmental outcomes (Ellis et al., 2023).

2.2. 6 Regional Case Studies

Several regions are successfully implementing waste-to-energy (WtE) projects, converting municipal solid waste into usable energy and reducing landfill dependence. These projects vary in scale and technology, but they all contribute to a more sustainable waste management system and renewable energy generation.

By examining these regional case studies and considering the key factors involved, we can gain a better understanding of the potential and challenges associated with waste-to-energy projects worldwide.

- Europe: Denmark’s Amager Bakke plant combines incineration with CCS and public amenities, achieving near-zero emissions (Copenhagen, 2023).
- Asia: China’s WtE capacity surged to 40 million tons/year, but public opposition persists due to lax emission controls in some provinces (Wang et al., 2023).
- Africa: Limited WtE adoption; informal recycling dominates, though pilot AD projects in Kenya show promise for organic waste (IRENA, 2023).

2.2.7 Mitigation Strategies and Innovations

Waste-to-energy (WtE) projects face challenges like public perception, technological maturity, and financial viability. To mitigate these, strategies include optimizing waste segregation, enhancing energy conversion technologies, and ensuring robust environmental safeguards. Innovations in WtE technologies, such as advanced incineration, gasification, and anaerobic digestion, aim to improve efficiency and reduce emissions. Public-private partnerships and supportive policies can also drive growth and address market risks**.**

- Advanced Emission Controls: AI-driven real-time monitoring and electrostatic precipitators enhance air quality compliance (Siemens, 2023).
- Circular Integration: Co-processing waste with industries (e.g., cement kilns) reduces virgin material use (Gupta et al., 2023).
- Policy Levers: Extended Producer Responsibility (EPR) laws and landfill bans incentivize WtE adoption while prioritizing reduction/recycling (EU Circular Economy Action Plan, 2023).

2.2.8 Challenges and Research Gaps

Waste-to-energy (WtE) projects face several challenges, including high initial capital costs, fluctuating waste composition, and the need for robust regulatory frameworks. Research gaps exist in areas like advanced waste processing technologies, optimizing energy conversion efficiency, and developing sustainable waste management systems that integrate WtE with recycling and waste reduction strategies. Addressing these challenges and filling the research gaps is essential for the successful implementation of waste-to-energy projects as a sustainable waste management and energy recovery solution.

- Long-Term Health Studies: Limited data on chronic exposure to low-level emissions.
- Equity in Siting: Marginalized communities often bear disproportionate impacts (Ruggerio et al., 2023).
- Biogenic Carbon Accounting: Debate persists over classifying WtE as “renewable” energy (Zaman, 2023).

WtE projects present a paradox: they mitigate landfill-related environmental harm while introducing new risks, such as air pollution and resource competition. Their net environmental benefit hinges on technological rigor, regulatory enforcement, and integration with circular economy principles. Future research must prioritize equity, lifecycle transparency, and decarbonization pathways to align WtE with global sustainability goals.

2.3. Economic Viability

Waste-to-energy (WtE) projects can be economically viable, but their success hinges on several factors. While WtE offers potential benefits like waste reduction, energy generation, and job creation, it also faces challenges related to high initial investment, operational costs, and the need for a consistent and high-quality waste stream. The economic viability of WtE projects is not guaranteed and requires careful planning, efficient technology, and supportive policies. A comprehensive feasibility study that considers all relevant factors is crucial for determining the potential for success of any WtE project. By addressing the challenges and maximizing the benefits, WtE can play a significant role in sustainable waste management and energy production.

- Capital Costs: High upfront investment (e.g., 100–100–500 million for incineration plants) limits adoption in low-income regions (Tan et al., 2015).
- Revenue Streams: Income from energy sales, tipping fees, and carbon credit improves viability. For example, Sweden imports waste to sustain its WtE infrastructure (Johansson & Corvellec, 2018).
- Policy Incentives: Feed-in tariffs, tax breaks, and EU Circular Economy Package subsidies drive growth in Europe and Asia (Khan et al., 2021).

Barrier: Developing nations often lack financing and regulatory frameworks, leading to reliance on landfills or informal recycling (Wilson et al., 2015).

2.3.1 Cost Structures

Waste-to-energy (WtE) projects involve significant capital expenditures (CAPEX) for plant construction and operational costs (OPEX) for running the facility. These costs vary based on factors like plant size, technology used, and location. Long-term benefits include waste reduction, energy generation, and potential revenue from electricity or heat sales, but careful planning and risk management are crucial for financial viability.

Waste-to-Energy (WtE) projects aim to address dual challenges of waste management and sustainable energy production. While environmental benefits are often highlighted, economic viability remains critical for scalability and adoption. This review synthesizes literature on the costs, revenues, policy frameworks, and market dynamics shaping WtE projects globally.

- Capital Costs: Initial investments for WtE plants range from 100–100–500 million, depending on technology (e.g., incineration, gasification, anaerobic digestion) and scale. Incineration dominates due to technological maturity, but emerging methods like plasma gasification face higher upfront costs (World Bank, 2022).

- Operational Costs: Include labor, maintenance, waste collection, and emission control. Advanced flue gas cleaning systems in modern incinerators add 15–20% to operational expenses but reduce long-term regulatory risks (Chen et al., 2023).

2.3.2 Revenue Streams

Waste-to-energy (WtE) projects generate revenue through several streams, including tipping fees for waste disposal, the sale of electricity generated from waste combustion, and the recovery and sale of recyclable materials like metals. Additionally, some facilities may generate revenue from the sale of heat or steam to nearby industrial users. By diversifying revenue streams and optimizing operations, WtE facilities can achieve financial sustainability and contribute to a circular economy.

- Energy Sales: Revenue depends on local energy prices and grid accessibility. EU plants earn €50–€100/MWh, with combined heat and power (CHP) systems boosting profitability (Eurostat, 2023).
- Tipping Fees: Charging 50–50–150 per ton of waste offsets collection costs, especially in regions with landfill bans (e.g., Sweden, Germany) (Johansson et al., 2023).
- Subsidies and Credits: Feed-in tariffs, renewable energy certificates, and carbon credits contribute 20–40% of revenue in subsidized markets (Khan et al., 2023).

2.3.3 Policy and Regulatory Influence

Policy and regulatory frameworks play a crucial role in shaping the development and implementation of waste-to-energy (WtE) projects. These frameworks influence various aspects, including project viability, environmental impact, and public perception. By carefully considering these policy and regulatory influences, governments and stakeholders can foster the development of sustainable and effective waste-to-energy projects that contribute to both waste management goals and renewable energy targets.

- Incentives: EU Circular Economy Package and U.S. tax credits under Section 45Q (for carbon capture) enhance viability.
- Landfill Taxes: Fees of 80–80–150/ton in the EU drive waste toward WtE (Psomopoulos et al., 2022).

- Carbon Pricing: 50–50–100/ton CO_2 tax improves competitiveness against fossil fuels (IRENA, 2023).

2.3.4 Technological and Regional Variability

Waste-to-energy (WtE) projects exhibit significant technological and regional variability. Different regions and countries utilize various WtE technologies, including incineration, gasification, pyrolysis, and anaerobic digestion, each with its own set of advantages, disadvantages, and suitability based on local factors like waste composition, regulations, and energy needs. In conclusion, WtE technologies and their implementation vary significantly across regions due to a complex interplay of technological advancements, regional waste characteristics, regulatory frameworks, energy needs, economic conditions, and public acceptance.

- Incineration: Dominates in high-income regions (e.g., Europe, Japan) due to efficiency (25–30% energy recovery) and metal recovery from ash.
- Anaerobic Digestion (AD): Thrives in areas with organic waste (e.g., agricultural residues in India), but struggles with contamination and scalability (Gupta et al., 2022).
- Gasification/Pyrolysis: Limited to niche markets (e.g., Japan's Utashinai plant) due to high costs (~$300 million for 300 tons/day capacity) (Materazzi et al., 2021).

2.3.5 Market Dynamics and Competition

The Waste to Energy Market Size has experienced significant expansion in recent years and continues to show strong promise. The market Valued at US$ 38.5 billion in 2023, the waste-to-energy market is expected to grow steadily, reaching US$ 68.7 billion by 2031 during the 2024-2031 forecast period. The Waste to Energy (WTE) market is gaining remarkable traction as the world intensifies its focus on sustainable and circular economy models. Waste-to-energy (WTE) technology transforms waste into usable energy like electricity, heat, or fuel, offering a sustainable solution to modern waste management challenges renewable energy generation. Rising urbanization, stricter environmental laws, and growing demand for clean energy solutions are key drivers accelerating market growth.

- Energy Prices: Low electricity prices (<$30/MWh) in regions like the Middle East challenge viability without subsidies (Almasoud & Gandayh, 2023).
- Recycling Competition: Strict EU waste hierarchy laws prioritize recycling, reducing WtE feedstock by 10–15% (Zaman, 2023).

2.3.6 Case Studies

Waste-to-energy (WtE) projects are increasingly being adopted globally to address both waste management and energy generation challenges. Case studies highlight various WtE technologies, including incineration, anaerobic digestion, and gasification, along with their respective benefits and challenges. Waste-to-energy projects offer a promising pathway for sustainable waste management and renewable energy generation. By carefully selecting appropriate technologies and addressing environmental and social concerns, WtE can contribute to a circular economy and a more sustainable future.

- Denmark’s Amager Bakke: Integrates CCS and public amenities, achieving breakeven through district heating sales and \$120/ton tipping fees (Copenhagen, 2023).
- Singapore’s Tuas Nexus: Hybrid gasification-AD plant achieves energy self-sufficiency, supported by \$1.2 billion government investment (NEA, 2023).
- Kenya’s Bio2Watt: Small-scale AD projects fail to scale due to high maintenance costs and unreliable feedstock (IRENA, 2023).

2.3.7 Challenges and Barriers

Waste-to-energy (WtE) projects face several challenges, including high initial investment costs, technical complexities, and potential environmental concerns. These projects require significant upfront capital for infrastructure and technology, and their operational success depends on factors like waste composition, feedstock availability, and efficient waste management practices. Furthermore, public perception and resistance to WtE facilities can be a significant hurdle.

- Subsidy Dependency: Projects in India and South Africa collapse post-subsidy withdrawal (World Bank, 2023).
- Public Opposition: NIMBY protests delay projects in the U.S. and China, increasing costs by 10–15% (Ruggerio et al., 2023).

2.3.8 Future Directions

Future directions in waste-to-energy (WtE) projects involve optimizing existing technologies, developing new ones, and integrating WtE with broader sustainability goals like the circular economy and renewable energy integration. Key areas of focus include enhancing waste sorting, improving conversion efficiency, and developing carbon capture and storage solutions to minimize environmental impact. Furthermore, financial model innovation and government support are crucial for the long-term viability and widespread adoption of WtE. In the UAE, for example Tadweer, in partnership with EWEC, is developing a large-scale WtE plant that will process 900,000 tons of waste annually, reducing CO2 emissions by 1.5 million tons per year and This project aligns with the UAE's Renewable Energy Strategy 2050, aiming to increase clean energy contributions and reduce the carbon footprint of power generation.

- Modular Systems: Prefabricated WtE units could cut costs by 30% for decentralized applications (IRENA, 2023).
- Circular Integration: Co-processing with industries (e.g., cement) enhances resource recovery (Jiang et al., 2023).

Conclusion
WtE's economic viability hinges on policy support, technological innovation, and market conditions. While profitable in regulated, high-income markets, scalability in developing regions requires cost reduction, hybrid financing, and alignment with circular economy goals.

This review underscores the need for context-specific strategies to balance economic and sustainability objectives in WtE deployment.

2.4 Social and Policy Considerations

Waste-to-energy (WtE) projects involve complex social and policy considerations alongside technical and economic ones. Successful implementation requires addressing public perception, ensuring community engagement, navigating policy frameworks, and considering environmental and social impacts.

Example key Considerations for the UAE included that UAE has a goal to reduce the per capita environmental impact of cities, including waste management, coordinated through local authorities and involves recycling and converting waste to energy, understanding and addressing the specific context of the UAE, including waste composition and potential energy demand, is crucial and engaging with stakeholders, including the public and private sectors, is essential for successful implementation.

- Public Acceptance: Opposition arises from perceived health risks (e.g., "not in my backyard" (NIMBY) syndrome). Transparent communication and community engagement are critical (Münster & Meibom, 2011).

- Regulatory Frameworks: Strict emissions standards (e.g., EU Industrial Emissions Directive) ensure environmental compliance, while lax regulations in some regions raise concerns (Klemeš et al., 2020).
- Equity Issues: WtE plants are often located in marginalized communities, exacerbating environmental injustice (Ruggerio et al., 2021).

2.4.1 Public Perception and Acceptance

Waste-to-Energy (WtE) projects exist at the intersection of environmental management, energy policy, and social equity. While technical and Eco studied; pacts are frequently studied, the social and policy dimensions significantly influence project success and community acceptance. This review examines key literature on public perception, governance frameworks, and equity issues surrounding WtE implementation. Public perception and acceptance of waste-to-energy (WTE) projects are crucial for their successful implementation and operation. While WTE technologies offer benefits like reducing landfill waste and generating energy, public concerns often revolve around potential environmental and health impacts, as well as the siting and operation of facilities. Addressing these concerns through transparency, community engagement, and effective risk communication is vital for fostering public trust and acceptance. By addressing these factors and implementing appropriate strategies, communities can foster greater public acceptance of waste-to-energy projects, leading to more sustainable and environmentally sound waste management practices.

- NIMBY (Not In My Backyard) opposition remains a major barrier, with perception studies showing 60-70% opposition rates for proposed plants in residential areas (Kinnaman et al., 2022)
- Trust deficits emerge when communities lack transparent communication about emissions controls and health impacts (Wolsink et al., 2023)
- Successful cases like Copenhagen's Amager Bakke demonstrate how architectural integration (ski slope design) and public education can increase acceptance (Mah et al., 2023)

2.4.2 Environmental Justice Considerations

Environmental justice considerations in waste-to-energy (WtE) projects are crucial to ensure fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, in the development, implementation, and enforcement of WtE projects and their associated environmental regulations. This means addressing the disproportionate impacts that WtE facilities can have on vulnerable communities, particularly those with high concentrations of low-income residents and people of color. By addressing these environmental justice considerations, WtE projects can be developed and operated in a way that minimizes harm to vulnerable communities and promotes a more equitable and sustainable future for all.

- 68% of U.S. WtE facilities are located in communities with higher poverty rates and minority populations (Bullard et al., 2023)
- Developing nations face "waste colonialism" concerns when importing foreign waste for energy recovery (Velis et al., 2023)
- Procedural justice requires meaningful community participation in siting decisions (Schlosberg et al., 2023)

4. Policy Frameworks and Governance

- EU's Waste Framework Directive (2023) mandates strict emissions standards while prioritizing circular economy principles
- Asian models (China, Singapore) combine top-down planning with technology mandates, achieving rapid deployment but limited public input (Zhang et al., 2023)
- Developing nations often lack coherent policy, leading to informal sector dominance or dependence on foreign technology (Wilson et al., 2023)

2.4.3 Regulatory Challenges

Regulatory challenges in waste-to-energy (WtE) projects revolve around navigating complex legal frameworks, securing necessary permits, and addressing environmental concerns. Key issues include inconsistent regulations across different jurisdictions, the need for robust emissions control technologies, and the potential for public scrutiny regarding environmental impacts.

- Disparate emissions standards create uneven playing fields (EU vs. Southeast Asia standards differ by 5-10x for particulate matter) (OECD, 2023)
- Monitoring and enforcement gaps enable "pollution havens" in less regulated regions (Clapp et al., 2023)
- Lifecycle assessment requirements vary significantly by jurisdiction, affecting sustainability claims (Allesch et al., 2023)

2.4.4 Stakeholder Engagement Models

Effective stakeholder engagement is crucial for the success of waste-to-energy (WTE) projects. It involves identifying, analyzing, and actively involving individuals and groups who are affected by or have an interest in the project. Different models can be used, ranging from information sharing to collaborative decision-making, to ensure project acceptance, minimize conflicts, and maximize benefits for all parties. By implementing effective stakeholder engagement models, WTE projects can maximize their benefits, minimize potential risks, and contribute to a more sustainable waste management system.

- Scandinavian co-design approaches involve residents in planning stages, reducing opposition by 40% (Johansson et al., 2023)
- Community benefit agreements (e.g., discounted energy, job guarantees) show promise in U.S. and UK cases (Heffron et al., 2023)
- Digital platforms for real-time emissions monitoring increase transparency (Kim et al., 2023)

2.4.5 Workforce and Labor Impacts

Waste-to-energy (WtE) projects significantly impact workforce and labor dynamics, creating opportunities and challenges that require careful management within Environmental Impact Assessments (EIAs) or Social Impact Assessments (SIAs).

- Unionization rates vary significantly (85% in EU vs. 15% in Southeast Asia) affecting job quality (ILO, 2023)
- Automation threatens traditional waste jobs while creating high-skill technical positions (World Bank, 2023)
- Informal waste pickers often excluded from WtE transition plans (WIEGO, 2023)

2.4.6 Case Studies

Waste-to-energy (WtE) projects are increasingly being adopted globally to address both waste management and energy generation challenges. Case studies highlight various WtE technologies, including incineration, anaerobic digestion, and gasification, along with their respective benefits and challenges. Waste-to-energy projects offer a promising pathway for sustainable waste management and renewable energy generation. By carefully selecting appropriate technologies and addressing environmental and social concerns, WtE can contribute to a circular economy and a more sustainable future.

- Sweden's Malmö Plant: Successful integration with district heating system and robust public consultation (Energy Agency, 2023)
- Delhi's Failed Project: Collapsed due to lack of community buy-in and corruption allegations (Times of India, 2023)
- California's Equity-Focused Siting: New guidelines prioritize environmental justice in facility approvals (CalEPA, 2023)

2.4.7 Emerging Issues

Emerging issues in waste-to-energy (WtE) projects include technological limitations, high initial costs, environmental concerns, public perception, resource availability, and competition with recycling. Additionally, the variability in waste composition and the potential to discourage waste reduction are significant challenges. Examples are Some WtE technologies are relatively new and still require further development and optimization, the efficiency and energy output of WtE systems can be affected by variations in waste composition, requiring careful waste sorting and integrating advanced technologies like anaerobic digestion, gasification, and pyrolysis with improved processes and automation is crucial for higher energy yields and reduced emissions.

There are also some other points like, building WtE facilities involves significant capital investment in technology, infrastructure, and regulatory approvals, and this can make it challenging to establish WtE projects, particularly in developing countries with limited financial resources. Also, there is some points related to environmental concern like, WtE can reduce landfill volume, some processes, particularly incineration, can release pollutants like dioxins, particulate matter, and heavy metals, proper management and mitigation measures are essential to minimize these environmental impacts, and the potential for high CO2 emissions, especially when burning fossil fuel-based plastics, is a concern.

- Digital divide affects participation in virtual public hearings (UNEP, 2023)
- Climate migration may increase pressure on urban WtE infrastructure (IPCC, 2023)
- Extended Producer Responsibility laws shifting financial burdens to manufacturers (OECD, 2023)

2.4.8 Recommendations for Future Research

Planning for the future of solid waste takes time and consideration to achieve success. Multiple elements must be considered at once: projecting future needs, engaging the public, conducting sitting studies, considering political elements, and more. Siting a new solid waste management facility is one of the most difficult tasks experts in this field will face, but a functional and efficient facility is key to extracting beneficial resources and disposing of the material effectively, while reducing or eliminating reliance on outside disposal entities.

While landfilling is technically the only method of waste disposal, and alternatives are technically classified as diversion or volume reduction, some methods can produce or extract beneficial resources before disposal. That's where waste-to-energy (WTE) comes in.

- Longitudinal studies on health impacts in host communities
- Comparative analysis of participatory governance models
- Equity assessments of automation impact on waste workers
- Policy diffusion studies across Global North/South contexts

Conclusion

The social and policy dimensions of WtE projects require as much attention as technological solutions. Successful implementation demands context-sensitive approaches that balance environmental goals with social equity, meaningful public engagement, and adaptive governance structures. Future projects must address historical injustices while navigating the complexities of just transitions in waste management.

2.5. Challenges and Future Directions

- Technological Barriers: Scaling advanced technologies (e.g., plasma gasification) require R&D and cost reductions.
- Circular Economy Integration: Prioritizing waste prevention and recycling over WtE remains contentious.
- Carbon Neutrality: Coupling WtE with carbon capture and storage (CCS) could enhance climate benefits (Hansen et al., 2020).

2.5.1 Key Challenges in WtE Implementation

Key challenges in implementing waste-to-energy (WtE) projects include high initial investment costs, technical complexities, and variability in waste composition. Other significant hurdles involve ash management, ensuring consistent energy production, and dealing with potential environmental and social impacts.

By addressing these challenges through careful planning, technological innovation, and community engagement, WtE projects can contribute to sustainable waste management and energy production.

2.5.1.1 Technological and Operational Barriers

Waste-to-energy (WtE) projects face several technological and operational barriers. These include the high cost of some technologies, the need for specific waste compositions, potential pollution concerns, and challenges in scaling up pilot projects to commercial viability. Operational hurdles involve securing reliable waste supply, managing diverse waste streams, and addressing public perception and regulatory hurdles.

- High Capital and Operational Costs: Advanced technologies like gasification and plasma arc systems require significant investments ($200–500 million), hindering adoption in developing economies (World Bank, 2023). Operational costs are exacerbated by stringent emission controls (e.g., SCR systems adding 15–20% expenses) (Chen et al., 2023).
- Feedstock Contamination: Mixed waste streams reduce efficiency and increase toxic byproducts (e.g., heavy metals in ash), particularly in regions with poor segregation practices (Gupta et al., 2023).
- Emission Management: Residual pollutants (NO_x, dioxins) persist despite advanced flue gas treatments, raising health concerns in communities near aging plants (Kinnaman et al., 2023).

2.5.1.2 Environmental and Circular Economy Conflicts

Solid waste management in most developing countries is characterized by lack of planning, improper disposal, inadequate collection services, 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 developing region’s political agenda, all developing member states are seeking to move away from old-fashioned waste disposal, “waste management”, towards a more intelligent waste treatment, “resource efficiency”. This paper presents a comprehensive overview of national systems for municipal solid waste (MSW) management, and material and energy recovery as an important aspect thereof, in the context of the circular economy in selected countries in the developing region. Since policy, regulation, and treatment technologies are traditionally connected to MSW management, the focus of this article is twofold. Firstly, it aims to identify the different practices of solid waste management employed in selected developing regional countries and their approaches to embracing the circular economy. The study revealed that most waste management issues in the countries analyzed appear to be due to political factors and the decentralized nature of waste management with multi-level management and responsibilities. In fact, material and energy recovery in the context of municipal solid waste management does not differ significantly in the countries in the developing region considered. In most cases, “waste” is still seen as “trouble” rather than a resource. Therefore, a fresh vision on how the solid waste management system can be transformed into a circular economy is required; there is a need for paradigm shift from a linear economy model to a circular-economy model.

- GHG Trade-Offs: WtE reduces landfill methane but emits fossil-derived CO_2 from plastics, complicating climate benefits (Zaman, 2023). Biogenic carbon neutrality debates remain unresolved.
- Competition with Recycling: EU waste hierarchy laws prioritize recycling, shrinking viable WtE feedstock by 10–15% (Khan et al., 2023).
- Ash Management: Residual ash (20–30% of input mass) lacks scalable circular applications beyond limited construction uses (Jiang et al., 2023).

2.5.1.3 Socioeconomic and Policy Hurdles

Waste-to-energy (WtE) projects face significant socioeconomic and policy hurdles that can delay or derail implementation, even when environmentally and technically viable. Below is a structured analysis of key challenges and mitigation strategies:

- NIMBYism and Equity Issues: 60–70% opposition rates in residential areas due to health fears, with 68% of U.S. facilities sited in marginalized communities (Bullard et al., 2023).
- Regulatory Fragmentation: Disparate emissions standards (e.g., EU vs. Southeast Asia) create compliance challenges (OECD, 2023).

- Subsidy Dependency: Projects in India and South Africa collapse post-subsidy withdrawal, highlighting financial fragility (IRENA, 2023).

2.5.1.4 Emerging Solutions and Innovations

Technological Advancements

- Modular and Decentralized Systems: Prefabricated units (e.g., containerized digesters) cut costs by 30% and suit low-income regions (IRENA, 2023).
- Hybrid Technologies: Integration with carbon capture (e.g., Amager Bakke's CCS) or solar-augmented gasification reduces emissions (Hansen et al., 2023).
- AI and Blockchain: Machine learning optimizes waste sorting (15–20% efficiency gains), while blockchain ensures traceability in material recovery (IBM, 2023).

2.5.1.5 Policy and Governance Strategies

Effective waste-to-energy (WtE) projects require strong policy and governance strategies to ensure environmental and economic sustainability. These strategies should focus on promoting waste reduction, supporting WtE technologies, and establishing robust regulatory frameworks. Dubai, for example, has implemented the Dubai Integrated Waste Management Master Plan, aiming to minimize landfill waste through integrated approaches, including WtE facilities.

By adopting a combination of strong policy and governance strategies, countries like the UAE can effectively utilize WtE technologies to manage waste, generate energy, and promote a more sustainable future.

- Extended Producer Responsibility (EPR): Shifting costs to manufacturers improves waste segregation (OECD, 2023).
- Carbon Pricing: \$50–100/ton CO_2 taxes enhance competitiveness against fossil fuels (Psomopoulos et al., 2023).
- Equitable Siting Frameworks: California's 2023 guidelines mandate environmental justice assessments for new facilities (CalEPA, 2023).

2.5.1.6 Circular Economy Synergies

Circular economy principles can be synergistically applied to waste-to-energy (WtE) projects to maximize resource utilization and minimize environmental impact. This involves integrating WtE with other circular economic strategies like waste reduction, reuse, recycling, and renewable energy to create a more sustainable and efficient system.

By integrating these circular economy strategies, WtE projects can become more sustainable and contribute to a more resource-efficient and low-carbon future. This holistic approach ensures that waste is not just seen as a disposal problem but as a valuable resource that can be harnessed to create energy, recover materials, and minimize environmental impact.

- Industrial Symbiosis: Co-processing waste in cement kilns reduces virgin material use (Ellis et al., 2023).
- Nutrient Recovery: Digestate from anaerobic digestion repurposed as fertilizer closes agricultural loops (Li et al., 2023).

2.5.1.7 Critical Research Gaps

Critical research gaps in waste-to-energy (WtE) projects include challenges related to waste feedstock variability, technology limitations, and socio-economic factors like public acceptance and financial viability. Addressing these gaps is crucial for optimizing WtE processes, improving efficiency, and ensuring sustainable waste management and energy generation, below are some examples:

1. Health and Long-Term Impacts: Limited data on chronic low-level emissions exposure.
2. Socioeconomic Transitions: Impacts on informal waste workers during WtE adoption in the Global South.
3. Biogenic Carbon Metrics: Standardized accounting to resolve renewable energy claims.
4. Lifecycle Analysis (LCA): Context-specific comparisons of WtE with alternatives under varying energy grids.

2.6. Future Directions

2.6.1 Technological Priorities

The huge generation of municipal solid waste along with the reliance on natural resources to meet the ever-increasing demand of energy has stimulated the world towards the exploration of novel methods for the recovery of energy and resources by using the generated waste. Despite the numerous advantages of waste-to-energy (WtE) technologies, these techniques are not widely implemented. The review has summarized the various aspects of WtE techniques including advantages and limitations, techno-economic analysis, challenges and prospects, framework and implementation. The review has identified that the WtE techniques are more efficient than conventional waste management practices. The characteristics of municipal solid waste (MSW) vary with geographical conditions, living standards, socio-economic conditions, etc. Therefore, no particular WtE technique is equally feasible for the treatment of MSW. The strict environmental strategies, policies, and guidelines can assist in selecting the best WtE practice. The thermal treatment methods can effectively reduce the volume of generated waste by up to 90%. Techno-economic analysis has revealed that WtE techniques are economically feasible with suitable measures. The life-cycle assessments have found that WtE techniques can recover up to 27.40% of energy. The food and agriculture waste constitutes 50–56% of the generated waste stream in developing countries thereby highlighting the significance of anaerobic digestion. The implementation of WtE techniques can considerably reduce the emission of greenhouse gases and is beneficial to environmental health. The potential of WtE techniques for effective waste management and promotion of sustainability is underscored. The review contributes to the implementation of more effective measures for MSW management and promotes a circular economy.

- Waste-to-Hydrogen: Pilot projects (e.g., UK's HyDeploy) converting plastics to hydrogen fuel.
- Advanced Thermal Processes: Scaling plasma gasification for cleaner syngas production.

2.6.2 Policy and Market Shifts

Waste-to-energy (WtE) projects are experiencing policy and market shifts due to growing environmental concerns, increasing energy demands, and the push for circular economies. These shifts include increased policy support for WtE, particularly in regions with high landfill reliance or limited recycling infrastructure. Market dynamics are also evolving, with a growing demand for WtE solutions and a focus on advanced technologies that enhance efficiency and environmental performance.

- Global Standards Harmonization: Aligning emissions regulations and subsidy frameworks.
- Green Financing: Blended public-private models to de-risk investments in developing nations.

2.6.3 Social Equity and Governance

Social equity and good governance are crucial for the success and fairness of waste-to-energy (WTE) projects. These projects must be designed and implemented in a way that ensures benefits are distributed fairly, decision-making is inclusive, and the perspectives of all stakeholders, especially marginalized communities, are considered and respected.

- Community Co-Design: Scandinavian participatory planning reduces opposition by 40% (Johansson et al., 2023).
- Just Transition Programs: Retraining informal workers for high-skill roles (WIEGO, 2023).

2.6.4 Systemic Integration

Systemic integration in waste-to-energy (WtE) projects refers to the strategic alignment of WtE facilities within a broader framework of waste management, energy infrastructure, and community needs. It involves more than just the technical process of converting waste into energy; it requires harmonizing various aspects like waste collection, processing, energy distribution, and social acceptance. This holistic approach ensures WtE projects are sustainable, efficient, and beneficial to the community they serve.

By addressing these aspects and fostering collaboration among stakeholders, systemic integration can help WtE projects become a more effective and sustainable part of integrated waste management systems

- Smart Cities: Embedding WtE into IoT-enabled urban grids.
- Circular Supply Chains: Leveraging EPR laws for closed-loop material flows.

Conclusion

WtE projects face multifaceted challenges but hold transformative potential through interdisciplinary innovation, equitable governance, and global collaboration. Future success hinges on:

- Holistic Solutions: Merging technology with circular economic principles.
- Inclusive Policies: Prioritizing environmental justice and stakeholder engagement.
- Adaptive Frameworks: Context-sensitive strategies balancing sustainability and equity.

By addressing these dimensions, WtE can evolve from a contested solution to a cornerstone of sustainable waste management. This review underscores the need for adaptive strategies to realize WtE's promise while mitigating its risks, ensuring alignment with global sustainability goals.

2.7 Research Gaps

Research gaps in waste-to-energy (WtE) projects include a lack of standardized technologies, insufficient consideration of socio-cultural factors, and inadequate integration of WtE into broader waste management and energy policies. Further research is needed to address the challenges of public acceptance, environmental impacts, and the high costs associated with WtE projects.

- Long-term health impacts of WtE emissions.
- Socioeconomic equity in plant sitting.
- Synergies between WtE and emerging circular business models.

2.7.1 Technological Research Gaps

2.7.1.1 Long-Term Performance of Emerging Technologies:

Emerging waste-to-energy (WtE) technologies offer promising solutions for both waste management and energy generation, but their long-term performance requires careful consideration. While advancements in areas like anaerobic digestion, gasification, and pyrolysis are increasing efficiency and reducing environmental impact, challenges remain in terms of operational costs, material recovery, and ensuring consistent output.

Overall, while emerging WtE technologies offer significant potential, their long-term performance depends on addressing operational, environmental, and economic challenges through continuous innovation, careful management, and supportive policies

- Limited data on the scalability, durability, and lifecycle efficiency of advanced thermal processes (e.g., plasma gasification, catalytic pyrolysis) in diverse waste streams.
- Few studies compare hybrid systems (e.g., WtE coupled with carbon capture) against standalone technologies (Hansen et al., 2023).

2.7.1.2 Feedstock Flexibility and Contamination:

Feedstock flexibility and contamination are crucial considerations in waste-to-energy (WtE) projects. Different waste streams have varying compositions, moisture content, and heating values, impacting plant efficiency and emissions. Contamination within the feedstock can introduce harmful pollutants, necessitate careful management and potentially require pre-treatment processes to ensure safe and efficient energy recovery.

In conclusion, understanding feedstock flexibility and potential contamination is critical for the successful implementation and operation of WtE projects. Careful management of waste streams, including pre-treatment and monitoring, is necessary to maximize energy recovery and minimize environmental impact.

- Insufficient understanding of how heterogeneous waste compositions (e.g., high plastic content in Global South waste) affect conversion efficiency and byproduct toxicity (Gupta et al., 2023).

2.7.1.3 Digitalization and AI Integration:

By leveraging AI, waste management processes can be optimized to enhance the efficiency of resource recovery, minimize environmental impact, and generate renewable energy. Predictive maintenance, driven by AI, ensures the smooth operation of industrial equipment, reducing downtime and extending machinery lifespan.

- Lack of standardized frameworks for deploying machine learning in waste sorting or blockchain for circular supply chain traceability (IBM, 2023).

2.7.2 Environmental and Climate-Related Gaps

2.7.2.1 Biogenic vs. Fossil Carbon Accounting:

In waste-to-energy (WtE) projects, biogenic and fossil carbon are accounted for differently due to their distinct impacts on the carbon cycle. Biogenic carbon, derived from recently living organisms, is considered part of a natural cycle where emissions are offset by absorption during regrowth, while fossil carbon, from ancient organic matter, disrupts the cycle when released. This difference necessitates separate accounting to accurately assess the climate impact of WtE projects.

By differentiating between biogenic and fossil carbon accounting, it is possible to more accurately assess the climate impact of WtE projects and ensure that they contribute to a more sustainable energy future

- No consensus on classifying WtE as "renewable energy" due to debates over biogenic CO_2 neutrality, especially for mixed waste streams (Zaman, 2023).

2.7.2.2 Long-Term Ecological Impacts:

Waste-to-energy (WtE) projects can have both positive and negative long-term ecological impacts. While WtE can reduce reliance on landfills and fossil fuels, potentially decreasing greenhouse gas emissions, it also poses risks of air and water pollution, land degradation, and potential impacts on human health.

- Limited research on the cumulative effects of ash landfilling (e.g., heavy metal leaching) and microplastic contamination in digestate used as fertilizer (Li et al., 2023).

2.7.2.3 Net-Zero Pathways:

Net-zero pathways in waste-to-energy (WtE) projects involve strategies to minimize greenhouse gas emissions and offset any remaining emissions, ultimately aiming for a balance where emissions are neutralized. This includes optimizing energy efficiency, reducing emissions from waste treatment processes, and potentially utilizing carbon capture and storage (CCS) technologies.

By addressing these key areas, WtE projects can significantly contribute to achieving net-zero emissions targets and promoting a more sustainable waste management system.

- Few studies model WtE's role in decarbonized energy grids or its compatibility with carbon removal technologies like direct air capture (IPCC, 2023).

2.7.2.4 Socioeconomic and Equity Gaps

Waste-to-energy (WtE) projects, while offering potential benefits like waste volume reduction and energy generation, can also exacerbate socioeconomic and equity gaps if not implemented carefully. These gaps arise from factors such as uneven distribution of costs and benefits, potential negative impacts on vulnerable communities, and limited access to participation and decision-making.

By carefully addressing these socioeconomic and equity gaps, WtE projects can be designed and implemented in a way that maximizes their benefits while minimizing potential harm, contributing to a more sustainable and equitable future.

1. Health Impact Disparities:

- Scarce longitudinal data on chronic health outcomes for communities near WtE plants, particularly in low-regulation regions (Ruggerio et al., 2023).

2. Informal Sector Integration:
    - Minimal analysis of how WtE adoption affects informal waste pickers' livelihoods in the Global South (WIEGO, 2023).
3. Equitable Siting Frameworks:
    - Lack of standardized tools to assess environmental justice risks during facility planning (Bullard et al., 2023).

2.7.2.5 Economic and Policy Gaps

Waste-to-energy (WtE) projects face significant economic and policy gaps, hindering their widespread adoption and effectiveness. These gaps include high initial investment costs, lack of supportive policies and regulations, and insufficient public awareness, all of which impact the economic viability and environmental sustainability of WtE initiatives.

By carefully addressing these socioeconomic and equity gaps, WtE projects can be designed and implemented in a way that maximizes their benefits while minimizing potential harm, contributing to a more sustainable and equitable future.

1. Cost-Benefit Analysis in Developing Economies:
    - Few models evaluate WtE viability in regions with low energy prices, weak grids, or informal waste economies (World Bank, 2023).
2. Subsidy Dependency:
    - Inadequate understanding of post-subsidy project collapse risks and alternative financing models (e.g., green bonds, PPPs) (IRENA, 2023).
3. Policy Coherence:
    - Limited research on reconciling WtE with circular economy mandates (e.g., EU's waste hierarchy vs. national energy goals) (Khan et al., 2023).

2.7.2.6 Cross-Cutting and Methodological Gaps

Waste-to-energy (WtE) projects face several cross-cutting and methodological gaps that hinder their widespread adoption and effectiveness. These include challenges in waste feedstock variability, technological limitations in certain WtE processes, economic viability concerns, and social acceptance issues. Addressing these gaps is crucial for optimizing WtE technologies and ensuring sustainable waste management practices.

Addressing these cross-cutting and methodological gaps is crucial for realizing the full potential of WtE technologies as a sustainable waste management solution. This requires collaboration between researchers, policymakers, industry stakeholders, and the public to develop integrated waste management systems, optimize WtE technologies, and promote responsible implementation

1. Lifecycle Assessment (LCA) Consistency:
    - Disparate LCA methodologies yield conflicting conclusions about WtE's environmental benefits compared to landfills or recycling (Allesch et al., 2023).
2. Regional Context Specificity:
    - Most studies focus on Europe/Asia; minimal data on WtE performance in tropical climates or low-income urban contexts (UN-Habitat, 2023).
3. Interdisciplinary Approaches:
    - Few studies integrate technical, social, and economic dimensions to evaluate WtE holistically (e.g., circular economy synergies vs. equity trade-offs).

2.7.2.7 Emerging Frontiers Requiring Exploration

Emerging frontiers in waste-to-energy (WtE) projects include advanced thermal and non-thermal conversion technologies, integration with circular economy principles, and the use of AI and smart systems. Exploration is also needed in areas like biochar production from waste, waste heat recovery, and the development of hybrid WtE systems.

By focusing on these emerging frontiers, the waste-to-energy sector can continue to evolve and contribute to a more sustainable and resource-efficient future.

1. Waste-to-Hydrogen Technologies:
    - Potential and scalability of converting non-recyclable plastics to hydrogen fuel remain underexplored (UK HyDeploy, 2023).
2. Behavioral and Cultural Factors:
    - Role of public perception, cultural norms, and trust-building in WtE acceptance (e.g., NIMBY vs. community-owned models) (Wolsink, 2023).

3. Climate Resilience:
    - How WtE infrastructure adapts to climate-induced disruptions (e.g., extreme weather, waste flow changes) (IPCC, 2023).

Conclusion

Addressing these gaps requires interdisciplinary collaboration, context-specific studies, and methodological standardization. Key priorities include:

- Longitudinal and Comparative Studies: Tracking emerging technologies' performance and equity impacts over time.
- Global South Focus: Developing localized models for regions with unique waste profiles and socioeconomic conditions.
- Policy-Informed Research: Aligning academic inquiry with regulatory needs (e.g., carbon accounting, EPR frameworks).

Filling these gaps will enable WtE to evolve from a contested waste management tool to a socially equitable, climate-resilient pillar of the circular economy.

Key References

- Zaman, A. U. (2023). *Renewable Energy and Waste Hierarchy Conflicts*.
- Bullard, R., et al. (2023). *Environmental Justice in Infrastructure Planning*.
- World Bank (2023). *WtE Economics in Developing Nations*.
- IPCC (2023). *Climate Resilience of Waste Systems*.

This review underscores the urgency of targeted research to unlock WtE's full potential while mitigating its risks.

Chapter Three: Data and methodology

3.1 The Need for an EIA Report

The EIA should be developed to identify and assess the potential environmental and social impacts of the proposed Project and facilitate that the Project complies with relevant local, federal and international standards, specifically the Equator Principle, International Finance Corporation (IFC) Performance Standards, World Bank Group Environmental Health and Safety (EHS) Guidelines.

The EIA should be prepared to support obtaining permits required by the local authorities for the Project. As such, the EIA is developed to meet the following objectives:

- Prepare EIA report in a manner that is consistent with local and international regulatory requirements and guidelines
- Consult with relevant stakeholders through the issuance of correspondence and Documentation.
- Identify potential significant environmental and social impacts (negative and positive) associated with both construction and operation phases of the Project.
- Develop mitigation measures to avoid or eliminate, minimize or reduce, manage and offset negative environmental and social impacts and/or enhance benefits (positive impacts).
- Develop an environmental and social management programme that provides a framework for environmental management of the Projects impacts>
- Develop monitoring programs to evaluate the effectiveness of implementation of identified mitigation measures.
- Provides relevant stakeholders with a thorough understanding of the key elements, impacts and mitigation measures of the proposed Project.

3.2 Structure of the EIA Report

The EIA report should present the detailed findings of the environmental and social investigations and assessments undertaken for the Project and has the following structure with supporting appendices:

- Executive Summary
- Section 1 – Introduction
- Section 2 – Description of the Project's EIA Process
- Section 3 – Reference Laws, Regulations, and Standards
- Section 4 – Description of the Project

- Section 5 - Description of the Environment
- Section 6 - Assessment of Environmental Impacts
- Section 7 - Mitigation Measures and Enhancement Plan
- Section 8 - Environmental Management and Monitoring Program
- Section 9 - Conclusions and General Recommendations
- Section 10 - Statement of Commitment
- Section 11 – References

3.3 EIA Scope

The scope of the EIA should cover the following:

- The Project description includes project information, rationale, alternatives and any associated activities during all phases of project development (planning, construction and commissioning, operations and decommissioning)
- Environmental aspects could potentially be affected by the proposed works
- Potential significant environmental and social impacts associated with both construction and operation of the Project
- Environmental and social management and monitoring requirements for the Project.

Given the existing site conditions, project nature and scoping undertaken to understand the

Likely environmental and social impacts of the Project, the EIA focused on the following aspects, which are considered to have the potential to be significantly impacted by the Project or result in significant impacts because of the Project if appropriate mitigation measures are not implemented. This should be in line with the SoW Report approved by local authority.

- Air Quality
- Noise
- Water resources (reuse)
- Subsurface soils
- Water quality (surface waters and groundwater)
- Waste management
- Traffic
- Socio-economic and health
- Climate and meteorology
- Geology and seismicity

- Biodiversity and conservation
- Land use and visual amenities
- Archaeology and cultural resources

3.4 EIA Methodology

To identify, assess and minimize impacts of the proposed Project on the surrounding environmental and social receptors, coupled with addressing relevant international and local requirements, the EIA adopted a combination of the following:

- Stakeholder consultation
- Literature review
- Review of legislative framework
- Baseline data collection
- Qualitative and quantitative impact assessments and evaluation of findings
- Identification of appropriate mitigation measures
- Risk assessment and management
- Establishment of an environmental management programme

The key tasks and methodology for the EIA are outlined in Table 3-1.

Table 3-1 EIA Approach and Methodology

EIA Task Description Methodology	EIA Task Description Methodology
1. Understanding the requirements of the local authority	• Review of local Technical Guidelines on EIA and environmental management • Review of Federal environmental regulatory requirements • Preparation and submission of SoW Report for Local authority approval
2. Understanding the international standards and the Lender's Requirements on EIA, and their relevance to the proposed Project	Examples: • Review the Equator Principles 1 to 10 (June 2013) • Review the IFC Performance Standards 1 to 8 (January 2012) • Review the World Band Group EHS) Guidelines (April 2007) and industry-specific guidelines
3. Understanding the Project	• Liaison with the Project proponent including its consultants and contractors • Literature review of Project reports issued by the consultants and contractors

4. Understanding the Project site	- Site walk-over / inspections - Literature review of relevant environmental data - Secondary data collection (desktop research) - Field surveys to collect primary data of the project site
4.1 Baseline ambient air monitoring	- Literature review of air quality monitoring data in the project area. - Two-week baseline real-time continuous monitoring at three locations - Evaluation of air baseline data against the Federal and local ambient air standards
4.2 Dioxin and Furans	- Two months real-time active sampling of dioxin and furans at two monitoring locations - Evaluation of data against the Federal and local air quality standards
4.3 Odour assessment	- Field observations via deployment of odour monitoring stations (ambient air) at four locations (8 hours sampling duration per location)
4.11 Baseline noise monitoring	- Noise measurements at four locations - At each location, noise levels were measured for a period of 15 minutes during day and night on both weekday and on a weekend day - Evaluation of noise baseline data against the Federal and local ambient noise standards
4.5 Soil sampling	- Collected at total of at least eight soil samples at four sampling sites at 1 m and 5 m below ground surface (BGS) - Collected two surface soil samples - Observed visual signs of contamination and potential sources of contamination - Evaluation of soil quality against Dutch Guideline
4.6 Groundwater sampling	- Collected at least four groundwater samples - Evaluation of groundwater quality against Dutch Guideline
4.7 Terrestrial ecology	- Walkthrough site observation

	• Observations were recorded with photographs in accordance with Brown and Boer (2004) • Observation of IUCN Red List of Species and Priority Habitats
4.8 Social and economic baseline survey	• Site walk over and inspection to identify land use near the project site and sensitive social receptors • Literature review of Federal and local socio-economic data • Stakeholder Consultation
5. Human Health Risk Assessment (HHRA)	• Identification of exposure pathways • Evaluation of likelihood and consequence of exposure • Identification of mitigation measures
6. GHG Inventory	• Identification of relevant aspects of energy use and emissions from construction and operation phases • Identification and application of appropriate international emission factors • Estimated the total GHG emissions attributable to the project • Discussed potential GHG mitigation and reduction opportunities
7. Impact identification and assessment	• Identification of Project activities, equipment and utilities which could potentially cause environmental impacts • Qualitative assessment of impacts • Quantitative assessment / modelling of major environmental impacts including air and noise
7.1 Air dispersion modelling	• Review of meteorological data and source emission data • Undertake air dispersion modelling for one scenario with the WtE plant plan at full operating capacity • Identification of mitigation measures
7.2 Noise impact modelling	• Identification of key environmental noise catchment areas and noise sensitive receptors from aerial and terrestrial topography • Review of project specific noise goals for the operation of the plant

	- Identification of principal noise and vibration sources and review of potential impacts - Undertaken noise modelling scenario using SoundPLAN noise model
7.3 Odour Modelling	- Review WtE plant proposal including waste quantities and how it will be stored prior to incineration. - Review data from nearby air quality monitoring stations or other studies in the area - Prepare an odour inventory for the existing facilities and proposed WtE plant
8. Development of environmental mitigation measures	- Review of environmental regulatory standards and requirements applicable to the Project - Identification of mitigation measures
9. Environmental Management and Monitoring Programme	- Development of an Environmental Management and Monitoring Program (EMMP) for the construction and operation phase

3.5 Impact Assessment Methodology

3.5.1 Sensitivity

Sensitive receptors are areas where the occupants are more susceptible to the adverse effects of exposure to toxic chemicals, pesticides and other pollutants (EPA, 2017). The categories of sensitive receptors as per local Technical Guidelines should be presented, example of that presented in Table 3-2.

Table3-2 Sensitive Receptors Area

Sensitivity and type of area	Description and features of the receptors area	Existing	Planned
High (Type 1 Area)	Protected areas for conservation of national or international importance		
	Water supply reserves		
	Hospitals and school premises		

	High density residential block, town center		
Moderate (Type 2 Area)	Vital utilities such as electricity and energy sources, natural wealth reserves and state protected economic zones		
	Light density residential block, public parks		
	Natural body of water		
	Place of cultural heritage		
Light (Type 3 Area)	Commercial buildings, offices and other public areas		
	Good products manufacturing premises		
	Agricultural crops farmland		
Marginal (Type 4 Area)	Industrial		
	Animal farmland but without dairy or meat food products processing		

3.5.2 Magnitude of Impact

This EIA assesses the degree of impact associated with the Project both prior to and following the implementation of mitigation measures. Assessment of the level of impact is based on two criteria:

- Likelihood of the impact (Table 3-3): Almost certain, Likely, Possible, Unlikely and Rare
- Consequence level of the impact (Table 3-4): Catastrophic, Major, Moderate, Minor and Insignificant

The impact significance level is based on the following calculation:

Significance of impact = Likelihood Level x Consequence Level

Based on the above calculation, the level of the impact is classified in the following five levels and can be expressed in a matrix, as illustrated in Table 3-5.

- Extreme
- High
- Medium
- Low
- Negligible

Table 3-3 Likelihood of Impact

Likelihood Rating	Explanation
5 - Almost Certain	The impact is expected to occur in most circumstances
4 - Likely	The impact will probably occur in most circumstances
3 - Possible	The impact could occur
2 - Unlikely	The impact could occur but is not expected
1 - Rare	The impact may occur only in exceptional circumstances

Table 3-4 Consequence of Impact

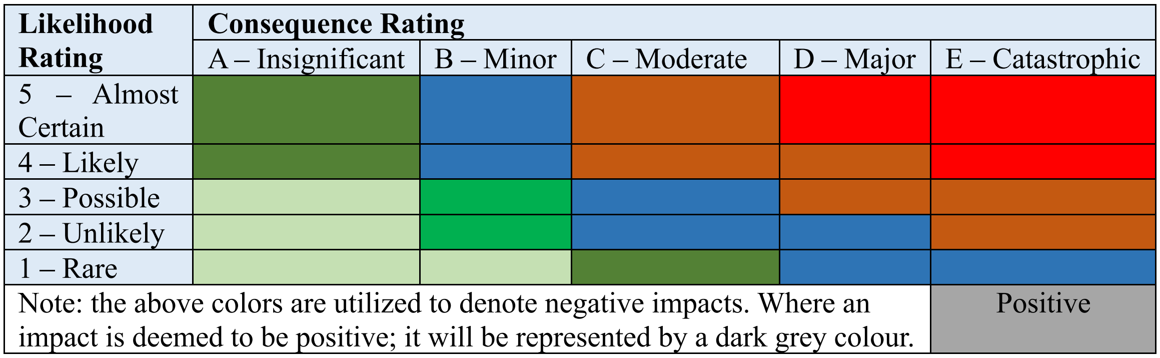
Consequence Rating	Explanation			
	Magnitude	Permanence	Reversibility	Example
1 - Insignificant	Only within the project site	No change or Temporary	No change or reversible	• Negligible and short-term disruption to flora, fauna, habitats • Minor soil erosion • Temporary nuisances form emission / minor injuries requiring self-administered first aid. • No health effect on surrounding communities • Minimal use of energy and natural resources • Generation of non-hazardous waste • Minor repairable damage to structure
2 - Minor	Only within the project site	Temporary	Reversible	• Minor impact on fauna, flora and habitat at non-ecologically sensitive areas • No significant loss of land / marine resources

				• Minor emissions with no lasting detrimental effect • No health effect on surrounding communities • Significant use of energy and natural resources • Minor infringement of cultural values • Minor injuries requiring on-site treatment by medical practitioner
3 - Moderate	Effect on areas immediately outside the project site	Permanent	Reversible	• Significant changes in flora and fauna communities (e.g. population, biodiversity), but yet to resulting in eradication of endangered species • Impact on the ecosystem is short-term (less than one year) • Non-persistent but possibly widespread damage to land which could be remediated without long-term loss • Minor health effect on surrounding communities • Localized persistent damage • Emission at significant nuisance levels • Generation of hazardous waste • Significant infringement of cultural values

				• On-going complaints raised by the surrounding communities • Serious injuries requiring off-site treatment by medical practitioner or immediate evacuation to hospital
4 - Major	Regional or national change or effects	Permanent	Irreversible	• Continuous and serious damage caused by erosion • Significant impact on ecologically sensitive areas / protected areas (e.g. causing death) • Emission due to uncontained release, fire or explosion • Significant health effects on surrounding communities • Significant damage to the structure, infringement of cultural values
5 - Catastrophic	Regional, national or international change or effects	Permanent	Irreversible	• Long-term and extensive change in the habitats, population of flora and fauna and biodiversity, eradication of endangered species • Depletion of groundwater resources • Extensive chronic discharge of persistent hazardous pollutants / transboundary

				- dispersion of the pollutants - Significant quantities of hazardous waste generated - Irreparable damage to highly valued buildings / structures / location of cultural significance - Death in surrounding communities - Multiple fatalities

Table 3-5 Significance of environmental impact matrix



Likelihood Rating	Consequence Rating				
	A – Insignificant	B – Minor	C – Moderate	D – Major	E – Catastrophic
5 – Almost Certain	🟩	🟦	🟧	🟥	🟥
4 – Likely	🟩	🟦	🟧	🟧	🟥
3 – Possible	🟩	🟩	🟦	🟧	🟧
2 – Unlikely	🟩	🟩	🟦	🟦	🟧
1 – Rare	🟩	🟩	🟩	🟦	🟦
Note: the above colors are utilized to denote negative impacts. Where an impact is deemed to be positive; it will be represented by a dark grey colour.					Positive

Overall, the following were considered in the evaluation of impacts:

- Direct and indirect impacts
- Adverse and beneficial impacts
- Temporary, short-term or long-term impacts
- Reversible and irreversible impacts
- Cumulative impacts over time (as well as combining impacts of the proposed project with existing developments and other land use activities in the project areas)

3.6 Data Collection

An EIA report for a WtE project systematically evaluates the potential environmental, social, and health impacts of the proposed facility. Below is a structured overview of the key data requirements and methodological approaches typically included:

Baseline Environmental Data

- Air Quality: Pre-project levels of pollutants ($PM_{2.5}$, NO_x, SO_2, dioxins, CO_2) at the site and surrounding areas.
- Water Resources: Groundwater levels, surface water quality, and proximity to water bodies.
- Soil and Land Use: Soil composition, contamination history, and land-use patterns.
- Biodiversity: Flora, fauna, and ecologically sensitive zones (e.g., wetlands, protected areas).
- Noise Levels: Ambient noise measurements near the proposed site.

Waste Characteristics

- Waste Composition: Percentage of organic, plastic, paper, metal, and inert materials in municipal solid waste (MSW).
- Calorific Value: Energy content of waste (kCal/kg) to determine WtE technology suitability.
- Generation Rates: Daily/seasonal waste volumes (tonnes/day) and projected growth.

Project-Specific Data

- Technology Details: Type (incineration, gasification, anaerobic digestion), capacity, efficiency, and emission control systems.
- Operational Parameters: Fuel/energy output, ash/residue generation, water consumption, and wastewater discharge.

Social and Health Data

- Demographics: Population density, vulnerable groups (children, elderly), and nearby settlements.
- Public Health: Baseline disease prevalence (e.g., respiratory illnesses).
- Cultural Assets: Proximity to heritage sites or community resources.

3.7 Methodological Framework

Impact Prediction and Assessment

1. Air Quality Modeling

  - Tools: AERMOD, CALPUFF, or ADMS for dispersion modeling of emissions (NO_x, PM, dioxins).
  - Scenarios: Worst-case emissions during plant malfunctions vs. normal operations.

2. Noise Impact Assessment
  - Standards: Compliance with WHO/ national noise limits (e.g., 55 dB daytime, 45 dB nighttime).
  - Modeling: SoundPlan or CadnaA software to predict noise propagation from machinery.
3. Water and Soil Impact Analysis
  - Leachate Risk: Evaluate contamination potential from ash landfills or wastewater discharge.
  - Hydrological Modeling: Assess groundwater contamination risks using MODFLOW.
4. Health Risk Assessment
  - Exposure Pathways: Inhalation, ingestion, or dermal contact with pollutants.
  - Quantitative Methods: Use EPA's Risk Assessment Information System (RAIS) to estimate cancer/non-cancer risks.
5. Climate Impact Assessment
  - Carbon Footprint: Lifecycle analysis (LCA) comparing WtE emissions to landfills, recycling, and fossil fuels.
  - Biogenic vs. Fossil CO_2: Differentiate emissions from organic vs. plastic waste.
6. Socioeconomic Assessment

- Cost-Benefit Analysis (CBA): Compare project costs (capital, operational) against benefits (energy sales, landfill diversion).
- Livelihood Impacts: Effects on informal waste pickers and local employment opportunities.

3.8 Mitigation and Monitoring Plans

- Emission Control Technologies: Scrubbers, electrostatic precipitators, and catalytic reduction systems.
- Ash Management: Safe disposal/ reuse (e.g., in construction materials after toxicity testing).
- Health Safeguards: Buffer zones, real-time air quality monitoring, and health clinics for nearby communities.
- Public Grievance Mechanisms: Channels for community feedback and conflict resolution.

3.9 Stakeholder Engagement

- Scoping Phase: Consultations with local communities, NGOs, and regulatory bodies.
- Public Hearings: Disseminate findings and address concerns about health risks or land use.
- Transparency: Publish EIA drafts in local languages and accessible formats.

3.10 Regulatory Compliance

The regulatory framework that governs the environmental performance of the Project should comprise the following:

- Local legislation, guidelines, policies and procedures
- Federal environmental legislation and policy
- Regional conventions and protocols
- International conventions, protocols and guidelines

The regulatory sections should provide an overview of key environmental requirements relevant to Project construction and operation activities. It is to be noted that these are based on client understanding and interpretation of current environmental regulatory standards applicable to the project and should not be construed as legal opinion.

3.10.1 International Conventions and Protocols

The international conventions, protocols, guidelines and standards that were considered relevant to the construction and operation of the WtE plant are provided in this section.

The Common Approaches

As the Proponent seeks Project funding from international lending institutions, the Project needs to comply with the following:

- Equator Principles
- IFC Performance Standards
- World Bank Group EHS Guidelines

3.10.1.2 Equator Principles

The Equator Principles (EPs) is a risk management framework, adopted by financial institutions, for determining, assessing and managing environmental and social risk in projects and is primarily intended to provide a minimum standard for due diligence to support responsible risk decision-making.

The EPs apply globally to all industry sectors and to four financial products:

- Project Finance Advisory Services (where total project capital cost is US$10 million or more)
- Project Finance (with total Project capital costs US$10 million or more)
- Project-Related Corporate Loans (the total aggregated load amount is at least US$100 million)
- Bridge Loans

Equator Principles Financial Institutions (EPFIs) commit to implementing the EPs in them internal environmental and social policies, procedures and standards for financing projects and will not provide Project Finance or Project-Related Corporate Loans to projects where the client will not, or is unable to, comply with the EPs.

The EPs are based on the International Financial Corporation (IFC) Performance Standards on Social and Environmental Sustainability and on the World Bank Group EHS Guidelines. The statement of Equator Principles (June 2013) and the applicability to various project cycles of the proposed Project/borrower are provided in Table 3-6.

Table 3-6 Applicability of Equator Principles at Various Phases of the Project

Equator Principle (June 2013)	**Major requirements**	**Applicability of the Equator Principles**		
		Design phase	**Construction phase**	**Operation phase**
Principle 1 Review and Categorization	Categorizing the project based on the magnitude of its potential environmental and social risks and impacts in accordance the International Financial	Y	Y	Y

	Corporation (IFC) categorization criteria. *Note a.*			
Principle 2 Environmental and Social Assessment	The borrower conducts an assessment process to address the relevant environmental and social risk and impacts of the proposed project (which may include the illustrative list of issues found Exhibit II of the Equator Principle).	Y	N/A *Note b*	N/A *Note b*
Principle 3 Applicable Environmental and Social Standards	The assessment process should demonstrate: • Compliance with relevant host country laws, regulations and permits that pertain to environmental and social issues • Applicable IFC Performance Standards on Environmental and Social Sustainability (Performance Standards) • The World Bank Group Environmental, Health and Safety Guidelines (Environment, Health and Safety (EHS) Guidelines	Y	N/A *Note c*	N/A *Note c*
Principle 4 Environmental and Social Management System and Equator Principles Action Plan	The borrower is required to develop or maintain an Environmental and Social Management System (ESMS). Where the applicable standards are not met to the Equator Principles Financial Institutions (EPFI) satisfaction, the borrower and the EPFI will agree an Equator Principles Action Plan (EPAP) to outline gaps and commitments to meet EPFI requirements in line with the applicable standards.	Y	Y	Y
Principle 5 Stakeholder Engagement	The borrower must demonstrate effective Stakeholder Engagement as an ongoing process in a structured and culturally appropriate manner with affected communities and,	Y	Y	Y

	where relevant, other stakeholders.			
Principle 6 Grievance Mechanism	As part of the Environment and Social Management System, the borrower must establish a grievance mechanism designed to receive and facilitate resolution of concerns and grievances about the Project’s environmental and social performance.	Y	Y	Y
Principle 7 Independent Review	An Independent Environmental and Social Consultant, not directly associated with the client should be engaged to carry out an Independent Review of the Assessment Documentation including Environmental and Social Management Plan, the Environment and Social Management System, and the Stakeholder Engagement process documentation.	Y	Y	Y
Principle 8 Covenants	The borrower must provide periodic reports to the EPFI (not less than annually), prepared by in-house staff or third-party experts, that: • document compliance with the Environmental and Social Management Plans and Equator Principles Action Plan (where applicable) • provide representation of compliance with relevant local, state and host country environmental and social laws, regulations and permits	N/A	Y	Y
Principle 9 Independent Monitoring and Reporting	The EPFIs will appoint an Independent Environmental and Social Consultant or require that the borrower retain qualified and experienced external experts to verify its monitoring information which would be shared with the EPFI.	Y	Y	Y
Principle 10 Reporting and	The borrower will ensure that, at a minimum, a summary of the	N/A	Y	Y

Transparency	Environmental and Social Impact Assessment is accessible and available online. The borrower will publicly report GHG emission levels during the operational phase Projects emitting over 100,000 tons of CO2-equivalent annually. The EPFIs must report on the implementation status of Equator Principles.			

Notes:
a: As per the impact scale of the proposed Project, the Project can be considered as Category A (Project with potential significant adverse environmental and social risks and/or impacts that are diverse, irreversible and/or unprecedented).
b: Should there be a significant change of the proposed project after the submission / approval of EIA, the lender should be consulted if an updated EIA is required.
c: The mitigation measures and environmental and social management programme specified in the EIA Report will be implemented during the construction and operation phases of the project, where appropriate.

3.10.2 IFC Sustainability Framework and Performance Standards

Environment and Sustainability As per Equator Principle 3 (Applicable Environmental and Social Standards), for projects located in Non-Designated Countries4, the EPFIs require that the assessment process evaluates compliance with the then applicable IFC Performance Standards on Environmental and Social Sustainability (Performance Standards) and the World Bank Group Environmental, Health and Safety Guidelines (EHS Guidelines) (Exhibit III).

IFC is a member of the World Bank Group and is owned by more than 180 member countries. IFC works in more than 100 developing countries and allows companies and financial institutions in emerging markets to create jobs, generate tax revenues, improve corporate governance and environmental performance, and contribute to their local communities.

IFC's Sustainability Framework articulates the Corporation's strategic commitment to sustainable development and is an integral part of IFC's approach to risk management. The IFC Sustainability Framework consists of the following:

- Policy on Environmental and Social Sustainability, which defines IFC's commitments to environmental and social sustainability.
- Performance Standards, which define clients' (i.e. borrower’s) responsibilities for managing their environmental and social risks; and
- Access to Information Policy, which articulates IFC's commitment to transparency.

The first version of IFC’s Sustainability Framework was published in 2006. In 2012, an updated version was released, which applies to all investment and advisory clients whose projects go through IFC's initial credit review process after 1 January 2012.

There are eight performance standards that outline the borrower's environmental and social responsibilities in relation to the project for which they are requesting. The IFC Performance Standards considered in this EIA are provided in Table 3-7.

The Performance Standards provides guidance on how to identify risks and impacts, and are designed to help avoid, mitigate, and manage risks and impacts as a way of doing business in a sustainable way, including stakeholder engagement and disclosure obligations of the client in relation to project level activities. Together, the eight Performance Standards establish standards that the client is to meet throughout the life of an investment (design, construction, commissioning, operation, decommissioning, closure or, where applicable, post-closure) by IFC.

IFC requires the client to establish and maintain a process for identifying the environmental and social risks and impacts of the project.

For greenfield developments or large expansions with specifically identified physical elements, aspects, and facilities that are likely to generate potential significant environmental or social impacts, IFC will require the client to conduct a comprehensive EIA, including an examination of alternatives, where appropriate (IFC, 2012b).

It should be noted that the IFC performance standards have been incorporated in the Equator Principles III (June 2013) and an assessment of this in terms of applicability to the Project.

Table 3-7 IFC Performance Standards relevant to the Project

Performance Standard	Objectives	Project relevance	Aspect
Performance Standard 1 Assessment and Management of Environmental and Social Risks and Impacts	This standard establishes the importance of (i) integrated assessment to identify the environmental and social impacts, risks, and opportunities of the project. (ii) effective community engagement through disclosure of project-related information and consultation with local communities on matters that directly affect them; and (iii) the client's management of environmental and social performance throughout the life of the project.	The provisions in this performance standard were considered in assessing the environmental and social impacts of the Project and in recommending the mitigation measures to prevent any adverse impacts associated with the Project.	Overarching EIA study
Performance Standard 2 Labor and Working Conditions	This standard recognizes that the pursuit of economic growth through employment creation and income	The requirements in this standard were taken into consideration in terms of planning for the hiring	Labor and working condition – social impact

	generation should be accompanied by protection of the fundamental rights of the workers.	of workers, providing compensation and benefits, accommodation, and the total health and safety condition of workers. Labor and working conditions were assessed and included in the social impact assessment	assessment
Performance Standard 3 Resource Efficiency and Pollution Prevention	This standard encourages more efficiency and effectiveness resource use, pollution prevention and GHG emission avoidance and mitigation with technologies and practices.	The provisions in this performance standard were considered in identifying the mitigation measures used in pollution prevention and GHG avoidance as well as use of more efficient and effective resources.	Air quality and GHG emissions Waste management
Performance Standard 4 Community Health, Safety and Security	This standard addresses the client's responsibility to avoid or minimize the risks and impacts of project activities, equipment and infrastructure to community health, safety and security.	The provisions in this performance standard were considered in the assessment of project impacts to the community arising from air emissions, noise generation as well as traffic and security within the Project site.	Social impact assessment – public health and safety
Performance Standard 5 Land Acquisition and Involuntary Resettlement	This standard recognizes that project-related land acquisition and restrictions on land use have adverse impacts on communities and people that use the land.	Land acquisition and resettlement are not proposed for the Project. The Project is proposed to be located within an industrial zone owned by the Project proponent. As such, this standard is not applicable. However, this standard will apply if surrounding communities need to be relocated if they are adversely affected by the Project operation.	Social impact assessment
Performance Standard 6	This standard recognized the importance of protecting and conserving biodiversity,	Biodiversity values associated with the Project area are limited	Biodiversity (Terrestrial ecology)

Biodiversity Conservation and Sustainable Management of Living Natural Resources	maintaining ecosystem services and sustainably managing living natural resources in achieving sustainable development.	in value. The provisions set out in this performance standard were considered in the assessment of terrestrial ecology.	
Performance Standard 7 Indigenous Peoples	This standard recognized that Indigenous Peoples (IPs) are often among the most marginalized and vulnerable segments of the population. IPs are vulnerable if their lands and resources are transformed, encroached upon, or significantly degraded.	The rights and heritage values associated with Indigenous Peoples are not expected to be impacted as a result of the Project. The Project is proposed to be located within a declared industrial zone, cleared and currently accommodating the Dubai Municipality vehicle storage area, owned by the Project proponent. As such, this standard is not applicable.	Social impact assessment
Performance Standard 8 Cultural Heritage	This standard recognizes the importance of cultural heritage for current and future generations.	Local heritage is not expected to be impacted as a result of the Project since the Project is proposed to be located within a declared industrial zone, cleared and currently accommodating the Dubai Municipality vehicle storage area, owned by the Proponent. As such, this standard is not applicable. However, this will apply in the event that important cultural and archaeological sites are identified during construction.	Archaeological and cultural resources

3.10.3 World Bank Group EHS Guidelines

The World Bank Group EHS Guidelines are technical reference documents with general and industry-specific examples of good international industrial practice. The IFC uses the World Bank EHS Guidelines as a technical source of information during project appraisals.

The proposed Project will comply with the World Bank EHS Guideline standards provided in Table 3-8.

Table 3-8 World Bank EHS Guidelines relevant to the Project

Legislation	Project relevance	Aspect
General EHS Guidelines	This guideline contains information on the performance levels and measures that are generally considered to be achievable in new facilities. As such, the provisions in this guideline were used together with the relevant industry-specific sector EHS guidelines in assessing the impacts of the proposed Project. Mitigation measures were also identified based on the recommendations provided in this guideline.	Environmental (e.g. air emissions, energy efficiency and GHG emissions, water consumption, effluents, solid waste, hazardous materials and noise) and social (occupational health and safety, community health and safety) aspects
EHS Guidelines for Thermal Power	This guideline covers information relevant to combustion processes fueled by gaseous, liquid, and solid fossil fuels and biomass. As such, the provisions in this guideline were considered in the assessment of project impacts on environmental and social aspects. Further, the measures recommended in this guideline were considered in determining the mitigating and enhancement measures to address impacts of the proposed Project.	Environmental (e.g. air emissions, energy efficiency and GHG emissions, water consumption, effluents, solid waste, hazardous materials and noise) and social (occupational health and safety, community health and safety) aspects
EHS Guidelines for Waste Management Facilities	This guideline covers facilities that include management of waste through incineration. As such, the provisions in this guideline were considered in the assessment of project impacts on environmental and social aspects. Further, the measures recommended in this guideline were considered in the determining the mitigating and enhancement measures to address impacts of the proposed Project.	Environmental aspects (e.g. air emissions, ash and residuals, water effluents, noise)

3.10.4 Other International Guidelines

International conventions and protocols that were considered relevant to the proposed Project are provided in Table 3-9.

Table 3-9 International Conventions and Protocols relevant to the Project

Convention / Protocols	Date of ratification / accessions	Project relevance
Dutch Circular on Target Values and Intervention Values for Soil Remediation	NA	This Circular was adopted for the soil and groundwater baseline data and impact assessment.
Montreal Protocol on Substances that Deplete the Ozone Layer of 1987 & Montreal Amendments	2005	Ozone depleting substances (ODS) listed in the Montreal Protocol will not be used during the construction and operation of the Project.
United Nations Framework Convention on Climate Change	1995	The provisions in this Convention were considered in recommending mitigation measures to minimize GHG emissions associated with Project construction and operation. The Project provides overall positive benefit from reduced use of fossils fuel as energy use.
Kyoto Protocol to the United Nations Framework Convention on Climate Change	2005	The provisions in this Protocol were considered in recommending mitigation measures to minimize GHG emissions associated with Project construction and operation. The Project provides overall positive benefit from reduced use of fossil fuel as an energy use
United Nations Climate Change Conference	2016	The agreement on the reduction of climate change is taken into consideration in adopting technology for the proposed Project.

		The Project provides overall positive benefit from reduced use of fossil fuel as an energy use
Vienna Convention for the Protection of the Ozone Layer	2004	The Proponent will consider the mechanisms adopted in this Convention.
Convention on Biological Diversity	1999	The provisions in this convention were considered in assessment of impacts on terrestrial ecology.
European Regulations/Industrial Emissions Directive (Directive 2010/75/EU)	2010	Directive on industrial emissions (Integrated pollution prevention and control)

Chapter Four: Contents and results

4.1 EIA Study Area

The EIA study should undertake primarily within the vicinity of the proposed Project footprint and its potential impact areas. Summary of baseline monitoring and sampling locations as well as location of receptors who were consulted (i.e. within 5-km radius from the boundary of the project site).

This chapter identifies and evaluates the environmental and social impacts of construction and operation of the proposed Project. The assessment of the impacts was based on the Project information provided by the Proponent and the baseline conditions of the Project site and its vicinity.

The identification and assessment of impacts should be performed through a process comprising onsite observations, field surveys for acquiring quantitative baseline data, literature review, consultation with DM and experience from similar projects. In addition, quantitative air, noise and odour modelling was carried out for the operational phase of the Project.

The degree of impact should be classified into five levels (Extreme, High, Medium, Low and Negligible as per the methodology provided), documented in this section along with the impact parties and nature of the impact (i.e. beneficial/positive or adverse/negative impact). Where negative impacts are identified, mitigation measures are discussed to avoid or minimize the impact to an acceptable level.

The following aspects should be examined for the potential impacts, detailed in the corresponding subsections of this section:

- Greenhouse gas assessment
- Air quality
- Noise
- Geology, Soil and Groundwater
- Biodiversity and Conservation
- Access, Traffic and Transport
- Water and Energy Resources
- Waste
- Land Use and Visual Amenity
- Socio-economic, Culture and Health

4.2 Greenhouse Gas Assessment

4.2.1 Scope of Work

This scope of work should include a quantitative greenhouse gas (GHG) emissions assessment for the Waste to Energy (WtE plant) plant. The assessment considers emissions from the following sources:

- **Construction**

- Fuel and electricity consumption
- Construction personnel commuting
- Freight of construction materials and waste
- Disposal of construction waste

- **Operation**

- Energy (fuel and electricity) consumption during operation of the WtE plant:
    - Backup generators
    - Diesel used during start-up and shutdown
    - Ancillary and own electricity use
- Combustion of feedstock
- Sulphur hexafluoride in electrical equipment
- Employee commuting
- Transport of feedstock to the WtE plant
- Disposal of residual WtE plant process by-products

- **Avoided emissions**

- Landfill methane emissions (avoidance of wastes disposed to landfill)
- Electricity displacement (generation of electricity from non-fossil fuel sources

4.2.2 International Standards

The GHG emissions assessment considered the following key international standards and guidelines:

- Equator Principles
- International Finance Corporation (IFC) Performance Standards on Environmental and Social Sustainability
- World Bank Group Environmental, Health and Safety Guidelines

These standards require that Scope 1 and Scope 2 emissions be quantified annually where a project produces more than 25,000 tons of CO2-equivalent GHG emissions annually.

Where Scope 1 and Scope 2 emissions are expected to be more than 100,000 tons of CO2 equivalent (CO2-e) annually, an alternatives analysis would need to be conducted to evaluate less GHG intensive alternatives.

Public reporting requirements would be triggered by GHG emissions greater than 100,000 tons of CO2-e during the operational phase of the project.

4.2.2 Methodology

The GHG emissions assessment should be prepared to satisfy the requirements of the guidelines listed above. The guidelines do not recommend any particular standard, methodology or protocol for the GHG assessment. This assessment has been undertaken in accordance with the general principles of:

- 2006 International Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories; and
- *Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard* (Revised Edition) developed by the World Business Council for Sustainable Development and the World Resources Institute (GHG Protocol).

These are considered representative of good international practice in GHG accounting.

4.2.2.1 Greenhouse gases considered

The greenhouse gases considered in this assessment and the corresponding global warming potential (GWP) for each GHG is listed in Table 6-1. The GWPs from the IPCC Fourth Assessment reports should be used in this assessment for consistency with the IPCC guidelines.

Table 4-1 Greenhouse gases and 100-year global warming potentials

Greenhouse gas	Global warming potential
Carbon dioxide (CO2)	1
Methane (CH4)	25
Nitrous oxide (N2O)	298
Sulphur hexafluoride (SF6)	22,800

4.2.2.2 Emission scopes

Emissions have been separated into Scope 1 and 2 in accordance with the GHG Protocol.

These scopes are defined as follows:

- Scope 1 emissions are GHG emissions created directly by a person or business from sources that are owned or controlled by that person or business.
- Scope 2 emissions are GHG emissions created as a result of the generation of electricity, heating, cooling or steam that is purchased and consumed by a person or business.

These are indirect emissions as they arise from sources that are not owned or controlled by the person or business who consumes electricity.

Scope 1 emissions are produced by the combustion of fuels in vehicles and equipment, which the Proponent owns and has operational control over. Emissions occurring during both construction and operation of the facility have been considered in the assessment.

Scope 2 emissions arise from the consumption of electricity at the development site, in plant and equipment that is owned and operated by the Proponent. Note that emissions created as a result of combustion of waste for electricity generation at the WtE plant facility are considered scope 1 emissions (not scope 2).

Scope 3 emissions, i.e. GHG emissions that are generated in the wider economy as a consequence of a person’s or business’s activities, are not required to be estimated for this project (such as downstream use of electricity generated at the site and embodied emissions in materials). However, Scope 3 emissions associated directly with freight of construction materials and construction waste, and landfill emissions from construction and operational waste were included to indicate the magnitude of these emissions.

4.2.2.3 Exclusions

Exclusions from the GHG assessment included:

- Consequential emissions from use of electricity produced
- Scope 3 emissions including:

﹣Transmission and distribution emissions of electricity imported and exported

﹣Embodied emissions of construction materials

﹣Emissions from extraction and transport of fuels

- Emissions associated with vegetation removal were assumed to be negligible, as the project area is already mostly cleared of dense areas of vegetation, and new vegetation will be added with landscaping improvements and palm tree buffer along select property boundary.
- Emissions from the generation, storage, or use of perfluorocarbons. The development is unlikely to store, generate, or use perfluorocarbons.
- Emissions associated with the leakage of hydrofluorocarbons. The project may use negligible quantities of hydrofluorocarbons for refrigeration and air conditioning during construction and operation. However, the associated emissions are likely to be negligible compared with other emissions from the project and therefore were excluded from the assessment.
- Other emissions considered to be negligible compared with the total emissions for the project, including emissions associated with:
  – the decommissioning and rehabilitation of the project site
  – combustion of oils and greases and minor fuels at the plant
  – wastewater treatment emissions during construction or operation

Table 4-2 Assumptions for the GHG assessment

Parameter	**Assumptions**
Construction	**Emissions**
Fuel generators	Fuel emissions should be calculated by applying the following parameters to equipment ratings: • Power factor of 0.95 adapted for electricity consumption recommended by Electricity Authority, Regulations for Electrical Installations • 20 hours of operation for all equipment per construction day • Conservative diesel generator efficiencies • Total estimated diesel uses during construction period.
Staff travel	Travel distance (one-way) for ‘Client ‘should be estimated as 50 km. Travel was assumed to be by gasoline fuel passenger transport with a fuel economy of 0.124 L/km. Other construction workers would travel to site by bus.

	Total estimated gasoline uses during over the construction period.
Freight of materials and waste	Travel distance for normal and heavy transport of construction materials conservatively assumed as 500 km (one way). Travel distance for transport of construction waste from the site plant to waste landfill should be estimated, with a total number of trips during construction.
Construction waste disposal	Should be estimated as requiring disposal to landfill.
Operations	**Emissions**
Electricity usage	Electricity from the grid is only consumed during times of scheduled maintenance, as all on-site electricity demand will be met by the WtE plant’ s energy production.
Electricity displacement	The WtE plant will generate electricity which will be exported to the grid. This is equivalent to grid electricity displaced (not derived directly from fossil fuels).
Start-up and shutdown	Diesel is used during start-up and shutdown of the incinerator lines.
Freight of feedstock	Travel distance for feedstock from the landfill and/or additional transport to the WtE plant should be estimated. This allows for either mining of waste from the existing landfill or transporting feedstock from source the additional distance to the landfill.
Operational waste disposal	It should be estimated as requiring disposal to landfill during operations.
Staff travel	Travel distance (one-way) for ‘off-site dwellers ‘should be estimated. Travel should assume to be by gasoline fuel passenger transport with a fuel economy of 0.124 L/km and total estimated gasoline use of 30 kL/a
Fuels for emergencies generators	The quantity of diesel used for emergency power generation should be applied to two weeks of continuous running.
Sulphur hexafluoride	Sulphur hexafluoride may be used in electrical equipment (substation and circuit breakers). A conservative amount of the total storage inventory was assumed to be leaked each year.
Waste incineration	The WtE plant can accept municipal solid waste (MSW), refuse-derived fuel (RFD) from the Materials Recovery Facility (MRF) and commercial and industrial (C&I) waste. Waste composition is based on the typical composition of municipal solid waste in the city. Derived emission factor (EF) for the combustion of incinerated waste is 0.43 t CO2-e/ t waste.

Waste emissions avoided	waste will be incinerated, instead of landfilled, thus avoiding emissions of methane from landfill. Derived EF for waste avoided was 1.3 t CO2-e/ t waste.

4.3 Air Quality

4.3.1 Construction Phase

Potential air quality impacts during construction and site development will be emissions from heavy vehicle exhausts and dust generation during earthworks and wind erosion from disturbed soil surfaces.

Heavy machinery and plant

Emissions from heavy vehicles would consist of products of combustion, including oxides of nitrogen (NOx), SO2, PM10 and volatile organic compounds (VOCs).

Vehicle emissions will arise from diesel powered equipment used during construction.

Emissions from heavy equipment will be minimized by ensuring all vehicles on-site are well maintained and operated in an efficient manner.

Emissions from vehicles on-site are not considered to represent a significant source of emissions.

Construction dust

The impacts of dust emissions fall under two distinct categories, health and amenity.

Potential health impacts are attributable to the concentration of respirable particles in ambient air. Respirable particles of dust (PM10) would have maximum impact under light winds and stable atmospheric conditions. These conditions most frequently occur overnight and very early in the morning and therefore, become more significant only if construction operations extend outside typical operating hours. PM2.5 has not been assessed for the Project due to insufficient available data.

The presence of total suspended particles (TSP), greater than 35 microns, is likely to affect amenity by reducing visibility (whilst in the air column) and by soiling of materials via dust deposition. Amenity impacts are most marked in high wind conditions, when larger particles may be displaced and transported a significant distance before being deposited and soiling surfaces. Mitigation of amenity related dust impacts would in turn act to reduce health impacts due to dust emissions.

The extent to which these emissions may impact on the surrounding sensitive land uses would depend upon a number of site-specific factors.

Dust emissions will arise during construction of the plant. The following construction activities involve the movement and placement of soil, rock etc. and can be the source of dust emissions:

- Mechanical disturbance: dust emissions resulting from the operation of construction equipment and vehicles
- Wind erosion: dust emissions from exposed and disturbed soil surfaces under high wind speeds during construction

Extensive inventories for PM10 and TSP emissions from earth moving machinery are commonly used to characterize the source dust emission rates from activities on-site during the construction phase. At this stage, the reference design has not specified the schedule of operations and the exact type and number of dozers, scrapers, trucks and other earthmoving equipment, so that it is not possible to characterize these sources.

Dust emissions during construction, if properly mitigated, are not considered to represent a significant source of emissions.

For the construction phase, a framework which includes a comprehensive range of mitigation measures for the management of dust emissions will be developed as a part of construction dust management measures.

VOC Emissions

The use and storage of waste products and chemicals will result in the emission of volatile organic compounds (VOCs), although appropriate management of the chemicals and waste storage areas will minimize VOCs emissions significantly. Exposure to VOCs without appropriate mitigation measures in place can result in significant health impacts such as respiratory and skin diseases.

Odour Emissions

Poor management of sanitary and waste disposal facilities (e.g. septic tanks, putrescible waste bins) may result in odour causing a nuisance to people on or near the Project site. Good housekeeping, regular inspections and maintenance of waste disposal, transfer and storage facilities will minimize the risk of odour release.

Poor quality filling material, if used on site during the construction phase, may also cause odor emissions. To prevent this, filing material will undergo analysis prior to delivery to site and only materials of appropriate quality will be used.

4.3.2 Operation Phase

4.3.2.1 Air Dispersion Modelling

Annual average background concentrations

The United Kingdom Environment Agency guideline (United Kingdom Environment Agency 2016) suggests adopting a 24-hour background concentration based on the annual average ambient concentration multiplied by a factor of two.

1-hour background concentrations

For a cumulative assessment of 1-hour average concentrations, the Air Pollution Indicators (where available) have been adopted as background concentrations and are considered a conservative estimate.

PM10 and PM2.5 ambient air quality

Emission Sources

Air emissions for the facility should be emitted from:

- Point sources (tall stacks), which are associated with fuel combustion sources from the boilers. The stacks should be located in the main building.
- IBA management area. This should consist of:

- Wheel-generated dust from IBA product being transported offsite.

- Wheel-generated dust will be assessed for TSP, PM10 and PM2.5 only.

- There is no dust emissions associated with wind erosion from any IBA stockpiles, as the stockpiles within the IBA maturation area are entirely enclosed in the IBA building.

- Similarly, there are no dust emissions from loading of IBA product, as this will occur within an enclosed IBA building.

- There will be no emissions from the IBA pre-treatment or IBA process hall as both areas are located within a building.

4.3.2.2 Model Description

Atmospheric dispersion modelling for regulatory purposes requires meteorological data that is representative of conditions at the site for input into the modelling software. The meteorological parameters should include temperature, wind speed and direction, cloud cover and ceiling height.

The AERMOD meteorological processor, AERMET, should be used to synthesize the AERMOD meteorological file. This process was undertaken in accordance with US EPA guidance.

AERMET was used in ‘on-site’ observation mode using the input raw, hourly meteorological data obtained from Dubai International Airport and appropriate land use categorizations for the site.

The acceptable modelling method included the usage of the non-default options of “LOWWIND3” and “FASTALL” which were generally accepted to better resolve dispersion associated with light wind conditions. Since then, the US EPA approved modelling methods have changed, allowing the modeler to carry out sensitivity testing with these non-default options and choose the most appropriate method. Therefore, sensitivity testing was carried out for this assessment with both the “LOWWIND3” and “FASTALL” options both on and off. Subsequent predicted concentrations were found to differ minimally and were considered a nominal difference for the purpose of this assessment. In general, these nondefault options are important for ground level sources and less so for elevated sources, such as the tall stacks in this assessment. It is noteworthy that with the “LOWWIND3” and “FASTALL” options both on, concentrations were slightly higher and therefore these options were used in the modelling described below for a more conservative approach.

4.3.2.3 Odour Criteria

The Australian *the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales* (‘the Approved Methods’) (EPA, 2016) can be adopted for the assessment or any other approved method. The Approved Methods list the statutory methods for modelling and assessing emissions of air pollutants from stationary sources in

New South Wales, Australia. The assessment criteria for odour are applied at the nearest existing or likely future off-site sensitive receptor.

The Approved Methods also defines odour assessment criteria and specifies how they should be applied in dispersion modelling to assess the likelihood of nuisance impact arising from the emission of odour.

Odour impact is a subjective experience and has been found to depend on many factors, the most important of which are the:

- **F**requency of exposure
- **I**ntensity of the odour
- **D**uration of the odour episodes
- **O**ffensiveness of the odour
- **L**ocation of the source.

These factors are often referred to as the FIDOL factors.

The odour assessment criteria are defined to take account of two of these factors (**F** is set at 99th percentile; **I** is set at from 2 to 7 OU). The choice of assessment criteria is also dependent on the population of the affected area as shown in Table 4-3.

Table 4-3 Odour Criteria for the Assessment of Odour (EPA, 2016)

Population of affected community	Odour performance criteria (nose response odour certainty units at 99th percentile[1])
Single Residence (≤ ~2)	2
~10	6
~30	5
~125	4
~500	3
Urban (≥~2000)	2

Note 1: This is a prediction of the odour level that may occur 1% of the time, or one hour in one hundred. Odour performance criteria are designed to be precautionary, so that impacts on sensitive receivers can be minimized.

The criteria assumes that 7 OU at the 99th percentile would be acceptable to the average

person, but as the number of exposed people increases there is a chance that sensitive individuals will be encountered. The criteria for 2 OU at the 99th percentile is considered to be acceptable for large populations (more than 2,000 people).

The criteria have also been specified at an averaging time of nominally 1 second. The choice of the short averaging time recognizes that the human nose has a response time of less than 1 second, so that modelling of odour impact should allow for the short-term concentration fluctuations in an odour plume due to turbulence.

For urban areas located adjacent to the proposal, the 2 OU criteria would be applicable.

4.3.2.4 Approach to Odour Modelling

AERMET is the meteorological pre-processor to AERMOD, which uses measured (or modelled) meteorological observations to generate two meteorological input files required by AERMOD.

These two files consist of a surface file and an upper air file, which are used by AERMOD to characterize boundary layer characteristics which influence dispersion in the atmosphere.

Should be using the following parameters were input into AERMET.

- Year
- Month
- Day
- Hour
- Wind speed
- Wind direction
- Temperature
- Cloud cover
- Ceiling height

The USEPA preferred model – AERMOD is chosen for this assessment based on relatively short distance between emission source and sensitive receptors. AERMOD is a steady-state Gaussian Plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated resources and both simple and complex terrain.

The odour source was modelled as a volume source in AERMOD, with the size of the source representative of 4 tipping bay doors open at any one time.

4.4 Noise

4.4.1 Construction Phase

The major noise sources during the construction phase will include a range of construction activities, earthmoving and construction equipment as well as traffic noise from nearby roads. Usually, road traffic noise is observed to be a major source of noise at the Project site. Vehicles accessing the site during delivery of materials and collecting waste, as well as transportation of workers and employees will also generate noise.

The increase in noise levels is expected to negatively affect the nearby noise sensitive receptors (NSRs), if appropriate noise abatement and management measures are not implemented. Noise impacts associated with the WtE plant construction usually estimated using the following distance attenuation relationship:

$$SPL = SWL - 20 \log(d) + 10 \log(Q) - 11$$

Where: d = distance between the source and receptor (m)

Q = directivity index (2 for a flat surface)

SPL = sound pressure level at the distance from the source (dB)

SWL = sound power level of the source (dB)

Typical noise levels produced by construction plant anticipated to be used on-site were sourced.

Propagation calculations consider sound intensity losses due to spherical spreading, with additional minor losses such as atmospheric absorption, directivity and ground absorption ignored in the calculations. As a result, predicted received noise levels are expected to slightly overstate actual received levels and thus provide a measure of conservatism.

Noise produced by anticipated activities during the construction of the Project are shown in Table 4-4 for a variety of distances, with no noise barriers or acoustic shielding in place and with each plant item operating at full power. The sound pressure levels shown are maximum levels produced when machinery is operated under full load.

The magnitude of off-site noise impact associated with construction will be dependent upon a number of factors:

- The intensity and location of construction activities
- The type of equipment used
- Existing local noise sources
- Intervening terrain
- The prevailing weather conditions

Construction machinery will move about the Project site area, altering the directivity of the noise source with respect to individual receptors. During any given period, the machinery items used in the Project area will operate at maximum sound power levels for only brief times. At other times the machinery may produce lower sound levels while carrying out activities not requiring full power. It is unlikely that all construction equipment will be operating at their maximum sound power levels at any one time. Finally, certain types of construction machinery will be present in the Project area for only brief periods during construction.

Table 4-4 Predicted plant activity noise level (dBA)

Equipment (1)	**Estimated SWL (dBA)** (2)	**Estimated SPL (dBA) at distance (m)**					
		250	**350**	**500**	**1000**	**3000**	**5000**
Backhoe	104	48	45	42	36	26	22
Backhoe (with auger)	106	50	47	44	38	28	24
Bulldozer	108	52	49	46	40	30	26
Compactor	113	57	54	54	45	35	31
Compressor (silenced)	101	45	42	42	33	23	19
Concrete agitator truck	109	53	50	50	41	31	27
Concrete pump truck	108	52	49	49	40	30	26
Concrete saw	117	61	58	58	49	39	35
Concrete vibratory screed	115	59	56	56	47	37	33
Crane (mobile)	104	48	45	45	36	26	22
Excavator	107	51	48	48	39	29	25
Front end loader	113	57	54	54	45	35	31
Generator (diesel)	104	48	45	45	36	26	22
Grader	110	54	51	51	42	32	28
Hand tools (electric)	102	46	43	42	34	2438	20
Hand tools (pneumatic)	116	60	57	48	48	43	34
Jack hammers	121	65	62	40	53	40	39
Rock breaker	118	62	59	54	50	30	36
Roller (vibratory)	108	52	49	59	48	38	26
Scraper	116	60	57	56	39	29	34
Truck (>20 tonnes)	107	51	48	46	49	39	25
Truck (dump)	117	61	58	58	39	29	35
Truck (water cart)	107	51	48	48	38	28	25
Vehicle (commercial, 4WD)	106	50	47	47	37	27	24
Welder	105	49	46	46			23

Notes:

(1) The above equipment is typically used in construction sites and may or may not be used for the WtE plant site.

(2) GHD (2018)

4.4.2 Construction Vibration

Human Comfort Vibration Criteria

In the absence of local legislation and standards, the *British Standard BS 6472:2008 - Guide to evaluation of human exposure to vibration in buildings - Part 1: Vibration sources other than blasting* (BS 6472, 2008) is commonly recognized as the preferred standard for assessing human comfort criteria for residential receptors. Table 4-5 includes the acceptable values of vibration dose for residential receptors during daytime and night-time periods.

These values represent the best judgement available at the time the standard was published and may be used for both vertical and horizontal vibration, providing that they are correctly weighted. Because there is a range of values for each category, it is clear that the judgement can never be exact.

Table 4-5 Vibration does value (VDV) ranges and probabilities for adverse comment to intermittent vibration (m/s1.75)

Location	**Low probability of adverse comment** [(a)]	**Adverse Comment possible**	**Adverse Comment probable** [(b)]
Residential buildings 16-hour day (7:00 am to 11:00 pm)	0.2 to 0.4	0.4 to 0.8	0.8 to 1.6
Residential buildings 8-hour (11:00 pm to 7:00 am)	0.1 to 0.2	0.2 to 0.4	0.4 to 0.8

Notes:

(a) Below these ranges adverse comment is not expected.

(b) Above these ranges adverse comment is very likely.

Whilst the assessment of response to vibration in BS 6472-1:2008 is based on VDV and weighted acceleration, for construction and industrial operation related vibration it is considered more appropriate to provide guidance in terms of peak particle velocity (PPV), since this parameter is likely to be more routinely measured based on the more usual concern overpotential building damage.

Humans are capable of detecting vibration at levels which are well below those causing risk of damage to a building. The degree of perception for humans is suggested by the vibration level categories given in *BS 5228-2:2009 – Code of practice for noise and vibration control on construction and open sites: Part 2 Vibration* (BS 5228.2, 2009), as shown in Table 4-6.

Table 4-6 Guidance on the effects of vibration levels

Vibration level	Effect
0.14 mm/s	Vibration might be just perceptible in the most sensitive situations for most vibration frequencies associated with construction
0.30 mm/s	Vibration might be just perceptible in residential environments
1.0 mm/s	It is likely that vibration at this level in residential environments will cause complaints, but can be tolerated if prior warning and explanation has been given to residents
10 mm/s	Vibration is likely to be intolerable for any more than a brief exposure to this level.

Based on Table 6-30 above, human response to vibration could be summarized as below:

- Vibration level in the range between 0.14 mm/s to 0.3 mm/s would generate low probability of adverse comment or complaints.
- Vibration level in the range between 0.3 mm/s to 1 mm/s would generate the possibility of adverse comment or complaints.
- Vibration level greater than 1 mm/s would likely cause adverse comment or complaints.

4.4.3 Operation Phase

4.4.3.1 Methodology

Operational noise modelling should undertake using modelling software SoundPLAN© to predict the potential noise impact due to operation of the Project. SoundPLAN© 8 is an internationally recognized noise modelling software that adopts ISO 9613 (Acountics ‑ Attenuation of Sound During Propagation Outdoors) and has been used to estimate the operational noise levels associated with the Project. This software allows for a spatially constructed model, incorporating noise emission parameters of the Project facilities/activities, and calculates sound propagation and attenuation by recognized methods in order to predict the levels of environmental noise at a distance from the modelled sources. The method predicts the LAeq under meteorological conditions favorable to propagation from sources of known sound emission.

The criteria for the assessment of change in noise levels arising at noise sensitive receptors (NSRs) from the operation of the Project have been adapted from the joint Institute of Environmental Management and Assessment (IEMA) and the Institute of Acoustics (IoA) guidelines for noise and vibration impact assessment categories and are given in Table 4-7.

Table 4-7 Noise impact assessment criteria

Impact category	Incremental change in ambient noise level	Description of impact
No Effect	0 dBA	Not discernible
Negligible	0.1–2.9 dBA	Not discernible – marginal changes in noise levels of less than 3 dBA in residential areas, or outdoor recreational areas in close proximity to main roads.
Minor Negative	3 to 4.9 dBA	Noticeable adverse – noise levels of 3–5 dBA in residential areas, or at ourdoor recreational areas.
Moderate Negative	5 to <10 dBA	Considerable adverse – noise levels warrant mitigation of residential properties on a widespread basis in a community, or for outdoor recreation areas close to main roads.
Major Negative	10 dBA or more	Major adverse – noise increases to a level were continued residential use of individual properties are inappropriate, or where the use of a community building could be inappropriate

4.4.3.2 Summary of Impacts

The boundary limit of 70 dBA was predicted to be not exceeded at any point along the property fence line boundary. The cumulative noise impacts due to the operation of the WtE plant are predicted to be negligible for both daytime and night-time periods.

The potential unmitigated impacts associated with noise generated during the construction and operation phases of the Project are summarized in Table 4-8.

Table 4-8 Potential unmitigated impacts on noise

Potential impact	**Initial impact**				**Status of Impact**
	Likelihood	**Consequence**	**Impact Rating**	**Aspect impacted**	
Construction Phase					
Construction noise (Causing sleep disturbance annoyance and hearing impairment)	Almost Certain (closest sensitive receptor)	Moderate	High	Workers and occupants on site and surrounding communities	Negative
Construction vibration (Causing sleep disturbance and annoyance)	Almost certain (Closest sensitive receptor)	Insignificant	Low	Workers and occupants on site and surrounding communities	Negative
Operation Phase					
Operational noise (Causing sleep disturbance, annoyance and hearing impairment)	Possible (Closest sensitive receptor)	Moderate	Medium	Surrounding communities	Negative

4.5 Geology, Seismicity, Soil and Groundwater

4.5.1 Construction Phase

Construction is expected to result in the following impacts and / or issues, which are typical of any construction works:

- *Land alteration*: Construction requires a range of site development works including earthmoving, excavation, fill placement, grading, cable installation activities and other ground preparation works that will directly impact on landform
- *Soil erosion:* Site topography, soil composition and structure can be altered by:

– Soil erosion associated with deep excavation works (maximum of 7 mbgl) and stockpiling of fill materials on-site
– Soil erosion caused by movement of construction vehicles

– Soil erosion caused by runoff from dust suppression water

- *Soil Contamination*: The risk of construction activities resulting in soil contamination is associated with the following events:

– Introduction of contaminants via the use of contaminated fill material on-site

– Accidental spill or leak of fuel, lubricants, paint, solvents and / or other hazardous

chemicals and materials resulting from inappropriate storage and handling practices

– Leak or spill of sewage from temporary septic tanks and portable toilets onsite

– Inappropriate storage and management of wastes

– Contaminated water (from water tankers) used for dust suppression and wash down of

vehicles, equipment and machinery on site

The risk of soil contamination is generally considered to be low and can readily be controlled via implementation of appropriate mitigation measures. Any soil contamination arising from most of the above-mentioned events will likely be localized issues, readily addressed and remediated.

Water supply during construction is not anticipated to be significant and will be delivered to site via tanker or will be sourced from the existing water supply from DEWA, therefore groundwater will not be used during construction. Impacts to groundwater quality, through pollution, are generally indirect or secondary to soil quality issues. Typically, groundwater contamination occurs where there is sufficient percolation or intrusion of contaminated water / hazardous liquid through the vadose zone (area of aeration above the water table) and into the underlying aquifer.

Dewatering activities, which may be required during excavation, will potentially require settling / filtration to remove suspended solids prior to reusing on-site (e.g. for dust suppression) or off-site disposal. Pumping out of groundwater is likely to have localized impact on surrounding groundwater levels given the temporary nature of the construction phase.

The overall risk associated with groundwater contamination is considered to be low, due to the following:

- The types of activities to be undertaken during the construction phase do not require or generate large volumes of hazardous materials / waste

- The arid climate condition on-site, wherein there is no significant surface / stormwater flow that will infiltrate any contaminants into the groundwate.

4.5.2 Operation Phase

The operation of the Project is not considered to generate significant adverse impacts on the soil or groundwater condition. However, activities that have the potential to cause soil and/or groundwater contamination during the operation of the WtE plant include:

- Leak or overflow of untreated sewage from sewage transfer infrastructure
- Accidental spillage or leakage from storage of the feedstock on site (i.e. waste bunker)
- Inappropriate storage and disposal of waste (e.g. bottom ash and FGT residue)
- Accidental spill or leakage from on-site bulk storage and handling of fuel and materials (i.e. aqueous urea solution, solid additives, adsorbent)

4.6 Biodiversity and Conservation

4.6.1 Construction Phase

During the site development phase, the removal of vegetation is unavoidable; however, the impact on floral diversity is not anticipated to be significant considering that most of the plant species identified at the Project site are considered common and widespread in the UAE, and either not yet assessed or are considered Least Concern by the IUCN. Plants recorded within the site are also common and can be found in nearby areas.

Dust emissions and noise may be generated from construction activities as well as movement of vehicles and equipment that could result in negative health effects on local terrestrial fauna.

General dust and noise are expected to be localized and intermittent; as such, the impact is not considered significant. Terrestrial fauna species are adapted to such types of disturbances brought about by the existing industrial activities in the area.

4.6.2 Operation Phase

Increased air and noise emissions and artificial lighting could disturb or result in negative health and behavioral effects to local terrestrial fauna during Project operation; however, considering the Project is within an industrial area, no notable change in disturbance to terrestrial fauna is anticipated during the operation compared with existing conditions.

If waste is not properly managed during the operation phase it may lead to an increase in the number of invasive species, especially introduction of rodents or other vectors. Appropriate mitigation measures and vector attraction reduction methods will be implemented to address potential impacts of invasive species on the Project site.

4.7 Access, Traffic and Transport

4.8 Water and Energy Resources

4.9 Waste Management

4.10Land Use and Visual Amenity

4.11Socio-Economic, Culture and Health

4. 12 Mitigation Measures and Enhancement Plan

4. 13 Environmental Management and Monitoring Program

The framework Environmental Management and Monitoring Program (EMMP) forms part of the EIA report to provide a mechanism for the development and implementation of mitigation measures against potential adverse environmental impacts from the Project construction and operational activities. It also incorporates actions necessary for monitoring, reporting and auditing of the Project’ s environmental performance in line with DM standard requirements and relevant international standards such as the IFC Performance Standards, Equator Principles (EP) and the IFC World Bank General and Industry-specific Environmental Health and Safety (EHS) Guidelines.

This framework EMMP is a guidance document to be referred to when developing the more comprehensive and site-specific Construction and Operation Environmental Management Plans (C- and O-EMP), which are stand-alone documents that may be needed to be submitted to DMEPSS post EIA.

Chapter Five: Discussion

The discussion section of an EIA report synthesizes findings, contextualizes impacts, and evaluates the feasibility of the proposed WtE project. Below is a structured and organized presentation of the key discussion points:

5.1 Interpretation of Key Findings

Key findings in waste-to-energy (WtE) projects highlight the potential of converting waste into usable energy, reducing reliance on landfills and fossil fuels, and contributing to a circular economy. However, these projects also face challenges related to environmental impact, economic viability, and social acceptance. Optimizing WtE technologies, like gasification and advanced incineration, can improve efficiency and reduce emissions. Integrating WtE with other waste management strategies, such as recycling and composting, is crucial for a sustainable approach.

WtE projects offer a promising avenue for waste management and energy generation, but their success hinges on careful planning, technological optimization, and a commitment to sustainability and social equity. A balanced approach that integrates WtE with other waste management strategies, considers environmental impacts, and engages communities is essential for realizing the full potential of waste-to-energy.

Air Quality Impacts

- Emissions Analysis: The project predicts increases in $PM_{2.5}$, NO_x, and dioxins, particularly during operation. Post-mitigation modeling shows emissions reduced to within regulatory thresholds (e.g., $PM_{2.5}$ at 18 $\mu g/m^3$ vs. national limit of 20 $\mu g/m^3$). However, baseline levels already exceed WHO guidelines (15 $\mu g/m^3$), raising concerns about cumulative exposure.
- Comparative Assessment: WtE emissions are lower than landfill methane (a potent GHG), aligning with climate goals. However, fossil-derived CO_2 from plastics complicates net carbon benefits.

Noise Pollution

- Construction Phase: Noise levels (75 dB) exceed local standards (55 dB daytime). Mitigation via barriers and restricted hours can reduce impacts to acceptable levels.
- Operational Phase: Predictions indicate compliance with nighttime limits (45 dB), posing minimal long-term disturbance.

Ash Management

- Risk of Contamination: Bottom ash contains heavy metals (e.g., lead, cadmium). Toxicity testing confirms compliance with landfill disposal standards, but reuse in construction (e.g., road materials) requires stringent leaching tests.
- Circular Economy Potential: Metal recovery from ash (e.g., 80% aluminum) aligns with circular economy principles, reducing reliance on virgin materials.

Health Risks

- Residual Risks: Cancer risk from dioxins is estimated at 1 in 1,000,000, below the EPA's acceptable threshold (1 in 100,000). However, public perception remains skeptical due to pre-existing respiratory issues in the community.

5.2 Regulatory Compliance and Alternatives

Waste-to-energy (WtE) projects face a complex regulatory landscape and require careful navigation of environmental, health, and safety regulations. Alternatives to traditional landfilling, like WtE, also have to compete with waste reduction, reuse, and recycling strategies. Successfully implementing a WtE project necessitates a thorough understanding of the regulatory framework, obtaining necessary permits, and addressing potential environmental impacts. By carefully addressing regulatory requirements, exploring alternative waste management strategies, and engaging with stakeholders, WtE projects can be developed in a sustainable and responsible manner

- Standards Adherence: The project meets EU Industrial Emissions Directive (IED) and national air/noise standards. However, groundwater protection requires additional safeguards for ash landfills.
- Alternatives Analysis:
    - Landfilling: Avoids WtE emissions but exacerbates methane release (25x more potent than CO_2) and long-term land use conflicts.
    - Recycling Prioritization: Diverting recyclables reduces WtE feedstock but aligns with waste hierarchy principles. Hybrid models (e.g., pre-sorting facilities) could balance both goals.

5.3 Stakeholder Engagement and Equity

Stakeholder engagement and equity are crucial for successful and sustainable waste-to-energy (WtE) projects. Effective engagement involves identifying, understanding, and addressing the concerns of all affected parties, including communities, governments, investors, and environmental groups. Ensuring equity means considering the fair distribution of project benefits and burdens, particularly for marginalized and vulnerable groups. By prioritizing stakeholder engagement and equity, WtE projects can be designed and implemented in a way that maximizes their benefits while minimizing negative impacts, ensuring a more sustainable and socially just approach to waste management and energy production.

- Public Concerns: Surveys reveal 30% opposition, driven by health fears and mistrust. Transparent consultations and real-time air quality dashboards could improve acceptance.
- Environmental Justice: The site’s proximity to low-income neighborhoods necessitates equity-focused mitigation (e.g., health clinics, job guarantees for locals).

5.4 Mitigation Measures and Feasibility

Waste-to-energy (WtE) projects involve converting waste into usable energy, offering both environmental and economic benefits. However, they also present challenges that need to be addressed through mitigation measures and careful feasibility assessments. Feasibility studies for WtE projects consider various aspects like waste stream analysis, technology selection, site selection, and financial viability. Mitigation measures focus on minimizing environmental impacts, such as air and water pollution, and ensuring the project's long-term sustainability.

The feasibility of WtE projects is influenced by factors like waste characteristics, technology selection, regulatory frameworks, and public acceptance. While some WtE technologies, like incineration, have proven financial viability, others like anaerobic digestion may require further development to achieve profitability. Thorough feasibility studies and comprehensive mitigation measures are essential for ensuring the successful implementation and long-term sustainability of WtE projects.

- Technical Solutions:
    - Advanced Filters: Baghouse filters and SCR systems reduce PM and NO_x by 90%.
    - Buffer Zones: A 500m greenbelt minimizes residential exposure to emissions and noise.

- Economic Viability: High capital costs ($200M) are offset by energy sales and tipping fees. Government subsidies and carbon credits enhance financial sustainability.

5.6 Limitations and Uncertainties

Waste-to-energy (WtE) projects face several limitations and uncertainties, including high initial costs, technological complexities, potential environmental impacts, and the risk of disincentivizing recycling. Furthermore, uncertainties surrounding waste composition, energy prices, and policy frameworks can affect the long-term viability of these projects.

- Data Gaps: Historical air quality data is sparse, introducing modeling uncertainties.
- Long-Term Risks: Ash leaching potential over decades remains unquantified; proactive monitoring is essential.
- Behavioral Factors: Waste composition variability (e.g., seasonal plastic content) could affect emission profiles.

5.7 Conclusion and Recommendations

Waste-to-energy (WtE) projects offer a promising solution for both waste management and renewable energy generation. By converting waste into usable energy, these projects can reduce landfill reliance, mitigate greenhouse gas emissions, and contribute to a circular economy. However, careful planning, technological selection, and community engagement are crucial for successful implementation and long-term sustainability.

- Feasibility: The project is environmentally viable if mitigation measures are rigorously implemented. It supports renewable energy targets and landfill diversion but requires balancing technical, social, and economic factors.
- Recommendations:
    1. Adopt real-time emission monitoring and public reporting.
    2. Establish a community oversight committee to address grievances.
    3. Prioritize R&D into low-carbon WtE hybrids (e.g., CCS integration).
    4. Align with circular economic policies through material recovery partnerships.

The WtE project represents a pragmatic step toward sustainable waste management, provided it operates within a framework of transparency, equity, and adaptive governance.

Continuous stakeholder dialogue and robust monitoring will be critical to reconciling environmental imperatives with societal acceptance.

Chapter Six: Conclusions

The proposed Waste-to-Energy (WtE) project presents a viable solution to address escalating waste management challenges while contributing to renewable energy generation. Based on the findings of this Environmental Impact Assessment (EIA), the project is environmentally and socially feasible, provided stringent mitigation measures, regulatory compliance, and stakeholder engagement are prioritized. Key conclusions are as follows:

6.1. Environmental Feasibility

Environmental feasibility in waste-to-energy (WTE) projects involve assessing the project's potential to minimize environmental impacts and maximize environmental benefits. This includes evaluating the project's impact on air and water quality, greenhouse gas emissions, and waste reduction, as well as considering the potential for resource recovery and a circular economy.

By carefully evaluating and addressing these aspects, WTE projects can be designed and operated to maximize their environmental benefits and minimize their potential negative impacts, contributing to a more sustainable and circular waste management system.

- Climate Benefits: The project will reduce greenhouse gas emissions by diverting 50,000 tons/year of waste from landfills, avoiding methane (CH_4) emissions equivalent to 25,000 tons of CO_2 annually. Energy recovery offsets fossil fuel use, contributing to regional decarbonization goals.
- Air Quality: Advanced pollution control systems (e.g., SCR, activated carbon filters) ensure emissions remain within EU Industrial Emissions Directive (IED) standards. Post-mitigation $PM_{2.5}$ levels (18 $\mu g/m^3$) comply with national limits but require continuous monitoring due to pre-existing air quality issues.
- Circular Economy Alignment: Metal recovery from ash (80% efficiency) and digestate reuse as fertilizer demonstrate synergies with circular economy principles.

6.2 Socioeconomic Considerations

Waste-to-energy (WtE) projects, while offering solutions for waste management and energy generation, significantly impact socioeconomic factors. These projects can create jobs, stimulate local economies, and improve public health through better waste management. However, they also face challenges like potential health risks from emissions, social acceptance due to concerns about pollution, and the need for significant initial investment.

Addressing these socioeconomic considerations is vital for ensuring that WtE projects are not only environmentally sound but also socially acceptable and contribute to sustainable development.

- Public Health: Residual health risks (e.g., dioxin exposure) are deemed low (1 in 1,000,000 cancer risk) but necessitate community health programs and transparent communication to address concerns.
- Employment: The project will create 150 direct jobs and 300 indirect jobs in waste collection and logistics, boosting local economies.
- Equity: Proximity to marginalized communities requires safeguards, including buffer zones, job guarantees for locals, and investment in social infrastructure (e.g., health clinics).

6.3 Key Risks and Mitigation

Waste-to-energy (WtE) projects face a range of key risks, including technical, environmental, social, financial, and regulatory challenges. Mitigation strategies involve careful planning, robust risk assessment, and implementing measures to address each potential issue.

By proactively identifying and addressing these risks through appropriate mitigation strategies, waste-to-energy projects can be developed and operated in a sustainable and environmentally responsible manner

- Ash Management: Safe disposal and reuse protocols must be enforced to prevent heavy metal leaching.
- Public Opposition: Persistent NIMBYism (30% opposition rate) underscores the need for ongoing dialogue and grievance redress mechanisms.
- Operational Uncertainties: Waste composition variability and long-term ash leaching risks demand adaptive management and R&D.

6.4 Recommendations for Approval

To successfully secure approval for a waste-to-energy (WtE) project, it's crucial to address various aspects including regulatory compliance, environmental impact, community engagement, and financial viability. Thorough planning, transparent communication, and addressing potential concerns are key to navigating the approval process.

By addressing these recommendations, WtE projects can increase their chances of securing approvals and contributing to a more sustainable waste management system.

1. Conditional Approval: Grant permits only if mitigation measures (e.g., advanced filters, buffer zones) are fully implemented.
2. Monitoring Framework:
    - Real-time air quality sensors and public dashboards for transparency.
    - Annual toxicity testing of ash and groundwater.
3. Stakeholder Engagement:
    - Establish a community oversight committee.
    - Allocate funds for local health and education initiatives.
4. Policy Alignment: Integrate with circular economy strategies (e.g., Extended Producer Responsibility) to prioritize waste reduction and recycling.

6.5 Final Statement

Waste-to-energy (WtE) projects are crucial for sustainable waste management and renewable energy production. They convert non-recyclable waste into usable energy, reducing reliance on landfills and fossil fuels. However, challenges like waste composition variability and public perception require careful planning and community engagement. Ultimately, WtE projects play a key role in the transition to a circular economy and a more sustainable future.

The WtE project represents a critical step toward sustainable waste management and energy transition. While it introduces localized environmental risks, these are outweighed by its broader climate and socioeconomic benefits when managed responsibly. Success hinges on rigorous enforcement of safeguards, proactive community engagement, and alignment with global sustainability frameworks.

Recommendation: Proceed with project implementation under the stipulated conditions to ensure alignment with environmental justice, regulatory standards, and long-term sustainability goals.

In conclusion, WtE projects offer a promising path towards sustainable waste management and renewable energy production. By addressing challenges and promoting community engagement, WtE can play a vital role in building a circular economy and a more sustainable future.

This conclusion affirms the project’s potential to serve as a model for balancing waste valorization with ecological and social responsibility.

Appendices

Appendix A: Technical Specifications of WtE Technologies

- Comparative Tables:
    - Efficiency metrics (energy output per ton of waste).
    - Capital and operational costs for incineration, gasification, pyrolysis, and anaerobic digestion.
    - By-products (e.g., ash, syngas, biochar) and their management.

Appendix B: Case Studies of WtE Projects

- Amager Bakke, Copenhagen:
    - Technology: Incineration with carbon capture.
    - Outcomes: 440,000 tons/year waste processed, 150,000 households powered.
- Tuas Nexus, Singapore:
    - Technology: Integrated gasification and anaerobic digestion.
    - Outcomes: 100% energy self-sufficiency, 2,900 tons/day waste capacity.

Appendix C: Regulatory Frameworks

- EU Circular Economy Action Plan: Key directives on waste hierarchy and recycling targets.
- U.S. EPA Standards: Emission limits for NO_x, SO_2, and dioxins.
- Asia-Pacific Policies: Japan’s Sound Material-Cycle Society, China’s WtE expansion initiatives.

Appendix D: Economic Analyses

- Cost-Benefit Models:
    - Capital costs ($200–500M for large-scale plants).
    - Revenue streams (energy sales, tipping fees, carbon credits).

    - Payback periods (5–15 years depending on subsidies).

Appendix E: Environmental Impact Assessments (EIA)

- Emission Data: $PM_{2.5}$, CO_2, and heavy metal levels pre/post-mitigation.
- Waste Diversion Rates: 80–90% landfill reduction in EU case studies.
- Mitigation Strategies: Scrubbers, electrostatic precipitators, ash vitrification.

Appendix F: Public Engagement Materials

- Survey Questionnaire: Sample questions on community acceptance of WtE facilities.
- Feedback Summary: Key concerns (health risks, noise) and mitigation responses.

Appendix G: Glossary and Acronym List

- Circular Economy: A system minimizing waste through reuse and recycling.
- Syngas: Synthetic gas from gasification, used for energy.
- CCS: Carbon Capture and Storage.

Appendix H: Technical Diagrams

- Process Flowcharts: From waste collection to energy generation.
- Plant Schematics: Layouts of integrated WtE and recycling facilities.

Appendix I: Raw Data Sets

- Waste Composition: Regional data (e.g., 50% organic waste in Southeast Asia).
- Energy Output: Historical trends (e.g., 15% global renewable energy from WtE by 2030).

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