ANALYSIS ON WASTE TO ENERGY TECHNOLOGIES IN KENYA

Final Report

ER&D/WtE-02/FY2023-2024

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BETA:	The Bottom-Up Economic Transformation Agenda
CBOs:	Community Based Organizations
EfW:	Energy-from-waste
EMCA:	Environmental Management and Coordination Act
R&D:	Energy Research and Development
EPR:	Extended Producer Responsibility
EPRA:	Energy and Petroleum Regulatory Authority
GHG:	Greenhouse gases
ISWM:	Integrated solid waste management
JICA:	Japan International Cooperation Agency
JKUAT:	Jomo Kenyatta University of Agriculture and Technology
KEBS:	Kenya Bureau of Standards
KERC:	Kenya Energy Regulatory Commission
KPLC:	Kenya Power and Lighting Company
LCPDP:	Least Cost Power Development Plan
LFG:	Landfill gas
MoEF:	Ministry of Environment and Forestry
MoEP:	Ministry of Energy and Petroleum
MSW:	Municipal solid waste
NGOs:	Non-Governmental Organizations
NEMA:	National Environment Management Authority
N*u*PEA:	Nuclear Power and Energy Agency
PPA:	Power Purchase Agreement
RCRA:	Resource Conversion and Recovery Act
REREC:	Rural Electrification and Renewable Energy Corporation
SDGs:	Sustainable development goals
SEFA:	Sustainable Energy Fund for Africa
WtE:	Waste-to-Energy

1 INTRODUCTION

1.1 BACKGROUND

Waste to energy is part of an integrated solid waste management (ISWM) that entails the implementation of various approaches to sustainable waste management while also ensuring the protection of human health and the environment in a manner that is affordable, environmentally friendly, and socially acceptable. Further, ISWM establishes the preferred order of solid waste management alternatives as follows: waste reduction, reuse, recycling, resource recovery, incineration, and landfilling.

Waste management is critical for worldwide cleanliness and sustainability initiatives. Managing waste is one of the major issues for all economies in the world. Based on a country's economic status and ways of life, the quantity of waste generated keeps increasing. Every year across the globe more than two (2) billion tonnes of municipal solid waste (MSW) is generated[1]. Waste to Energy projects help achieve global sustainable development goals (SDGs) including: SDG 3: Good Health and Well-being – Poor waste management leads to air, water, and soil pollution, which can cause diseases and health hazards; SDG 6: Clean Water and Sanitation – Proper waste disposal prevents contamination of water sources and promotes sanitation; SDG 11: Sustainable Cities and Communities – Efficient waste management systems help create clean, resilient, and sustainable urban environments; SDG 12: Responsible Consumption and Production – Encourages waste reduction, recycling, and sustainable consumption patterns; SDG 13: Climate Action – Proper waste disposal and recycling reduce greenhouse gas emissions from landfills and waste incineration; SDG 14: Life Below Water – Preventing marine pollution from plastic and other waste helps protect aquatic ecosystems; SDG 15: Life on Land – Effective waste management protects terrestrial ecosystems, forests, and wildlife from pollution and degradation. Further, the UN Habitat's New Urban Agenda and the Africa Agenda 2063 call for improvement in waste management practices and investment in environmentally sustainable and climate-resilient economies and communities.

Increase in world populations and scaling up production in cities among other factors have led to huge amounts of waste, hence necessitating the need to develop and implement integrated waste management policies and strategies. Around the world, waste generation rates are rising. In 2020, the

[1] https://datatopics.worldbank.org/what-a-waste/trends_in_solid_waste_management.html#:~:text=The%20world%20generates%202.01%20billion,from%200.11%20to%204.54%20kilograms.

world was estimated to generate 2.24 billion tonnes of solid waste, amounting to a footprint of 0.79 kilograms per person per day. With rapid population growth and urbanization, annual waste generation is expected to increase by 73% from 2020 levels to 3.88 billion tonnes in 2050[2].

Strategies for WtE include: Landfilling, Incineration, Anerobic Digestion, Pyrolisis and Gasification. In order to deploy WtE technology(ies), a comprehensive feasibility study has to be undertaken to determine the feed stock (quantity, composition, density, moisture content, and calorific value), siting of the facility, economic viability, financing aspects, legal issues relating to environmental protection.

1.2 PROBLEM STATEMENT

Kenya's population is projected to grow from 53.3 million in 2025 to 70.2 million in 2045. Based on the waste generated per day (0.79) provided by the World Bank in 2025 the waste generated per day will be 42,107 tonnes per day and 55, 458 tonnes per day in 2045. Consequently, this will result to increase in energy demand. For instance, according to the Least Cost Power Development Plan (LCPDP), the effective interconnected power capacity is projected to rise from 2,170MW in 2023 to 8,152 MW in 2043[3].

1.3 JUSTIFICATION

The need for the deployment of WtE in Kenya is driven by the country's growing population, which contributes to increased waste generation and energy demand. These challenges have strained existing waste management systems and increased pressure on the country's energy infrastructure. Conducting this study therefore will allow for the evaluation of various available technologies, providing a scientific basis to identify and recommend the most suitable technology (ies) that align with our local conditions. This will support the development strategies for effective waste management and renewable energy generation.

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[2] https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management

[3] LEAST COST POWER DEVELOPMENT PLAN 2024 - 2043

1.4 OBJECTIVES

The main objective of this activity is to analyze WtE conversion technologies. The specific objectives are:

i. To establish the situation of waste to energy conversion practices and framework.

ii. To review the available waste to energy conversion technologies.

iii. To conduct case studies on waste to energy conversion practices

iv. To conduct a comparative assessment of the WtE conversion technology(ies) and propose a suitable option.

1.5 SCOPE

This study focuses on assessing the utility-scale deployment of Waste-to-Energy (WtE) technologies. While waste-to-energy conversion can occur through thermal, biochemical, physical, and bio-electrochemical processes, the scope of this assessment is limited to thermal and biochemical technologies due to constraints in available data. The specific technologies analyzed include Anaerobic Digestion (AD), Landfill Gas Recovery (LFGR), Incineration (INC), Gasification (GAS), and Pyrolysis (PYR). Each technology is evaluated against a set of key social, environmental, technical, operational, and economic indicators to determine its overall performance and suitability for large-scale application.

2 SITUATIONAL ANALYSIS

This section addresses the: Supporting legal, institutional, and policy frameworks, WtE project initiatives, overview of waste generated in Kenya, and Stakeholder mapping.

2.1 SUPPORTING LEGAL, INSTITUTIONAL, AND POLICY FRAMEWORKS

This section identifies the legal /policy and plans and its provision to Waste management. Additionally, this section details the gaps and opportunities that can be leveraged on to support the WtE.

2.1.1 NATIONAL LEGAL AND REGULATORY FRAMEWORK

The national legal and regulatory framework provides the foundation for waste-to-energy (WtE) initiatives in Kenya by outlining laws, policies, and strategies that guide sustainable waste management. These instruments emphasize environmental protection, renewable energy promotion, and alignment with global sustainability goals. Table 2.1 highlights the key legal and policy provisions relevant to WtE development and implementation.

Table 2.1: Relevant Legal and Regulatory Framework

SNo.	LAW/POLICY/PLAN	PROVISION(S)	REMARKS
1.	Constitution of Kenya, 2010	The Constitution prescribes that every person has the right to a clean and healthy environment, which includes the right - (a) to have the environment protected for the benefit of present and future generations through legislative and other measures, particularly those contemplated in Article 69; and (b) to have obligations relating to the environment fulfilled under Article 70. On obligations to the Environment, the Constitution provides public participation, environmental impact assessment, environmental audits, and utilization of natural resources as key activities in conserving the environment and ensuring ecological sustainable development	The constitution emphasizes sustainable development as one of the national values and principles of governance forming a good baseline for waste to energy initiatives. Waste management is a devolved function.
2.	Environmental Management and Coordination Act (EMCA), Amendment 2023	**EMCA** provides recommendations to identify materials and processes dangerous to human, health and environment and prescribe standards and regulations for waste, their classification and analysis, and formulate and advice on standards of disposal methods and means for such wastes	The Act captures promotion of renewable energy but no focus is put in waste to energy as a resource.
3.	Environmental	EMCA regulations point out regulations shall	Regulations on re-use

SNo.	LAW/POLICY/PLAN	PROVISION(S)	REMARKS
	Management and Coordination (Waste Management) Regulations 2006.	apply to plants and sites established for re-use or re-cycling of wastes.	and recycling plants captured
4.	The National Solid Waste Management Strategy, 2015	The Strategy proposes the promotion of resource recovery through energy generation by developing waste to energy generation plants.	This strategy proposes the development of waste to energy generation plants.
5.	The Sustainable Waste Management Act, 2022	The Act permits the Cabinet Secretary, in consultation with the Authority and county governments, to make regulations prescribing the promotion of health, safety and environmental standards, including: (i) Labour and health standards for waste handlers; (ii) Quality and certification standards for organic waste; (iii) Operational standards for dumpsites; (iv) The classification of engineered sanitary landfills; (v) The formation of waste collection, materials recovery, and recycling savings and credit cooperative organizations; (vi) The facilitation of waste-to-energy and waste-to-manure projects; and (vii) The facilitation of the collection of different types of waste, including medical waste, chemical waste, and construction waste. The Act mandates county governments to make regulations for: (a) Land use for waste management within their jurisdiction. (b) County governments shall establish waste management infrastructure to promote source segregation, collection, reuse, and set up for materials recovery.	The Act promotes waste recovery and the use of waste for energy generation.
6.	National Sustainable Waste Management Policy, 2021	The Policy prescribes the measures to be undertaken to ensure the country's transition into circular economy and zero waste status through minimized waste generation, separation at source, enhanced waste collection, reusing waste, recycling, and disposal of unusable waste to secure sanitary landfills. Policy Measures for Incineration (Waste to Energy) This is the thermal treatment of waste to convert it to energy, heat ash, and flue gas and shall be the last preferred option as per the waste hierarchy for waste management in Kenya.	The Policy promotes waste recovery and the use of waste for energy generation. Development of guidelines and regulations for WtE. Limited to landfill and incineration technologies

SNo.	LAW/POLICY/PLAN	PROVISION(S)	REMARKS
7.	Sustainable Development Goals (SDG)	● SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all. ● SDG 12: Ensure sustainable production and consumption patterns ● SDG 13: Take urgent action to combat climate change and its impacts ● SDG 3: Good Health and Well-being – Poor waste management leads to air, water, and soil pollution, which can cause diseases and health hazards; ● SDG 6: Clean Water and Sanitation – Proper waste disposal prevents contamination of water sources and promotes sanitation; ● SDG 15: Life on Land – Effective waste management protects terrestrial ecosystems, forests, and wildlife from pollution and degradation	The aligning the objects of WtE with the global sustainable development goals
8.	Vision 2030	Vision 2030, recognizes the need for efficient and sustainable waste management systems to be established as the country develops into a newly industrialized state by 2030.	WtE will help attain the social pillar of vision 2030
9.	Energy Act, 2019	The Energy Act outlines the functions of national energy entities that regulate, generate, and promote renewable energy. It also specifically outlines promoting the use of municipal waste for energy production. The Act also describes County Energy Planning, where Physical planning relating to energy resource areas such as dams, solar and wind farms, municipal waste dumpsites, agricultural and animal waste, ocean energy, woodlots, and plantations for the production of bio-energy feedstock are part of county functions.	The Energy Act, 2019 fully supports waste to energy initiatives
10.	National Climate Change Action Plan 2023 - 2027	Aims at furthering Kenya's development goals by providing mechanisms and measures that achieve low carbon climate resilient development. A five-year plan that helps Kenya adapt to climate change and reduce greenhouse gas emissions.	Explore the role of WtE to reduce GHG emission in the energy sector
11.	Bioenergy strategy (2020-2027)	It places the country on track to meet clean cooking targets by 2028. The plan aims at providing investors with information on viable opportunities for bioenergy development and promotes sustainable production and consumption of bioenergy with attendant human health, economic, and environmental benefits.	

SNo.	LAW/POLICY/PLAN	PROVISION(S)	REMARKS
		Section 3.2.4 specifically highlights agricultural waste for cogeneration. 3.2.5 highlights medical and other industrial waste for incineration Section 3.3 and 3.4 also describes generation of biofuels (liquid and gaseous)	
12.	National Energy Policy, 2018	Aims at ensuring affordable, competitive, sustainable and reliable supply of energy at the least cost in order to achieve the national and county development needs, while protecting and conserving the environment for inter-generational benefits.	The Policy is currently under review

2.1.2 INTERNATIONAL LEGAL FRAMEWORK

The international legal framework provides global obligations and commitments that are/will shape Kenya's approach to sustainable waste management and waste-to-energy (WtE) initiatives. These conventions and treaties focus on environmental protection, climate change mitigation, and safe handling of hazardous substances. Table 2.2 outlines the key international agreements relevant to WtE development and compliance.

Table 2.2: Relevant International Legal Framework

SNO.	LAW/POLICY/PLAN	PROVISION(S)	REMARKS
1.	Montreal Protocol on substances that deplete the ozone layer.	A global agreement to protect the ozone layer by phasing out production and consumption of ozone depleting substances such as chlorofluorocarbons and halons using innovative and flexible approaches.	Ratified on 09/11/1988 Pre-treatment and processing of waste to remove chlorofluorocarbons.
2.	UN Framework Convention on Climate Change.	Calls upon parties to protect the climate system for the present and future generations by taking precautionary measures to anticipate, prevent, minimise the causes of climate change and mitigate its adverse effects.	Ratified on 30/08/1994 Kenya committed to reduce its GHG emissions by 30% compared to a business-as-usual scenario of 143 $MtCO_2$ emissions.
3.	Basel Convention on the Trans-Boundary Movement of Hazardous Waste and their Disposal.	It obligates parties to reduce trans-boundary movement of waste, minimise toxicity of hazardous waste and ensure waste disposal and recovery is as close as possible to the	Ratified on 01/06/2000 The convention recognizes WtE as one of the watts managing hazard waste. Gives limitations on the

SNO.	LAW/POLICY/PLAN	PROVISION(S)	REMARKS
		source of generation.	importations of hazardous waste hence it might affect local supply of feed stock.
4.	Amendment to the Basel Convention to include Plastics.	This was amended and obligates parties to reduce trans-boundary movement of plastic waste, minimise pollution of plastic waste and manage plastic waste as close as possible to its source of generation.	Amended on 13/04/2019 The convention recognizes WtE as one of the waste management companies.
5.	Stockholm Convention on Persistent organic pollutants.	Requires all parties to take measures and reduce the release of Persistent Organic Pollutants (POPs) that can lead to serious health defects including certain cancers, birth defects, dysfunctional immune system and reproductive system and damage to central nervous system.	Ratified on 24/09/2004 WtE can be used in the management of the POPs.
6.	Minamata Convention on Mercury.	It is a global treaty to protect human health and environment from adverse effects of mercury. It includes the ban on mercury mines and phase out of use of mercury in a number of products.	Signed on 10/10/2013 The Convention includes provisions for controlling and reducing mercury emissions from point sources like Waste-to-energy facilities, which involve burning waste, thus subject to these regulations.
7.	Bamako Convention 1998.	Bans the import to Africa and controls trans boundary movement and management of hazardous waste within Africa.	Signed the Convention on the 17th of December 2003 but is yet to accede to it. The convention recognizes WtE as one of the watts managing hazard waste. Gives limitations on the importations of hazardous waste hence it might affect local supply of feed stock.

2.2 OVERVIEW OF WASTE GENERATED IN KENYA

Analyzing the composition, quantity, and characteristics of waste generated in Kenya is a critical step in designing effective waste management strategies, policies, and interventions. Waste in the country comprises solid, liquid, and gaseous streams, each presenting unique management challenges and opportunities. However, there remains a significant gap in comprehensive and reliable data on the amounts, trends, and projections for the different types of waste. This limitation has hindered long-term planning and the adoption of context-specific solutions, making it essential to strengthen data collection, monitoring, and reporting systems at both national and county levels[4]

2.2.1 SOLID WASTE

Solid waste constitutes the largest and most visible component of Kenya's waste streams. It is generated across all 47 counties from diverse sources, including households, commercial establishments, industries, markets, and institutions. The composition is dominated by organic waste (estimated at 50 - 60%), plastics, paper, glass, and metals, reflecting both urban consumption patterns and rural agricultural residues[5].

Table 2.3 provides estimates of solid waste generated at the county level, derived from available datasets. In generating these estimates, certain assumptions were applied to bridge existing data gaps and ensure consistency across counties. These assumptions, drawn from World Bank data and national population projections[6] are as follows:

i. The amount of solid waste generated per person per day (kg/person/day) remains constant over the projection period.
ii. The rate of population growth is assumed to be constant, thereby influencing the total waste generated in proportion to population changes.

These assumptions allow for a standardized estimation of solid waste quantities across Kenya, but they also highlight the need for more localized studies that consider factors such as urbanization rates, income levels, consumption patterns, and seasonal variations, all of which affect waste generation rates and composition.

[4] World Bank. (2012). What a Waste: A Global Review of Solid Waste Management. Washington, DC: World Bank.
[5] UNEP. (2016). Global Waste Management Outlook. Nairobi: United Nations Environment Programme.
[6] Kenya National Bureau of Statistics (KNBS). (2019). 2019 Kenya Population and Housing Census: Volume I. Nairobi: KNBS.

Table 2.3: Annual Solid Waste Generated Tonnes in Kenya

No.	YEAR	2019		2020	2021	2022	2023	2024	2025
	COUNTY	POPULATION	TONNES/YEAR	WASTE GENERATED TONNES/YEAR					
1.	Mombasa	1,208,333	348,422.82	356,088.12	363,922.06	371,928.35	380,110.77	388,473.21	397,019.62
2.	Kwale	866,820	249,947.55	255,446.39	261,066.21	266,809.67	272,679.48	278,678.43	284,809.36
3.	Kilifi	1,453,787	419,199.48	428,421.87	437,847.15	447,479.79	457,324.34	467,385.48	477,667.96
4.	Tana River	315,943	91,102.16	93,106.41	95,154.75	97,248.16	99,387.62	101,574.14	103,808.78
5.	Lamu	143,920	41,499.33	42,412.32	43,345.39	44,298.99	45,273.56	46,269.58	47,287.51
6.	Taita/Taveta	340,671	98,232.48	100,393.60	102,602.26	104,859.51	107,166.42	109,524.08	111,933.61
7.	Garissa	841,353	242,604.14	247,941.43	253,396.14	258,970.86	264,668.21	270,490.91	276,441.71
8.	Wajir	781,263	225,277.19	230,233.28	235,298.42	240,474.98	245,765.43	251,172.27	256,698.06
9.	Mandera	867,457	250,131.23	255,634.11	261,258.06	267,005.74	272,879.87	278,883.22	285,018.66
10.	Marsabit	459,785	132,579.00	135,495.74	138,476.65	141,523.14	144,636.64	147,818.65	151,070.66
11.	Isiolo	268,002	77,278.38	78,978.50	80,716.03	82,491.78	84,306.60	86,161.34	88,056.89
12.	Meru	1,545,714	445,706.63	455,512.18	465,533.45	475,775.18	486,242.24	496,939.56	507,872.24
13.	Tharaka-Nithi	393,177	113,372.59	115,866.78	118,415.85	121,021.00	123,683.47	126,404.50	129,185.40
14.	Embu	608,599	175,489.52	179,350.29	183,296.00	187,328.51	191,449.74	195,661.63	199,966.19
15.	Kitui	1,136,187	327,619.52	334,827.15	342,193.35	349,721.60	357,415.48	365,278.62	373,314.75
16.	Machakos	1,421,932	410,014.09	419,034.40	428,253.16	437,674.73	447,303.57	457,144.25	467,201.42
17.	Makueni	987,653	284,789.74	291,055.12	297,458.33	304,002.41	310,690.47	317,525.66	324,511.22
18.	Nyandarua	638,289	184,050.63	188,099.75	192,237.94	196,467.18	200,789.45	205,206.82	209,721.37
19.	Nyeri	759,164	218,904.94	223,720.85	228,642.71	233,672.85	238,813.65	244,067.55	249,437.04
20.	Kirinyaga	610,411	176,012.01	179,884.28	183,841.73	187,886.25	192,019.75	196,244.18	200,561.55

No.	YEAR	2019		2020	2021	2022	2023	2024	2025
	COUNTY	**POPULATION**	**TONNES/YEAR**	**WASTE GENERATED TONNES/YEAR**					
21.	Murang'a	1,056,640	304,682.14	311,385.15	318,235.62	325,236.81	332,392.02	339,704.64	347,178.14
22.	Kiambu	2,417,735	697,153.89	712,491.27	728,166.08	744,185.73	760,557.82	777,290.09	794,390.47
23.	Turkana	926,976	267,293.53	273,173.99	279,183.81	285,325.86	291,603.03	298,018.29	304,574.70
24.	West Pokot	621,241	179,134.84	183,075.81	187,103.48	191,219.75	195,426.59	199,725.97	204,119.94
25.	Samburu	310,327	89,482.79	91,451.41	93,463.34	95,519.54	97,620.97	99,768.63	101,963.54
26.	Trans Nzoia	990,341	285,564.83	291,847.25	298,267.89	304,829.79	311,536.04	318,389.84	325,394.41
27.	Uasin Gishu	1,163,186	335,404.68	342,783.59	350,324.83	358,031.97	365,908.67	373,958.67	382,185.76
28.	Elgeyo/Mara kwet	454,480	131,049.31	133,932.39	136,878.91	139,890.24	142,967.83	146,113.12	149,327.61
29.	Nandi	885,711	255,394.77	261,013.45	266,755.75	272,624.37	278,622.11	284,751.80	291,016.34
30.	Baringo	666,763	192,261.11	196,490.86	200,813.65	205,231.55	209,746.65	214,361.08	219,077.02
31.	Laikipia	518,560	149,526.78	152,816.37	156,178.33	159,614.25	163,125.76	166,714.53	170,382.25
32.	Nakuru	2,162,202	623,470.95	637,187.31	651,205.43	665,531.95	680,173.65	695,137.47	710,430.50
33.	Narok	1,157,873	333,872.68	341,217.88	348,724.67	356,396.61	364,237.34	372,250.56	380,440.07
34.	Kajiado	1,117,840	322,329.16	329,420.41	336,667.65	344,074.34	351,643.98	359,380.15	367,286.51
35.	Kericho	901,777	260,027.40	265,748.00	271,594.46	277,569.53	283,676.06	289,916.94	296,295.11
36.	Bomet	875,689	252,504.92	258,060.03	263,737.35	269,539.57	275,469.44	281,529.77	287,723.43
37.	Kakamega	1,867,579	538,516.40	550,363.77	562,471.77	574,846.15	587,492.76	600,417.60	613,626.79
38.	Vihiga	590,013	170,130.25	173,873.11	177,698.32	181,607.69	185,603.05	189,686.32	193,859.42
39.	Bungoma	1,670,570	481,708.86	492,306.45	503,137.20	514,206.21	525,518.75	537,080.16	548,895.93
40.	Busia	893,681	257,692.92	263,362.16	269,156.13	275,077.56	281,129.27	287,314.11	293,635.02
41.	Siaya	993,183	286,384.32	292,684.77	299,123.84	305,704.56	312,430.06	319,303.52	326,328.20

No.	YEAR	2019		2020	2021	2022	2023	2024	2025
	COUNTY	**POPULATION**	**TONNES/YEAR**	**WASTE GENERATED TONNES/YEAR**					
42.	Kisumu	1,155,574	333,209.76	340,540.38	348,032.27	355,688.98	363,514.13	371,511.44	379,684.70
43.	Homa Bay	1,131,950	326,397.78	333,578.53	340,917.26	348,417.44	356,082.62	363,916.44	371,922.60
44.	Migori	1,116,436	321,924.32	329,006.66	336,244.80	343,642.19	351,202.32	358,928.77	366,825.20
45.	Kisii	1,266,860	365,299.08	373,335.66	381,549.05	389,943.12	398,521.87	407,289.35	416,249.72
46.	Nyamira	605,576	174,617.84	178,459.43	182,385.54	186,398.02	190,498.78	194,689.75	198,972.93
47.	Nairobi City	4,397,073	1,267,896.00	1,295,789.71	1,324,297.09	1,353,431.62	1,383,207.1	1,413,637.67	1,444,737.7
	TOTAL	**47,564,296**	**13,715,164.75**	**14,016,898.38**	**14,325,270.1**	**14,640,426.0**	**14,962,5165**	**15,291,690.8**	**15,628,108**

Source: KNBS Population Data of 2019 and world Bank data of solid waste Generated per person per year.

2.2.2 LIQUID WASTE

Liquid waste management in Kenya primarily involves domestic wastewater, industrial effluents, stormwater, and agricultural runoff. Major urban centers such as Nairobi, Kisumu, and Mombasa face significant challenges due to inadequate sewerage networks, aging infrastructure, and limited treatment capacity. According to NEMA, only about 40% of Nairobi's population is connected to a sewer system, with most treatment plants operating below design capacity or discharging partially treated effluents into rivers[7].

In rural and peri-urban areas, pit latrines and septic tanks dominate, with limited safe containment or treatment. Industrial liquid waste, especially from agro-processing, tanneries, and manufacturing, often exceeds permitted discharge levels, contributing to water pollution in rivers and groundwater sources[8]. With population growth, rapid urbanization, and climate change intensifying water stress, improving liquid waste collection and treatment systems remains a critical priority.

2.2.3 GASEOUS WASTE

Gaseous waste in Kenya arises mainly from energy production, industrial activities, and open burning of waste. Municipal open dumpsites, such as Dandora in Nairobi, release significant levels of methane and carbon dioxide due to the anaerobic decomposition of organic matter, while frequent open burning contributes to toxic air pollutants including dioxins and furans[9].

Industrial processes, including cement manufacturing, tea processing, and petroleum refining, are also key sources of gaseous emissions, alongside growing vehicle emissions in urban centers. Kenya's commitment to reducing greenhouse gas emissions under its Nationally Determined Contribution (NDC) to the Paris Agreement underscores the importance of integrating waste management with air quality and climate policies[10]. Despite these challenges, there are emerging opportunities through Waste to Energy (WtE) initiatives, biogas production, and stricter emission controls in industries. However, limited monitoring infrastructure and weak enforcement of emission standards constrain effective management of gaseous waste.

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[7] National Environment Management Authority (NEMA). (2020). Kenya State of the Environment Report 2020. Nairobi: NEMA.
[8] UNEP. (2018). Africa Waste Management Outlook. Nairobi: United Nations Environment Programme.
[9] UNEP. (2016). Global Waste Management Outlook. Nairobi: United Nations Environment Programme.
[10] Government of Kenya (GoK). (2020). Updated Nationally Determined Contribution (NDC) under the Paris Agreement. Nairobi: Ministry of Environment and Forestry.

2.3 WTE PROJECTS AND INITIATIVES IN KENYA

Stakeholders that implement WtE programs/initiatives have different primary objectives based on either their mandates and/or economic/financial interests. Entities mandated by the constitution and/or legislation to manage waste pursue WtE initiatives with a primary objective being waste management. Conversely, industrial and/or private stakeholders pursue WtE to either subsidize their energy requirements and/or get revenue from energy sales.

There are various WtE initiatives by the MoEP and private stakeholders across the country. These are mainly small-scale biogas digesters/facilities. Only a few large-scale WtE plants are currently in operation.[11]For instance, *biogas* in Kenya is widely produced with over 8000 biogas plants/digesters utilizing various raw materials including agricultural wastes, slaughterhouse waste, and municipal wastes. However, there is no consolidated data on biogas production making it a challenge in determining the country's overall capacity[12]. Additionally, only a few of these plants are operational due to technical and management challenges. Table 2.4 below capture some of WtE programs/initiatives in Kenya specifying their ownership, type of fuel, power rating, and status of operation.

[11] https://www.energy.go.ke/biogas

[12] https://renewableenergy.go.ke/technologies/bioenergy/

Table 2.4: Waste to Energy Initiatives in Kenya

No.	Initiative[13]	Ownership	Location	Technology	Feed Stock	Capacity/ Utilization	Status
1.	WtE Processing Plant, Dandora-Nairobi.	County Government of Nairobi & KenGen	Dandora, Nairobi	Thermal incineration	MSW	45 MWe/ Electricity	Planned
2.	The Kibra Waste-to-Energy (WTE), 2017 project[14]	Asticom Kenya Ltd	Kibra, Nairobi	Anaerobic digestion, ethanol production, electricity	MSW, Crop residues, Livestock waste	12 MWe	Project stalled; AfDB withdrew funding due to delays
3.	Waste-to-energy plant in Eldoret	County Government of Uasin Gishu	Eldoret	Solar photovoltaic	MSW, industrial waste	123,000 MWh/year	Planned
4.	Geocycle- Bamburi PLC[15]	Bamburi Cement	Bamburi	Incineration	Waste Oil, Tyres, counterfeit products, industrial waste, rice husks	Alternative fuel	Operational
5.	Kisumu County	Kisumu County	Kisumu	Gasification and recycling	Industrial and human waste	9 MWth	Planned; aiming for carbon neutrality by 2025
6.	Kakamega Waste to Energy Plant	VR Holding AB	Kakamega	Thermal incineration	Solid waste	10 MW	Planned
7.	Mumias Sugar Company	Mumias Sugar Company	Mumia	Bagasse-fired co-generation	Bagasse	34 MW/Electricity	Revival in progress as of January 2025
8.	Gorge farm	VegPro Company	Naivasha	Anaerobic digestion	Crop residue	2.2MWe/ 2MWth	Operational; Africa's first grid-connected biogas plant

[13] This represents a sample of the various initiatives under implementation, thus not exhaustive.
[14] Kenya - Kabira Waste-To-Energy - SEFA Project Summary Note | African Development Bank Group (afdb.org)
[15] Circular economy (lafarge.co.ke)

No.	Initiative[13]	Ownership	Location	Technology	Feed Stock	Capacity/ Utilization	Status
9.	P. J. Dave Flower Farms Ltd.	MoEP & PJ Dave	Isinya	Anaerobic digestion	Flower waste, cattle dung	0.10 MW	to generate 100kW. (https://www.energy.go.ke/biogas)
10.	Eureka Holdings Ltd, Simbi Roses,	Eureka Holdings Ltd	Thika	Anaerobic digestion	Flower waste	55kW	Operational
11.	James Finlay Ltd	James Finlay Ltd	Kericho	Anaerobic digestion	Spent tea waste from soluble tea factory	700 kW	Abandoned/shut down
12.	Biogas Power Holdings (East Africa) Ltd	Biogas Power Holdings (East Africa) Ltd	Kilifi	Anaerobic digestion	Sisal waste, mango residues, cattle slurry (ratio of 14:3:2)	150 kWe	Operational
13.	Olivado	Olivado EPZ Ltd	Murang'a	Anaerobic digestion	Avocado skins, stones, pulp, and process water	410 kWe	Operational
14.	Keekonyokie SlaughterHouse	Keekonyokie Slaughterhouse	Kajiado	Anaerobic digestion	Abattoir waste	20 kWe	Operation suspended
15.	Nyongara Slaughter House	Nyongara Slaughterhouse	Nairobi	Anaerobic digestion	Abattoir waste	15 kWe	Abandoned/shut down
16.	Muhoroni Sugar Company (MUSCO)	Muhoroni Sugar Company	Kisumu	Bagasse-fired co-generation	Bagasse	6 MW	Operation suspended
17.	Del Monte Kenya	Del Monte Kenya Ltd	Kiambu	Anaerobic digestion	Pineapple waste	5 MW	Operation suspended
18.	Amiran Kenya	Amiran Kenya	Nairobi	Anaerobic digestion	Not specified	40MW	Abandoned/shut down
19.	Makomboki Tea Factory	Makomboki Tea Factory	Muranga	Biomass combustion	Biomass briquettes and agri-processing residues (e.g. macadamia nut, cashew nut, rice husk residues etc)	Not specified	Operation suspended

2.4 STAKEHOLDER MAPPING

Effective waste management requires the identification and involvement of all waste management stakeholders. This, however, presents challenges and opportunities in waste management due to the often-conflicting nature of the diverse interests of stakeholder groups. Table 2.5 below presents a compilation of prospective waste management stakeholders and their roles and expectations

Table 2.5: Stakeholder Mapping for National Waste to Energy Conversion

No.	Stakeholder	Role
1.	National government	• Policymaker • Regulatory framework development • Resource allocation • Provide infrastructural inputs and services
2.	County (local) government(s)	• Operational approval • Collaborate with the relevant stakeholders • Community engagement • Ensure payment to the waste collector • Inclusion of Waste to Energy initiatives in the county action plans. (energy plans) • Develop a Regulatory framework for waste to Energy initiatives.
3.	Rural Electrification and Renewable Energy Corporation (REREC)	• Partnership and collaboration in renewable energy research and development • Promotion of waste to energy
4.	Kenya Electricity Generating Company PLC (KenGen)	• Power generation; WtE Implementation • Partnership and collaboration in research and development • Provide technical expertise in the implementation
5.	Nuclear Power and Energy Agency (N*u*PEA)	• Energy Capacity development • Implementation of research and development in all Energy fields • Collaboration with the relevant stakeholders.
6.	Private sector (industry and trading)	• Financing, developing, and operating WtE facilities • Providing technical support on WtE initiatives • Partnership and collaboration in WtE
7.	Development partners	• Funding/financing of WtE initiatives and project
8.	Academia and research institutions	• Research on WTE technologies • data provision • Education/Training • Publication of findings.
9.	Community Based Organizations (CBOs) and Non-Governmental Organizations (NGOs)	• Offer financial and technical support • WtE advocacy
10.	Disposal facilities' host communities	• Collection and transport of waste, sorting for WTE facilities

No.	Stakeholder	Role
		● To offer local support ● Environmental improvement and sustainability
11.	Industry and General Public (waste generators)	● Support of the WtE initiatives ● Segregation of waste
	Kenya Bureau of Standards (KEBS)	● Develop the standards
	Regulatory bodies (NEMA and EPRA)	● Licensing ● Establishing regulations, monitoring and implementation
	Material Recovery Facilities	● Sorting, segregation, Composting of waste

3 METHODOLOGY

3.1 METHODOLOGY DESCRIPTION

In this assessment, a multi criteria decision analysis tool was used to evaluate and compare various waste to energy technologies across multiple indicators. This tool integrates both qualitative and quantitative variables to produce a balanced assessment of different technological options. The technologies analyzed in this assessment include Anaerobic Digestion (AD), Landfill Gas Recovery (LFGR), Incineration (INC), Gasification (GAS), and Pyrolysis (PYR). Each of these technologies was evaluated on a set of key social, environmental, technical, operational, and economic indicators. However, Microbial Electrolysis Cells (MECs), Microbial Fuel Cells (MFCs), and Refuse Derived Fuel (RDF) were not included in the assessment due to a lack of reliable data as per the tool's evaluation criteria. These technologies are still under development and/or lack sufficient field scale implementation data. Without comprehensive information on their environmental impacts, system efficiencies, costs, and operational parameters, it is not feasible to objectively compare their performance to the more established technologies included in this study. Description of Evaluation Criteria

Figure 3.1 illustrates the Waste-to-Energy (WtE) technologies assessed, along with their associated processes and resulting products.

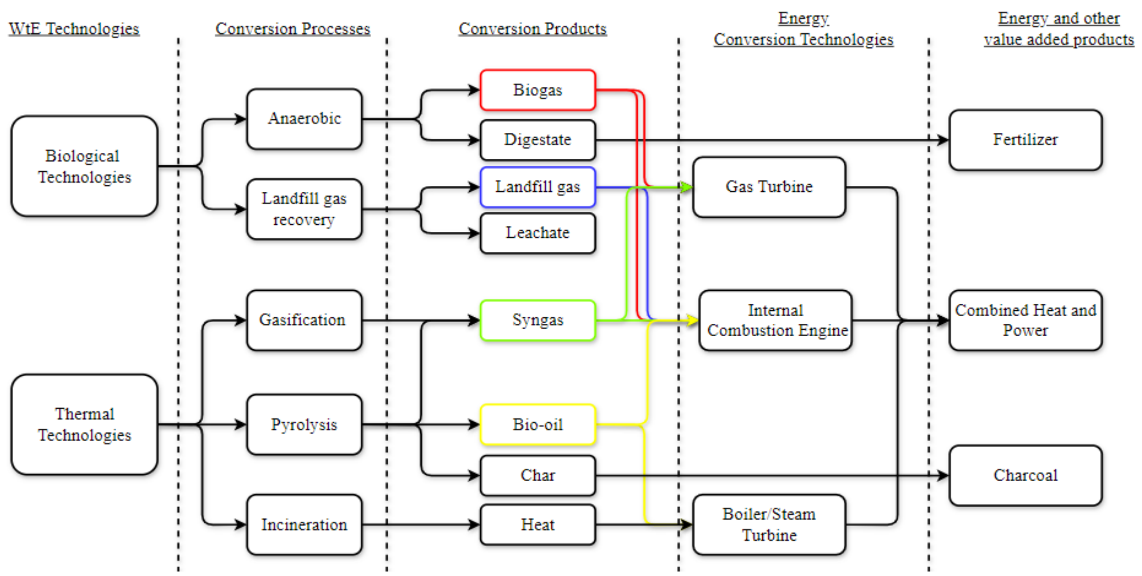

Figure 3.1: WtE Technologies, Processes, and Products
Source: GIZ[16]

[16] GIZ_WasteToEnergy_Guidelines_2017

Complementary and environmentally sustainable evaluation of WtE conversion technologies involves considering their effectiveness in managing waste while minimizing negative environmental impacts and promoting sustainability[17]. Table 3.1 below captures indicators that can be used in comparative evaluation of various aspects of WtE technologies:

Table 3.1: WtE Technology Evaluation Criteria

High level Objective	**Description**	**Measurement Parameter**
Cost	The proposed price of electricity/fuel generated by the WtE technology should be within the stipulated tariff range by EPRA	● Overnight Cost ● O&M Cost
Performance	The WtE facility should strive to function at peak operational efficiency, maximizing its capabilities to convert waste into usable energy resources while minimizing any inefficiencies or disruptions in its processes.	● Efficiency ● Number of output (electricity, heat, or biofuels) ● Product
Social economics and Environmental impacts	WtE technology should minimize the impact to the environment by observing the principle of waste management as stipulated by NEMA.	● Quantity of the GHG emitted by the WtE technologies ● Waste reduction in % ● WtE technology footprint ● Job creation (Impacts to livelihoods) ● Health impacts
Technology readiness level	The WtE technology should be readily available commercially and proven based on the technology maturity.	● Maturity

By systematically evaluating these factors, policymakers, industry stakeholders, and communities can make informed decisions about the adoption and deployment of WtE technologies that promote environmental sustainability and contribute to a circular economy. Figure 3.2 depicts framework for systematic selection of WtE technologies.

[17] https://www.frontiersin.org/articles/10.3389/frsus.2021.681690/full

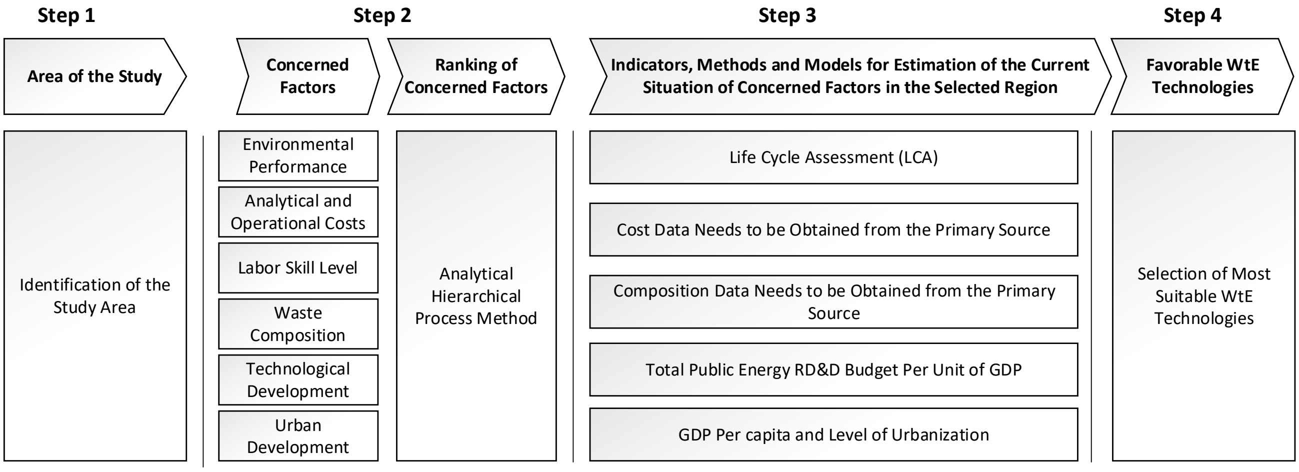

Figure 3.2: Schematic of the framework for the selection of WtE technologies[18]

4 EVALUATION OF WTE TECHNOLOGY

Waste-to-energy (WtE) involves utilization of a variety of treatment technologies that convert waste to electricity, heat, fuel, and/or other usable materials, as well as a range of residues. The process of waste to energy generation is achieved by breaking down waste through a series of biochemical or thermal processes[19].

4.1 TECHNICAL EVALUATION

WtE technologies are rapidly developing, with a wide array of technology options available, varying in approach, scale, complexity, and outcomes. The conversion of waste into energy generally occurs

[18] https://www.frontiersin.org/articles/10.3389/frsus.2021.681690/full

[19] A Framework for the Selection of Suitable Waste to Energy Technologies for a Sustainable Municipal Solid Waste Management System, 2021. Ahsan Farooq, Piyanon Haputta, Thapat Silalertruksa and Shabbir H. Gheewala

through four major processes: *thermal, biochemical, physical, and bio-electrochemical* as shown in Figure 4.1.

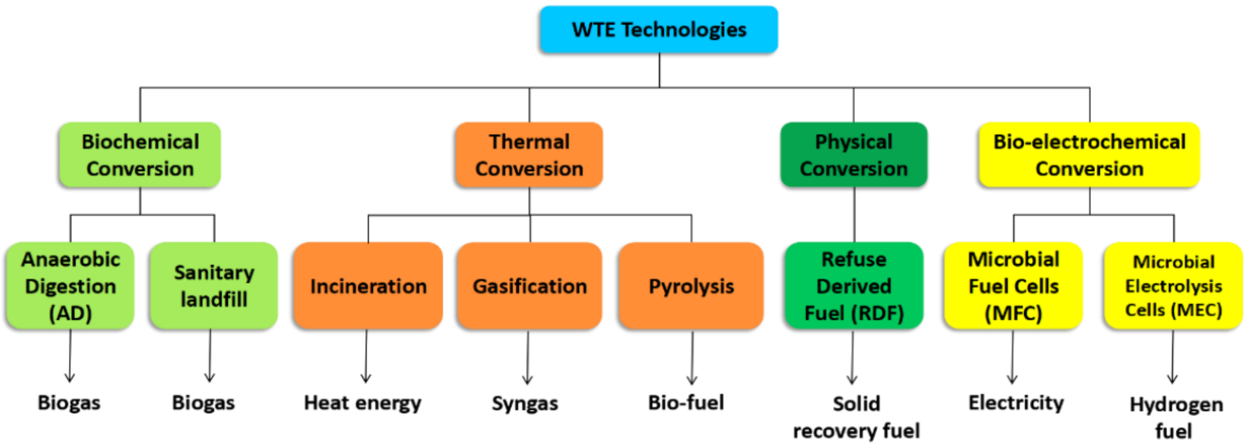

Figure 4.1: Major Processes of Waste to Energy Conversion

Source: Jamilatun, S., Pitoyo, J., & Setyawan, M. (2023). Technical, Economic, and Environmental Review of Waste to Energy Technologies from Municipal Solid Waste. *Jurnal Ilmu Lingkungan*, *21*(3), 581-593. (https://ejournal.undip.ac.id/index.php/ilmulingkungan/article/view/51251)

4.1.1 Thermal Processes

4.1.1.1 Incineration

Incineration involves burning waste materials at high temperatures in specially designed facilities called waste-to-energy plants or incinerators. It is an exothermic process involving total oxidation that generates flue gases, ash, and heat. During combustion, the organic components of the waste are converted into heat, which is used to produce steam. The steam then drives turbines to generate electricity.

The incinerator efficiency is determined by the makeup and characteristics of the waste as well as the end products i.e. heat, electricity or both (efficiency is higher when we have a combined system)[20]. In some cases, additional fuel is used along with the waste during incineration. For effective incineration operation, the average calorific value of the waste must be greater than 1900 kcal/kg[21]. Therefore, incineration is suitable for flammable non-biodegradable waste with a low moisture content. Due to

[20] https://www.planete-energies.com/en/media/article/incineration-heating-power-refuse#:~:text=%2C%20also%20known%20as%20combined%20heat,one%20ton%20of%20fuel%20oil

[21] https://igniss.com/calorific-value-waste?utm_source=chatgpt.com

the latent heat of vaporization, when the waste's water content rises, its calorific value will begin to drop. Therefore, waste is sometimes pretreated (thermal, mechanical, chemical, and biological) to eliminate excess moisture and harmful substances such as chlorine and mercury. The incinerator can generate 544 kWh of energy and 180 kg of solid residue per ton of municipal waste incinerated. The energy recoverable from 1 ton of waste depends heavily on (i) the characteristics of the waste and (ii) the characteristics of the WtE installation, particularly its size.[22]

The dominant incineration technology is currently moving grate because of its historical superiority and advantages. The mass feeding method used during combustion on a moving grate eliminates the need to pre-process waste carefully, being limited to sieving and loosening. Complete oxidative incineration in this case occurs at a temperature of 700–1200°C. The next common combustion technology is a circulating fluidized bed. The process temperature is the lowest in comparison to the other two technologies considered here and does not exceed 1000°C and involves an ascending airflow entry into the furnace chamber at high speed, which creates a kind of boiling fluid from MSW particles. For incineration using this technology, waste must be pre-sorted and shredded. Another disadvantage is the need to limit the combustion temperature to prevent the particles from sticking together, which simultaneously reduces the resulting fuel energy value and leaves more dangerous flue gases. The rotary kiln follows in terms of popularity. Incinerators with this technology can process safe solid and harmful liquid waste due to the secondary treatment presence in the form of afterburners. The combustion temperature lies in the range of 800–1300°C, taking into account the purpose of the furnaces and the degree of the hazard of the waste. It is the most capital-intensive technology in the combustion group.

4.1.1.2 Gasification

Gasification involves heating waste materials in the presence of limited oxygen (partial oxidation) or steam to produce a synthesis gas (syngas) consisting of carbon monoxide, hydrogen, other gases, and solid byproducts (char). The syngas can then be combusted in a gas turbine or engine to generate electricity (after purification) or converted into liquid fuels or chemicals through further processing. Gasification can handle a wide range of waste feedstocks, including biomass, municipal solid waste, and industrial residues. The temperature range is 1000 - 2000 °C, which is affected by the gasifying agent.

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Different gasification systems, such as fixed bed, fluidized bed, and retained gasification, can be characterized by reactor type and flow. Although gasification is well-established in the coal sector, syngas has only lately been investigated as a possible means of producing energy from municipal waste. According to the results of the experiments, the CO_2 emissions from the gasification process are lower than those from an incinerator of the same capacity. Gasification technology is applied widely in Asia, Europe, Africa, and the United States.

A more modern and innovative subset is plasma gasification, which uses high-temperature plasma torches to break down waste materials into syngas and vitrified slag and is carried out at 3,000 - 14,000 ^{o}C. The syngas can be used for energy generation and due to such an extremely high temperature, either complete decomposition of waste is ensured or no more than 7% non–toxic ash and slag, which are suitable materials for construction or other applications. However, the technology only has a medium level of maturity, because of society's ignorance about the potential risks of high-temperature processes, the lack of a regulatory framework for plasma gasification plants, and the complexity of field efficiency assessment due to the small number of enterprises in operation. Plasma gasification is suitable for treating various types of waste, including hazardous and non-recyclable materials, and can recover valuable metals from the waste stream.

4.1.1.3 Pyrolysis

Pyrolysis is a thermal decomposition process that converts organic materials into a mixture of solid char, liquid bio-oil, and gases (syngas), the yield and quality of which depends on the heating rate, process temperature, and duration of residence. Typically, the gaseous fraction increases with increasing temperature. In comparison, greater oil yields can be obtained with a reduced temperature and a rapid heating rate. Unlike combustion, pyrolysis occurs in the absence of oxygen, preventing complete oxidation of the feedstock. Anaerobic processes make it possible to use temperatures of 200 - 500^{o}C (400 - 800^{o}C) and generate a large amount of thermal energy. The resulting bio-oil can be used as a renewable fuel or feedstock for chemical production, while the syngas can be used for heat or power generation. Pyrolysis is relevant if there is a need to extract processed products; they can be gaseous substances, liquid (tar), or solid (char). This is facilitated by its two-stage process nature.

When comparing the environmental impact and potential energy generation, the MSW pyrolysis technology is superior to incineration technologies. Unlike incineration, which requires extensive exhaust gas cleaning, pyrolysis and gasification technologies can reduce the waste volume by up to 95% with far less effort. Using a gas turbine, pyrolysis may turn waste into energy with a net conversion efficiency of 28 - 30%. In terms of pyrolysis technology deployment, an MSW pyrolysis plant in Europe has been operating since 1986 in Burgau, Germany based on WasteGen UK Ltd. The facility processes approximately 38,000 Mg annually of municipal solid waste and sewage sludge. Multiple plants based on Mitsui Recycling 21 technology were constructed in Japan at the start of the twenty-first century to pyrolyze municipal solid waste.

4.1.2 BIOCHEMICAL PROCESSES

4.1.2.1 Anaerobic Digestion

Anaerobic digestion is a biological process that breaks down organic waste, such as food scraps, agricultural residues, and wastewater sludge, in the absence of oxygen. Microorganisms digest the organic matter, producing biogas (a mixture of methane and carbon dioxide) and a nutrient-rich digestate. Biogas can be used as a renewable fuel for electricity generation, heating, or vehicle fuel, while the digestate can be used as a fertilizer.

The process parameters and the composition of the biogas, which is usually 50 - 75% CH_4, 25 - 50% CO_2, and 1-15% other gases (e.g., water vapor, NH_3, H_2S, etc.), can affect the quality of the biogas. Through a series of four steps, an anaerobic digester decomposes organic waste and converts it into methane: "Hydrolysis," is the first step and occurs when complex organic compounds like carbohydrates, proteins, and fats in waste are broken down into dissolved organic substances like sugars, amino acids, and fatty acids; "Acidogenesis" is the second stage of anaerobic digestion. In this stage, acidogenic bacteria convert hydrolysis products into shorter-chain acids. These acids include Acetic, Butyric, Propionic, and Valeric; Acetogenesis is a microbial metabolism process that produces acetate. It's the third step of anaerobic digestion, which converts fermentation products into acetic acid, carbon dioxide, and hydrogen. The last step is methanogenesis in which methane is produced (hydrogen is oxidized to hydrogen ions, and carbon dioxide is reduced to methane).

Anaerobic digester technology offers economic benefits and is environmentally sustainable. This technology can produce 2 - 4 times as much methane per ton of waste in 3 weeks as a landfill can in 6–7 years. With a conversion efficiency of 35%, 1 m^3 of biogas generated by the anaerobic digestion process may provide 2.04 kWh of energy. Based on 60% organic matter and 40% moisture composition, 1 ton of waste can release about 150 kg of methane. However, the primary issue with anaerobic digesters is the duration of microbial responses (usually 20 - 40 days). Decomposition of biodegradable organic waste produces a gas with a high methane content which is 25 times more potent than CO_2 on climate change.

Specifically, Anaerobic digestion (AD) is a biological process that consists of multiple consecutive steps (hydrolysis, acidogenesis, acetogenesis, and methanogenesis) to break down the organic feed into an energy-rich gas stream (biogas) and a nutrient-rich slurry termed digestate or residual biosolids. The biogas is often used for energy production (heat and/or electricity) to utilize within the WWTP itself. The residual biosolids (sludge) can also be a feed to solid WtE (thermal treatment) plants enhancing both energy recovery and waste management, especially volume reduction. The solids are removed from the tank and sent to sludge drying beds where they are sun dried for eventual land application while the supernatant is drawn off and/or recycled. Studies on wastewater treatment however suggest that the potential for methane capture and utilization is relatively low because the methane potentials per cubic meter of wastewater are much lower than solid substrates due to the low content in organic material and high-water content.

4.1.2.2 Landfill Gas Recovery

Landfill gas recovery involves capturing and treating methane-rich gases produced by the decomposition of organic waste in landfills. The recovered landfill gas can be used as a renewable energy source for electricity generation, heating, or direct use in industrial processes. Landfill gas recovery helps mitigate greenhouse gas emissions and reduces odors and other environmental impacts associated with landfill operations.

Landfilling is managing or destroying waste by disposing and piling waste in a recessed location, compacting it, and then filling it with soil. It can also be defined as the controlled disposal of land trash to reduce environmental impacts. Even though unclean landfilling is a more straightforward and cost-effective method for disposing of vast volumes of waste, it poses major environmental risks. Sanitary landfill operation (landfill gas recovery) however mitigates negative environmental impacts by capturing methane gas. Recent research has revealed that landfilling has the most significant environmental impacts compared to alternative waste management choices due to negative health effects, land deterioration, and groundwater contamination. Landfill gas (LFG) contains 45-55% of methane, which is used for electricity generation. However, this process is not considered to be an effective WtE technology due to its disadvantages, such as air pollution, groundwater contamination, and foul odor.

4.1.3 PHYSICAL PROCESS

Physical process refers to the non-chemical and non-biological methods used to handle, prepare, or modify waste materials without altering their chemical structure. These processes are typically mechanical or thermal in nature and are essential in preparing waste for energy recovery.

4.1.3.1 Refuse Derived Fuel (RDF)

Refuse Derived Fuel (RDF) is produced through a series of mechanical and physical processes designed to prepare waste for efficient combustion. RDF production is considered an environmentally friendly method, as it diverts waste from landfills and utilizes materials that are otherwise difficult to recycle or dispose of safely. It begins with collection of solid waste; this waste is then sorted to remove recyclables and non-combustible materials such as metals and glass. The remaining combustible fraction, primarily consisting of plastics, paper, wood, and textiles, is shredded into smaller, uniform pieces. To enhance its energy content and combustion efficiency, the shredded material is then dried to reduce moisture content. Depending on the intended application, the final step may involve compressing the dried waste into pellets or leaving it as fluff, resulting in a versatile fuel suitable for various industrial and energy recovery uses.

4.1.4 BIOELECTROCHEMICAL PROCESS

A bioelectrical process is a waste-to-energy conversion process that integrates biological and electrochemical systems to convert chemical energy, from organic matter or waste, into useful forms of energy such as electricity or hydrogen. This process relies on electroactive microorganisms that interact with electrodes to facilitate redox reactions, enabling energy recovery or resource generation from various substrates. The main technologies in this category include Microbial Fuel Cells (MFCs) and Microbial Electrolysis Cells (MECs).

4.1.4.1 Microbial Fuel Cells (MFC)

Microbial fuel cells (MFC) is a non-combustive device providing electrical energy using microorganisms as catalysts and organic materials as substrate. The waste materials used in MFC include agricultural byproducts such as manure, corn stover, or used straw bedding.[23] The MFC works in a two-chamber compartment with anode (electrode on which microorganisms colonize and oxidation occurs) and cathode. Microorganisms are used as catalysts to oxidize organic and inorganic

[23] (PDF) Microbial Fuel Cells: Methodology and Technology †

matter and generate current. Electrons produced by the bacteria from the substrates are transferred to the anode and flow to the cathode linked by a conductive material containing a resistor, or operated under a load producing electricity.

4.1.4.2 Microbial Electrolysis Cells (MEC)

The technology uses electrochemically active bacteria to convert organic matter into hydrogen or a variety of by-products without polluting the environment. Exoelectronic microbes are used to convert the biodegradable matter present in the waste stream into electric current and protons, at the anode. The electrons are transferred to the cathode where the protons are reduced for Hydrogen (H_2) production. Advantages & Disadvantages for the Various Technology Options

The evaluation of these technologies was conducted against multiple criteria, including cost, performance, socio-economic and environmental impacts, and technology readiness level. Given the inherent complexity of these factors, it is rare for a single technology to fully satisfy all evaluation requirements. As a result, the selection process necessitates systematic trade-off analyses to balance competing priorities. The final selection and deployment of these technologies are therefore shaped by national policy priorities, strategic development goals, and international obligations, ensuring alignment with broader economic, social, and environmental agendas. Table 4.1 summarizes the advantages and disadvantages of these technologies across the various elements of the defined evaluation criteria.

Table 4.1: Advantages & Disadvantages for the various Technology Options

	WtE Technology	Advantages	Disadvantages
Thermal	Incineration	- Volume reduction up to 80% - Mass reduction of up to 70% - Can take larger waste amounts - Quick treatment	- Air and waterborne pollution - Cancer-forming chemical (dioxins) production - High investment - Social opposition - Solid waste (slag)production
	Gasification	- No greenhouse gas (GHG) emission - Any waste substrate can be used Technology can be easily expanded	- High operating and capital costs due to high energy requirements
	Pyrolysis	- Recovers up to 80% of energy from waste - Reduces land requirements - Products have higher calorific values - Liquid product separation in the vapor phase - Reduction of MSW volume up to 50-90%	- Liquid products have low yields - Pyrolytic water production from organic matter - Coke production from liquid products - Byproducts cleaning - Corrosion of metal tubes used in pyrolysis - High operating and maintenance cost
Biological (non-thermal)	Anaerobic	- Reduces methane emissions from landfills and replaces fossil fuels, lowering overall greenhouse gas emissions - Properly managed anaerobic digestion can improve sanitation and reduce health hazards associated with untreated organic waste.	- The decomposition of biodegradable organic waste produces a gas with a high methane content which is 25 times more potent than CO2 on climate change - Establishing anaerobic digestion facilities requires significant capital investment
	Landfill Gas Recovery	- The least cost/cheapest option - If gas is captured and recovered, can be a source of power generation and heat - No skilled labor requirements - Marshy land can be converted into useful land - Natural resources are returned to the soil	- surface runoff during rains - Soil and groundwater contamination High transportation costs - Expensive leachate treatment - Significant GHG emissions, if biogas is not captured and recorded. - Landfill area requirements - Odor problems
Physical Process	Refuse Derived Fuel	Feeds into other WtE technologies, reduction of waste volume.	Air pollution, toxic ash, Does not compliment recycling of waste.

	WtE Technology	Advantages	Disadvantages
Bio-electrochemical Process	Microbial Fuel Cells	- Directly convert organic matter into electricity via microbial metabolism. - Operate under mild conditions (ambient temperature and pressure). - Provide simultaneous wastewater treatment and energy recovery. - Environmentally friendly with low GHG emissions. - Suitable for decentralized/off-grid applications.	- Low power density compared to conventional technologies. - High cost of electrode/catalyst materials (e.g., platinum). - Limited scalability for large-scale applications. - Sensitive to operating conditions (pH, temperature, substrate). - Long-term stability and durability issues.
	Microbial Electrolysis Cells	- Produce hydrogen or other value-added products (e.g., methane, acetate). - Higher energy recovery efficiency with external voltage input. - Can integrate with renewable electricity sources. - Support waste treatment and resource recovery. - Flexible product generation based on system design.	- Require external energy input (unlike MFCs). - High electrode and membrane costs. - More complex system design and operation. - Hydrogen recovery and storage challenges. - Scale-up constrained by efficiency and stability limitations.

4.2 FINANCIAL EVALUATION OF WTE TECHNOLOGY

Waste-to-energy projects are complex and capital intensive to build as shown in Table 4.2. Most of the investor's economic interest is driven by financial incentives, renewable identification numbers, tax credits, etc. In addition to other economic streams, waste-to-energy projects usually require high tipping fees. A tipping fee is what the trash hauler has to pay in order to dump the trash at the facility. With WtE projects, the tipping fee can end up being 50-60% of the overall revenue stack. A WtE plant of capacity 40,000 tons per annum (tpa) costs about $41 million, or $1,026 per ton of annual capacity. A medium-sized WtE plant with 250,000 tpa costs about $169 million, or $680 per ton of annual capacity [8].

Table 4.2: Approximate Cost Estimates of Five WtE Technologies in Developing Countries

WtE Technology	Incineration	Pyrolysis / gasification plant	Anaerobic digestion plant	Landfill gas capture collection	
Capacity	150,000 t/a	250,000 t/a - 20y operation	50,000 - 150,000 t/a, 20y operation	390,000 - 850,000 t/a, 21y operation	
Initial Investment	25 - 64 million $	68 – 101 million $	10 – 17 million $		4.5 million $ (CDM-China)
Capital costs per ton of waste input	18-46 $/t	25-32 $/t	10 – 16 $/t	0.7 $/t	1.2 $/t
O&M costs per ton	17-30 $/t	25-34 $/t	8 – 13 $/t	0.7 $/t	0.25 $/t
Total cost per ton	35-76 $/t	55-72 $/t	18 – 29 $/t	1.3 $/t	1.4 $/t
Revenues from energy sales per ton	1.7-8.5 $/t (electricity)	1.5-4 $/t	6 – 13 $/t	2 $/t	2.8 $/t
Cost to be covered per ton waste input	34-15 $/t	53-68 $/t	12 – 15 $/t	0.7 $/t	1.4 $/t

5 WASTE TO ENERGY TECHNOLOGY ASSESSMENT

5.1 RESULTS

A summary of findings on key indicators derived from the analysis tool used in this study are presented in Table 5.1. The data feeding into the tool was collected obtained primarily through literature review, drawing from published reports, academic literature, government documents, and international best practices. The results provide a comparative basis for assessing different WtE technology options.

The indicators were organized around four main dimensions to ensure a comprehensive assessment of Waste to Energy (WtE) technologies, as follows:

- Technical aspects
- Social factors
- Environmental aspects
- Economic factors

By synthesizing information across these dimensions, the results provide a structured comparative basis for evaluating the suitability, feasibility, and potential trade-offs of different WtE technology options within the Kenyan context. The following summary highlights the relative strengths and weaknesses of each technology, thereby serving as a decision-support framework for policymakers and stakeholders.

Table 5.1: Summary of Findings on Key Indicators

High Level Objective	Assessment Area	Key Indicators	Findings on Key Indicators							Score Range	
			AD	LFGR	INC	GAS	PYR	Min	Max	Min Score	Max Score
Social and Environmental	ESIA	GHG Emissions	Very Low	Low	Extremely High	High	High			1.0	5.0
			4.0	3.0	1.0	2.0	2.0				
Technical	Waste	Waste type	Organic Fraction	Mixed waste	Mixed waste	Homogeneous waste	Homogeneous waste				
			2.0	3.0	3.0	1.0	1.0			1.0	5.0
		Waste Volume Reduction (%)	47.50	5.00	82.50	82.50	70.00	5.00	82.50		
			5.4	1.0	9.0	9.0	7.7			1.0	9.0
	Technology	Technology Maturity	Very High	Very High	Extremely High	Emerging	Emerging				
			2.0	2.0	3.0	1.0	1.0			1.0	5.0
		Technology complexity/Labour skill requirement	Low	Low	Low	High	High				
			1.0	1.0	1.0	2.0	2.0			1.0	3.0
		Land requirement	Large	Very Large	Small	Medium	Large				
			2.0	1.0	4.0	3.0	2.0			1.0	5.0
		Pre-treatment	Required	Not Required	Not Required	Required	Required				
			1.0	2.0	2.0	1.0	1.0			1.0	5.0
	Operation	System efficiency (%)	60	10	55	75	70	10	75		
			4.1	1.0	3.8	5.0	4.7			1.0	5.0
		Residence time	Very Long	Extremely	Extremely short	Short	Long				

High Level Objective	Assessment Area	Key Indicators	Findings on Key Indicators							Score Range	
			AD	LFGR	INC	GAS	PYR	Min	Max	Min Score	Max Score
				Long							
			2.0	1.0	5.0	4.0	3.0			1.0	5.0
Economic	Cost	Capital Cost per ton of waste input	10	1.2	18	25	25	**1.20**	**25.00**		
			6.0	9.0	3.4	1.0	1.0			1.0	9.0
		Operation and maintenance costs	8	0.25	17	25	25	**0.25**	**25**		
			6.5	9.0	3.6	1.0	1.0			1.0	9.0

5.2 DISCUSSION

The overall ranking result of the WtE technologies considering three (3) high level objectives (social and environmental, technical and economic) is illustrated in Figure 5.1. From the results, Landfill Gas Recovery (LFGR) is the most desirable technology with of **0.645** while Pyrolysis (PYR) is the least desirable with a score of **0.270.**

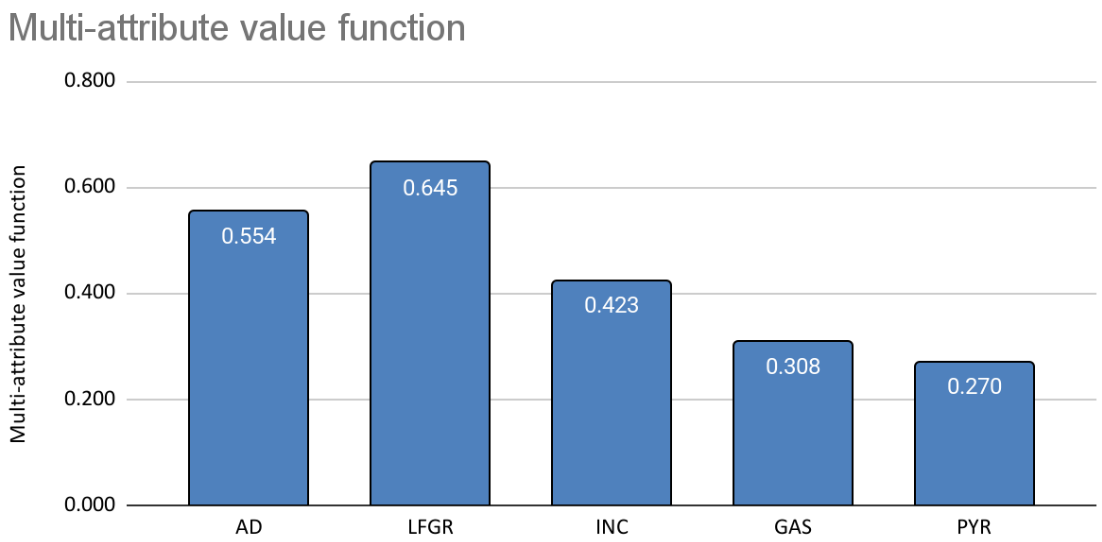

Figure 5.1: Overall Ranking Result of the WtE Technologies

5.2.1 FINDINGS OF THE HIGH-LEVEL OBJECTIVES (SOCIAL AND ENVIRONMENTAL, TECHNICAL, AND ECONOMIC)

Detailed explanation of the dominance of one WtE technology over another was represented by the decomposition of the multi-attribute value function into components corresponding to each evaluation area (High-level Objectives and the Assessment Areas) in accordance with the objective tree structure. High-level objectives scores are represented in Figure 5.2.

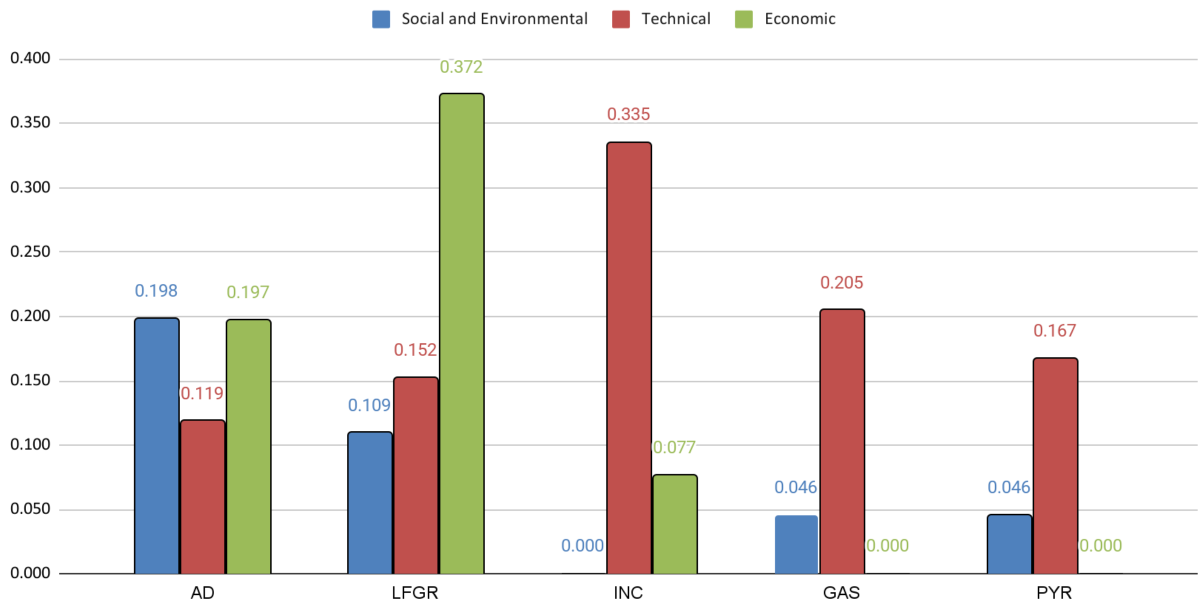

Figure 5.2: Decomposition of the Multi-Attribute Value Function per High-level Objectives

In regards to social and environmental aspects, Anaerobic Digestion (AD) **(0.198)** and Landfill Gas Recovery (LFGR) **(0.109)** achieved the highest scores. This was largely due to their relatively low greenhouse gas emissions and manageable environmental impacts. Gasification (GAS) and Pyrolysis (PYR) followed with identical score **(0.046)**, reflecting moderate environmental performance. In contrast, Incineration (INC) received the lowest score **(0.00)** indicating comparatively higher greenhouse gas emissions and greater environmental concerns.

With respect to technical aspects, Incineration (INC) achieved the highest score **(0.335)** due to its overall system efficiency and effective conversion of waste into energy, whereas Anaerobic Digestion (AD) recorded the lowest score **(0.119).** Technically, INC, Gasification (GAS), and Pyrolysis (PYR) demonstrated strong waste volume reduction capabilities, making them effective in minimizing landfill demand. However, these technologies typically require homogeneous waste streams and depend on advanced preprocessing infrastructure. In contrast, AD and Landfill Gas Recovery (LFGR) demonstrated lower efficiency in waste reduction but greater flexibility in handling mixed or organic waste. Furthermore, GAS and PYR were identified as emerging technologies characterized by higher operational complexity, while AD, LFGR, and INC are considered mature and relatively easier to operate; making them more suitable for contexts with limited technical capacity.

In terms of economic performance, Landfill Gas Recovery (LFGR) achieved the highest score **(0.372)**, due to its low capital (CAPEX) and operational (OPEX) costs. Conversely, Gasification (GAS) and Pyrolysis (PYR) recorded the lowest scores, reflecting their high capital and maintenance expenditures. Although GAS and PYR demonstrated superior operational efficiency, their economic feasibility remains limited by these high costs. LFGR, on the other hand, proved to be the most cost-effective option, even though with lower efficiency, while Anaerobic Digestion (AD) and Incineration (INC) provided a balanced trade-off between cost and performance. Technologies with shorter residence times, such as INC, are advantageous for rapid waste processing, whereas those with longer durations, like LFGR, are more suitable for less time-sensitive applications. Overall, the selection of a waste-to-energy technology involves balancing cost, efficiency, technical capacity, and environmental performance.

5.2.2 FINDINGS OF ASSESSMENT AREAS (EIA, WASTE, TECHNOLOGY, OPERATION AND COST)

Figure 4.3 presents the ranking results across the evaluated areas. In terms of Environmental and Social Impact Assessment (ESIA), Anaerobic Digestion (AD) ranked highest **(0.198),** while Incineration (INC) ranked lowest **(0.000)**. With respect to waste management performance, INC achieved the highest score **(0.115)**, whereas Landfill Gas Recovery (LFGR) had the lowest **(0.046).** In the technological category, INC again ranked highest **(0.127)**, while AD obtained the lowest score **(0.029).** From an operational perspective, Gasification (GAS) performed best **(0.050)**, and LFGR ranked lowest **(0.000)**. Finally, in terms of cost, LFGR achieved the highest score **(0.372)**, while GAS and Pyrolysis (PYR) recorded the lowest **(0.000)**.

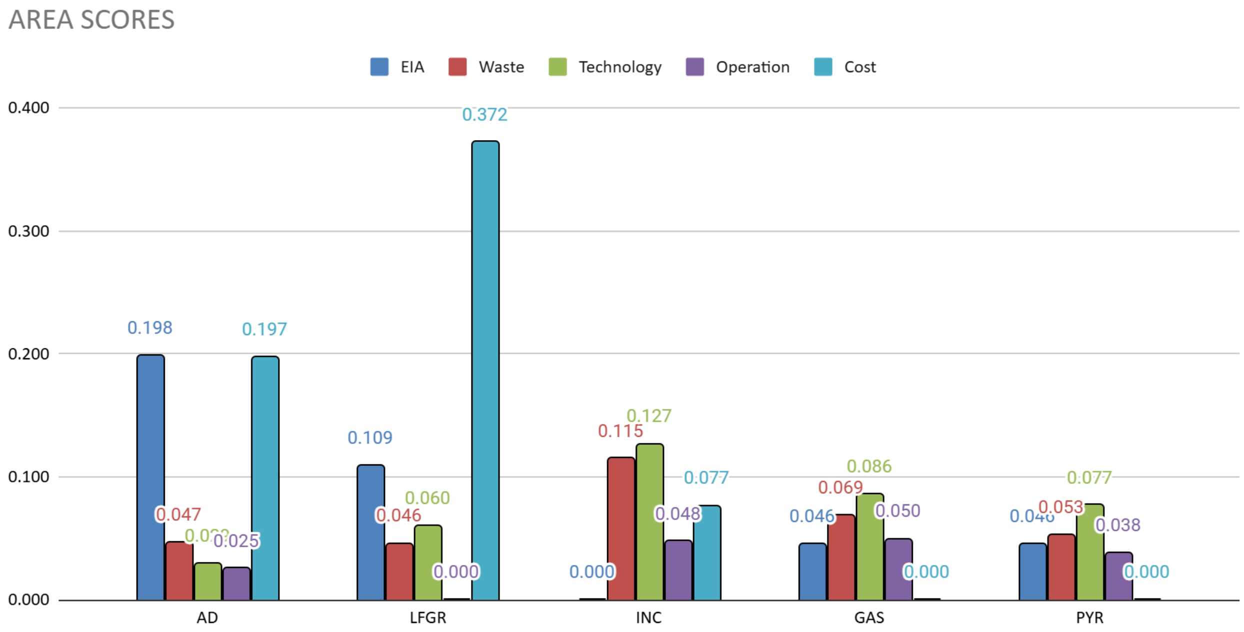

Figure 5.3: Ranking Results in respect to the Areas

6 LOCAL AND INTERNATIONAL PROJECTS' CASE STUDIES ON WASTE TO ENERGY CONVERSION

Table 5.1 presents selected international case studies on waste-to-energy (WtE) conversion projects. The case studies were chosen to represent a range of technologies, scales, and regulatory contexts, highlighting both developed and emerging market experiences. This comparative overview illustrates how different WtE approaches address environmental, economic, and policy considerations.

Table 6.1: Case Studies - High Level

Country	Technology Used	Capacity and Scale	Environmental Impact	Residue Management	Economic Aspects	Financial Viability	Energy Efficiency	Waste Management Integration	Regulatory Compliance
China	Incineration, Anaerobic Digestion	4000+ plants, total capacity >200,000 TPD	High emissions, improving standards	Fly ash and bottom ash, used in construction	Government subsidies, large market	Rapid growth, high investment costs	20-30% for incineration	Extensive integration with recycling	Stricter regulations, national policies
USA	Incineration, Landfill Gas Recovery	71 plants, total capacity ~97,000 TPD	Moderate emissions, strict controls	Fly ash, bottom ash managed, used in roads	Tax incentives, high operational costs	Long-term contracts ensure stability	20-27% for incineration	Well-developed infrastructure	EPA regulations, state-level policies
Canada	Incineration, Gasification	7 major plants, smaller scale <5000 TPD	Low emissions, advanced tech	Ash used in construction, hazardous waste carefully managed	Government grants, high initial costs	Growing sector, supported by government	25-30% for incineration	Integrated with municipal systems	Stringent environmental standards
South America	Incineration, Landfill Gas Recovery	Emerging market, varied scale ~10,000 TPD	High emissions, less regulated	Minimal residue management strategies	Lower costs, less developed economy	Financially challenging, needs investment	15-20% for incineration	Limited integration, emerging	Developing regulatory framework
Denmark	Incineration, Anaerobic Digestion	~28 plants, capacity >10,000 TPD	Low emissions, high standards	Ash reused in construction, strict controls	High initial investment, efficient operation	Highly viable, supported by policy	30-35% for incineration	Fully integrated, circular economy	Very strict EU regulations

Country	Technology Used	Capacity and Scale	Environmental Impact	Residue Management	Economic Aspects	Financial Viability	Energy Efficiency	Waste Management Integration	Regulatory Compliance
Germany	Incineration, Gasification	96 plants, total capacity ~20,000 TPD	Low emissions, advanced tech	Ash used in road construction, strict disposal	Strong government support, high costs	High viability, mature market	27-35% for incineration	Comprehensive integration, recycling	Stringent EU regulations
Japan	Incineration, Pyrolysis	380+ plants, total capacity ~200,000 TPD	Low emissions, high standards	Ash used in cement, strict disposal	Government funded, expensive technology	Viable due to government support	20-30% for incineration	Highly integrated, advanced tech	Very strict national regulations
South Africa	Incineration, Landfill Gas Recovery	Emerging market, capacity ~5000 TPD	Moderate emissions, developing standards	Limited residue management strategies	Lower costs, economic challenges	Emerging market, needs investment	15-25% for incineration	Limited integration, growing sector	Developing regulations
Ethiopia	Incineration, Anaerobic Digestion	Emerging market, capacity ~500 TPD	High emissions, limited controls	Minimal residue management strategies	Low costs, significant economic challenges	Financially challenging, needs support	15-20% for incineration	Limited integration, nascent stage	Minimal regulations, emerging framework

Table 5.2 provides detailed case studies of waste-to-energy (WtE) projects implemented across different countries. The cases illustrate a variety of technologies, scales, and operational contexts, highlighting their environmental, economic, social, and regulatory dimensions. This detailed overview demonstrates practical lessons and innovations that can inform WtE development in Kenya and beyond.

Table 6.2: Case Studies – Detailed

Country	Project	Location and Context	Technology Used	Capacity and Scale (Tonnes/Yr)	Environmental Impact	Economic Aspects	Energy Efficiency	Waste Management Integration	Regulatory Compliance	Social and Community Impact	Innovation and R&D	Output
China	LFGR	Shuangkuo Tianjin	Landfill Gas Recovery	1.03MW (Plant cc 4.3MW)	Improved solid waste disposal Reduced gas emissions (130,444 metric tonnes of CO_2	Increased revenues to municipality from electricity and carbon		Integrated with electricity generation and grid connection system	Clean development mechanism (CDM) Monitoring mechanism	Job creation Use of local resources Supply of electricity	Registered as a CDM project Green financing	Electricity

Country	Project	Location and Context	Technology Used	Capacity and Scale (Tonnes/Yr)	Environmental Impact	Economic Aspects	Energy Efficiency	Waste Management Integration	Regulatory Compliance	Social and Community Impact	Innovation and R&D	Output
					equivalent per annum)	credits sold					from WorldBank	
USA	Covanta Energy-from-Waste Facility	New York										
	Anaerobic Digestor	Jordan Dairy Farms, Rutland, MA, USA	Anaerobic Digestion	9,125 wet tons of manure and 16,425 tons of source-separated organics	Improves air and water quality, mitigates odors, and reduces farm greenhouse gas emissions							2.24 million kWh of electricity
Denmark	Incineration	Amager, Copenhagen	Incineration	400,000 tons of waste per year	emissions control systems employed (Selective catalytic reduction and flue gas treatment)	Initial investment of around €470 million,		Integrated with city's collection and sorting infrastructure	The project has obtained all the necessary permits and licenses required to operate in Denmark	Job creation, public perception and acceptance	Use of a sloped roof to create a ski slope. Employed one of the largest climbing walls for climbers	63MW elec and 106MW heat
Ethiopia	Reppie waste-to-energy plant	Koshe dump site, Addis Ababa	Incineration	511,000 Approx 80% of Addis rubbish	Meets EU emissions standards	$120 million		Waste management and energy - supply 30% of Addis Ababa's household energy needs	Meets EU emissions standards	Energy security		Electricity: 25MW; 185 million KWh/Yr Up to 1,800 ºC
Austria	Incineration Spittelau WtE Plant	Vienna	Incineration	250,000 tonnes per year MSW	Air emissions are compliant with the Austrian Clean Air Act 1988	Eur 130 million during renovations	Cogeneration technology, where gas and steam-powered turbines are combined and the energy	Thermal waste treatment, Recycling and disposal is done	City of Vienna environmental agency does continuous monitoring and evaluation to ensure	Clean heating and cooling energy as well as electricity, Customer care and energy-related advice at the customer	Photovoltaic technology relies on solar cells to convert solar radiation into electrical power.Two	120 GWh of electricity ■ 500 GWh of district heating ■ 6,000 tonnes of scrap iron,

Country	Project	Location and Context	Technology Used	Capacity and Scale (Tonnes/Yr)	Environmental Impact	Economic Aspects	Energy Efficiency	Waste Management Integration	Regulatory Compliance	Social and Community Impact	Innovation and R&D	Output
							released is used to produce both electricity and district heating. Increasing efficiency as high as 86% from 50%		compliance,	service centre An e-vehicle charging station and two photovoltaic facilities,Tours for various target groups, Art, exhibitions and events	such solar power plants are located at the site for research and E-mobility- two charging stations	and ■ 60,000 tonnes of clinker, ash and filter cake
Germany	Essen-Karnap waste incineration plan	Essen, North Rhine-Westphalia	incineration	700,000 tonnes of non-recyclable waste per year								
	Salzbergen thermal waste treatment plant	Salzbergen, Lower Saxony	Incineration	130,000 t/a								
	Thermoselect plant in Karlsruhe, Germany	Karlsruhe	pyrolisis	Capable of processing up to 220,000 tons of municipal solid waste per year								
Singapore	Keppel Seghers Tuas WtE Plant											
UK	Ince Bio Power[24]	England	Gasification (Outotec	160 kt/year of class A								26.5 MWe

[24] Microsoft Word - Gasification uk.docx (supergen-bioenergy.net)

Country	Project	Location and Context	Technology Used	Capacity and Scale (Tonnes/Yr)	Environmental Impact	Economic Aspects	Energy Efficiency	Waste Management Integration	Regulatory Compliance	Social and Community Impact	Innovation and R&D	Output
			fluidised-bed)	to C waste wood								
	Billingham Waste-to-Energy Plant	England, UK	gasification technology	Estimated to convert 200,000 tonnes of non-recyclable household and commercial waste each year		Construction cost: £8.6m				create jobs and deliver environmental and economic improvements to the local community		25MW of green electricity and 34MW of heat production.
Finland[25]	Lahti Gasification Facility (Kymijärvi II)	Lahti; Population: ~102,000.	Combined Heat and Power (CHP) waste gasification using Circulating Fluidised Bed (CFB) reactors.	250,000 tonnes/year of solid recovered fuel (SRF)	Reduces CO2, NOx, and SO2 emissions; Annual CO2 emissions: 230,000 tonnes (down from 410,000 tonnes)	Construction cost: €160 million	Achieves nearly 90% overall efficiency.	Comprehensive waste management chain including waste processing, material recovery, SRF/RDF production, and gasification. Waste is collected from a 200km radius including Helsinki.	Complies with the Waste Incineration Directive. Emission limits: NOx 240mg/MJ, SOx 240mg/MJ.	Provides electricity to 87,000 customers and district heating to 7,600 customers. Reduces heating and electricity bills for local customers.	Developed a new concept for gasifier-based power plants. Unique gas cooling and cleaning components developed by Metso Corporation.	50 MWe; 90 MW district heating

[25] Case Study 1 Lahti Gasifier Finland FINAL

7 RECOMMENDATIONS/INTERVENTIONS/STRATEGIES

This section presents a set of comprehensive recommendations, interventions, and strategies designed to guide the effective adoption and management of Waste to Energy (WtE) initiatives. The proposals are structured across five thematic areas (legal and regulatory, technological, social, economic, and further research and strategic planning) reflecting the multi-dimensional nature of sustainable waste management. Each sub-section provides targeted actions that align national priorities with international best practices, while also addressing local challenges and opportunities. Together, these recommendations aim to establish a robust framework for ensuring that WtE initiatives are environmentally sound, socially inclusive, economically viable, and strategically grounded.

7.1 LEGAL AND REGULATORY RECOMMENDATIONS

To establish a strong foundation for Waste to Energy (WtE) development, Kenya must strengthen its legal and institutional environment. This includes aligning frameworks with international conventions, enhancing enforcement, and empowering county governments. Key recommendations are as follows:

- Develop, review, and implement national frameworks aligned with ratified international conventions, ensuring consistency with global best practices.
- Establish and enforce comprehensive regulations and guidelines on all stages of waste management sorting, collection, transportation, and disposal anchored on an Expanded Producer Responsibility model.
- Strengthen enforcement mechanisms and penalties to enhance compliance at all levels of government and industry.
- Empower county governments with clearer mandates and resource support to enforce regulations and oversee local implementation effectively.
- Integrate stakeholder engagement frameworks, especially involving the Ministry of Environment, to align legal mandates with operational and financial frameworks for Waste to Energy (WtE) development.
- Incorporate mandatory environmental education and proper waste management practices into national curricula to institutionalize long term behavioral change.

7.2 TECHNOLOGICAL RECOMMENDATIONS

Technology adoption must be tailored to Kenya's waste composition while ensuring environmental sustainability, energy efficiency, and minimal emissions. To achieve this, the following actions are recommended:

- Adopt WtE technologies that are tailored to the specific characteristics of local waste (e.g., high organic content and moisture levels)
- Encourage segregation of waste at the source to improve feedstock quality for energy conversion processes and minimize secondary pollution.
- Implement decentralized waste collection and treatment systems to reduce transportation costs and improve system efficiency.
- Ensure that selected technologies balance energy efficiency with minimal greenhouse gas emissions and avoid the generation of new waste streams.
- Utilize ICT tools for instance in real time waste tracking, mapping of WtE potential sites, and optimization of waste collection streams.

7.3 SOCIAL RECOMMENDATIONS

The social dimension of WtE requires inclusive approaches that protect livelihoods, promote awareness, and strengthen community participation. To foster acceptance and ensure active engagement, the following measures are proposed:

- Address potential disruptions to existing informal waste dependent livelihoods by integrating affected stakeholders into the formal waste management ecosystem.
- Proactively manage resistance from entrenched interests or illegal cartels by strengthening institutional transparency and local governance.
- Deploy grassroots champions and sensitization campaigns to promote community awareness on proper waste management practices.
- Build a culture of responsible waste behavior through sustained advocacy, public education, and social inclusion strategies.
- Invest in stakeholder capacity building initiatives to ensure local communities, CBOs, and SMEs can actively participate in and benefit from the WtE initiatives.

7.4 ECONOMIC RECOMMENDATIONS

Sustainable WtE systems require robust financial strategies, incentives, and long-term economic planning that prioritize public benefit over short-term returns. The key recommendations include:

- Prioritize waste management as a public service and environmental necessity, rather than focusing solely on short term economic returns of WtE plants.
- Explore diverse project financing models including green financing, PPPs, the Green Climate Fund, and carbon credit markets to improve financial viability.
- Introduce targeted incentives to attract private sector investment and innovation in waste collection, segregation, and energy conversion.
- Develop zero landfill policies that encourage maximum recovery of resources through WtE and other sustainable methods.
- Promote a regional deployment approach for WtE plants to optimize infrastructure sharing and economies of scale across counties.

7.5 FURTHER RESEARCH AND STRATEGIC PLANNING

To guide effective long-term implementation, research and evidence-based planning are crucial in bridging knowledge gaps and shaping resilient strategies. The following actions are recommended:

- Conduct detailed case studies on successful international and regional WtE projects to derive best practices, with particular focus on enabling legal and institutional frameworks.
- Address existing knowledge gaps in resource and waste stream assessments to guide technology selection and siting.
- Map existing and potential WtE sites across Kenya, with pilot projects in progressive counties at REREC energy centers to build national interest.
- Undertake a comprehensive SWOT analysis for WtE in Kenya, and develop strategic implementation plans that capitalize on strengths and opportunities while mitigating weaknesses and threats.
- Investigate and establish mechanisms for integrating WtE into carbon markets, supporting long term sustainability and global climate goals.