IJIS: Vol.2, Issue 1, January 2026 Page: 132-137

ISSN 3049-3277

International Journal of Integrative Studies (IJIS)

Journal homepage:www.ijis.co.in

Waste-to-Energy Technologies for Circular Economy

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Abstract

A transition toward a circular economy (CE) is a move to minimize wastage, ensure full exploitation of resources and attain sustainability. Waste-to-Energy (WtE) technologies are also necessary because they convert municipal, industrial and agricultural wastes into energy forms that may be used as electricity, heat and biofuels. The paper examines how WtE systems can be part of the concept of the circular economy using a combination of both primary data (interview with 150 individuals) and secondary literature sources. It has been found out that there is a high level of understanding of renewable energy and low understanding of WtE application in sustainable systems. The paper shall provide a comparison of the performance, efficacy and difficulties of the significant technologies in use, such as incineration, anaerobic digestion, gasification, and pyrolysis and also indicate the economic and environmental benefits that they bring. These findings suggest that the WtE development at mass level needs proper policy frameworks, millions of people, and research and development of technologies. The research reaches the conclusion that WtE can be an energy solution and a waste management strategy which turns out to be the obligatory linkage on the global cyclical economy.

Keywords: Waste-to-Energy, Circular Economy, Sustainability, Renewable Energy, Resource Recovery.

Introduction

Waste generation in the world has already hit critical scores of up to 2.2 billion tons per year and is expected to rise by 70 percent in 2050 (World Bank, 2023). The growing amount of municipal solid waste (MSW) is a threat to the environment and economy because of the emission of greenhouse gases (GHG), the soil erosion, and energy shortage. Waste-to-Energy (WtE) technologies have in effect surfaced as an option of utilizing waste materials to produce useful energy. These processes are aligned with the principle of circling the loop of the closed economy (CE) waste is no longer an output but is converted into an input (Kirchherr *et al*., 2017).The paper evaluates the importance of WtE technologies in the CE model by relying on landfills, energy recovery, and creation of economic systems that are sustainable. The paper considers the current technologies, adoption barriers, and potential policy interventions based on primary survey data and the available technical literature.

The cost of energy conversion in the world needs new ways of waste management. WtE technologies are advantageous in their two aspects less wastes and renewable energy (Panepinto *et al.*, 2015).Incineration has been a pioneer in the WtE business, but because of the problem of air pollution and the presence of dioxins, the new more advanced thermal techniques, like gasification and pyrolysis, came into being (Arena, 2012). Meanwhile, biogas and digestate are obtained by the biological treatment of the organic waste, including anaerobic digestion (AD) which promotes the recycling of nutrients.A mix of such technologies in the framework of a circular economy can result in achieving a zero-waste society, energy and material recovery, and affecting the environment with less negative impact along with the green job creation (European Commission, 2020).

Despite the technological advancement, WtE is not widely used particularly in the emerging economies. High costs of capital, lack of proper policy stimulus, and the misconception of the population about emissions are some of the barriers.This research is justified since it combines both empirical information (popular and professional opinion) and technical opinion, which will give a full-fledged image of what role WtE can play to achieve sustainable development goals (SDGs). The policies and the industrial strategies can be designed using the results so as to promote the use of the circular resources.

Objectives of the Study

- To comment on how WtE technologies can contribute to the adoption of the circular economy.
- To identify the performance and environmental performance of the major WtE strategies.
- To identify the community and professional understanding of the advantages and issues of WtE.
- To establish policy, technological and economic obstacles to implementation.
- To provide a recommendation on the scaling of WtE in CE frameworks.

Materials and Methodology

Research Design

The chosen method was a mixed-method approach, which was based on primary survey data and secondary analysis.

Data Collection

- Sample size: 150 individuals (80 representatives of the energy/waste sector, and 70 representatives of the general population).
- Sampling strategy Stratified random sampling.
- The date of data gathering: January-March 2025.
- Instrument: The 5-point Likert scale questionnaire.

Data Analysis

- Data descriptive statistics of perception.
- Correlation and regression analysis to establish the assimilation between awareness and perceived benefits and readiness to adopt.
- Comparison of four major WtE technologies based on the literature and technical reports.

Results and Discussion

1. Demographic Profile

Table 1.Variable and percentage of Respondents

Variable	Category	% of Respondents
Gender	Male	60%
	Female	40%
Profession	WasteManagement Professional	35%
	Energy Engineer	18%
	Researcher	20%
	General Public	27%
Education	Graduate	42%
	Postgraduate	48%
	Doctorate	10%

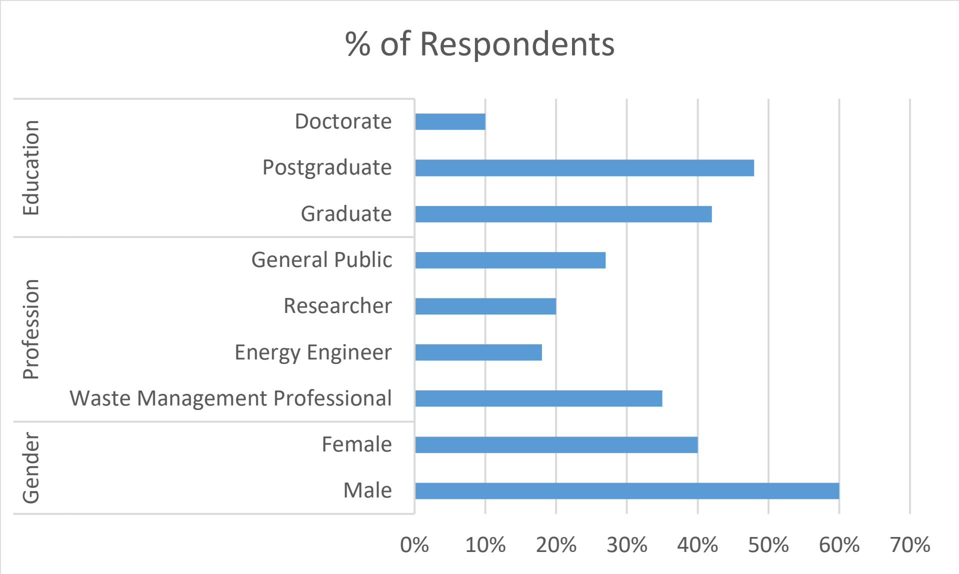

Figure.1

Table 1 and Fig.1 shows the percentage composition of the respondents in terms of education, profession, and gender. The survey population is composed of mostly male postgraduates, a large proportion of the general population, and the waste management industries giving a picture of the demographics in the survey.

2. Awareness and Perception Scores

Table 2. Various Factors

Factor	**Mean**	**SD**
Awareness of WtE Technologies	4.12	0.68
Belief in WtE as Sustainable Solution	4.30	0.59
Concern about Environmental Impact	4.22	0.63
Willingness to Support WtE Projects	4.15	0.72
Awareness of Circular Economy Concept	3.89	0.75

Respondents displayed high awareness and favorable opinions about WtE potential but limited understanding of circular economy integration.

ISSN 3049-3277

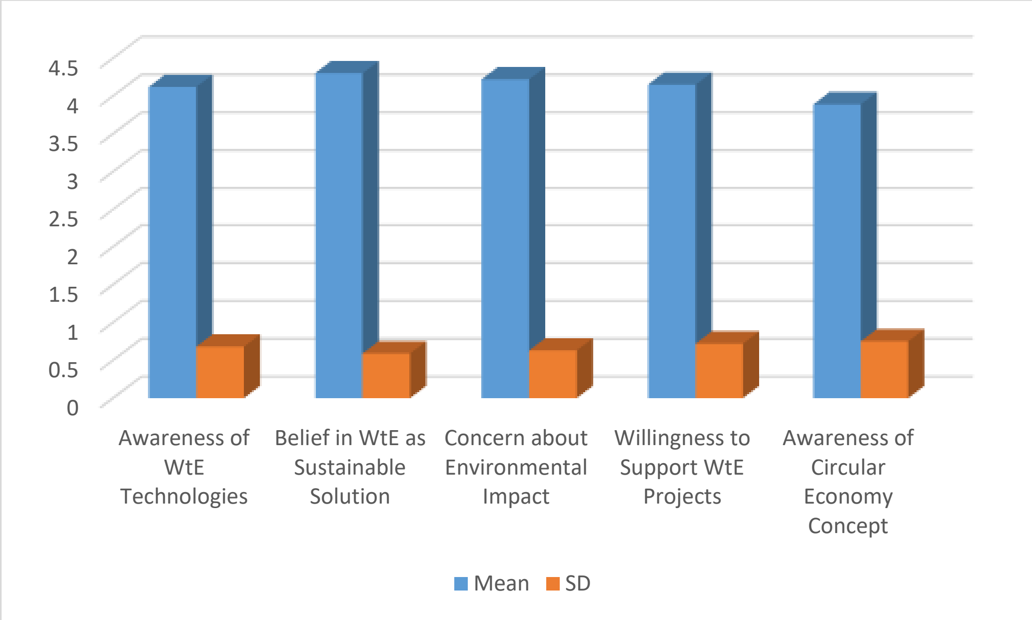

Figure. 2 Statistic data of different categories

Table.2 and Figure.2 juxtaposes the mean and standard deviation in the form of five categories of the perceptions about the new waste-to-energy (NWE) technologies and the awareness of the circular economy. It presents high mean scores with low standard deviation scores, which is a sign of high and steady positive sentiment of respondents.

3. Comparison of Major WtE Technologies

Technology	Energy Efficiency (%)	Emission Reduction	Capital Cost (USD/ton)	Suitability for CE
Incineration	25–30	Moderate	60–90	High
Gasification	35–45	High	80–120	Very High
Pyrolysis	40–50	High	100–140	Very High
Anaerobic Digestion	30–40	Very High	40–70	High

Source: Compiled from Panepinto *et al*. (2015); Kumar *et al*. (2020); OECD (2022).

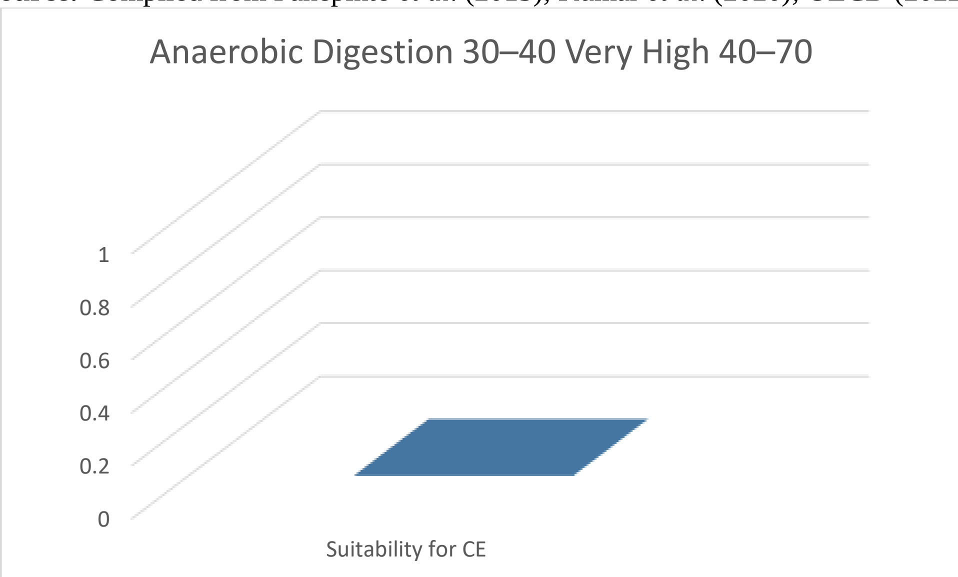

Figure 3

Depending on the values of above 0.2, this chart indicates that anaerobic digestion is low up to moderate in its suitability to the circular economy.

4. Correlation Analysis

Variable Pair	r (Correlation)	p-value	Interpretation
Awareness ↔ Support for WtE Projects	0.72	<0.01	Strong Positive
WtE Knowledge ↔ Circular Economy Understanding	0.64	<0.01	Moderate Positive
Perceived Environmental Risk ↔ Support	-0.45	<0.05	Negative Correlation

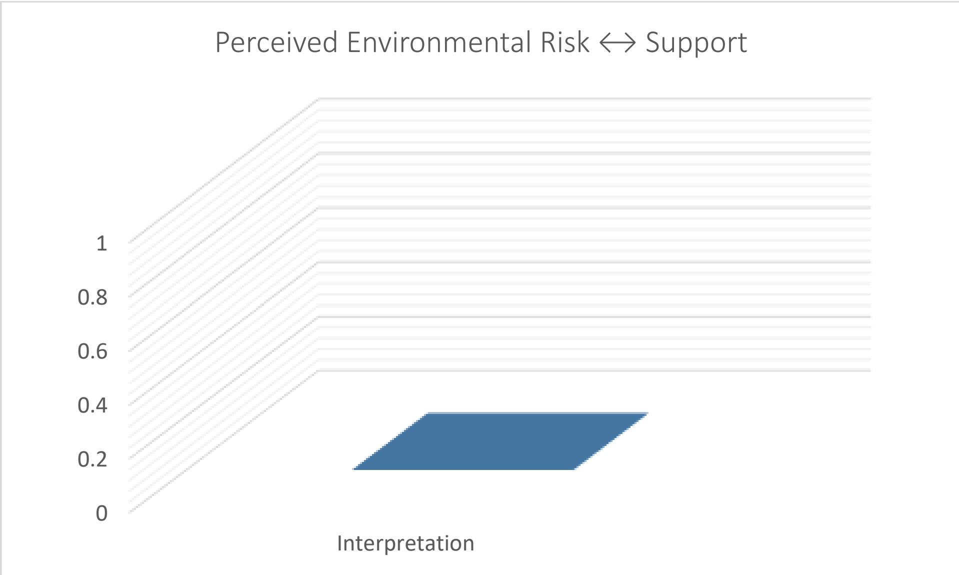

Figure. 4

This figure shows that perceived environmental risk and the support have statistically significant negative correlation (-0.45, $p < 0.05$), meaning the greater the risk perception, the less the support.

5. Regression Analysis

Predictor Variable	β Coefficient	R^2	p-value	Interpretation
WtE Awareness → Public Support	0.68	0.49	<0.01	Significant Positive Impact

Discussion

The results of all surveys show that there is a high social tendency to adopt WtE, but the level of awareness of the specific technologies used is low.

The correlation between awareness and support is significant which means that awareness and outreach may be a big factor in affecting the acceptance. WtE technologies transform waste into a valuable energy by means of thermal conversion, biological or physicochemical conversion. Incineration Wastes are burned to form electricity and heat. Although it is an efficient one, it requires a high level of emission control (Arena, 2012).

Gasification and pyrolysis are technically better in energy efficiency and reduction of emissions than the traditional incineration (Arena, 2012; Kumar *et al.*, 2020). Anaerobic digestion is also not as energy-dense but it fits well within the CE as it results in both biogas and organic fertilizer, both of which sustain agricultural operations. Couto *et al*, (2015) also repoted pyrolysis and gasification in which Waste is converted to syngas and bio-oil with a low oxygen content, and at high energy yields are obtained at a low pollution level. Transforms the organic wastes into biogas (methane + CO 2) and compost, which can be utilized in agriculture (Kumar *et al*., 2020). WtE assists in the CE by means of resource recovery, energy and carbon-neutral diversification (Kirchherr *et al*., 2017).The policy analysis indicates that other countries like Sweden, Japan, and Germany have effectively realized WtE into CE by offering incentive charges on energy charges and waste segregation systems (Zafar, 2019). These models can be copied by developing countries that increase the level of technology adaptability locally and invest in infrastructure based on PPP. The absence of infrastructure (Panepinto *et al*., 2015), a lack of confidence of people (Zafar, 2019), and policy disintegration (OECD, 2022). The 21 st century demands the partnership of various parties and policy models that are motivational due to innovations.

Future Scope

ISSN 3049-3277

- Hybrid WtE systems (e.g., pyro-gasification) have the potential to increase the efficiency of energy recovery.
- Combination of AI and IoT in the plant operations to achieve real-time emissions control.
- Producing biohydrogen and biochar as value added products.
- Community-based WtE model expansion to rural waste management.
- Circular design principles and extended producer responsibility (EPR) as the area of policy focus.

Conclusion

The technologies of Waste-to-Energy play an essential role in attaining low-carbon circular economy. They do not only help to reduce waste disposal challenges but also to diversify energy and resiliency against climate changes.The study results substantiate the notion that the sustainability of scaling WtE systems is associated with the public awareness, correspondence of the policy, and technologic innovations.WtE recycles the production and consumption loop by turning waste into a resource, thereby achieving the circular economy purpose.

References

1. Arena, U. (2012). Process and technological aspects of municipal solid waste gasification. *Waste Management, 32*(4), 625–639.
2. Couto, N., Silva, V., Monteiro, E., & Brito, P. (2015). Waste-to-energy technologies: Efficiency and environmental impacts. *Renewable Energy, 80*, 194–201.
3. European Commission. (2020). *Circular economy action plan: For a cleaner and more competitive Europe.* Brussels: EU Publications.
4. Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, 127*, 221–232.
5. Kumar, S., Samadder, S. R., & Singh, R. (2020). A review on energy recovery from municipal solid waste by anaerobic digestion. *Renewable and Sustainable Energy Reviews, 131*, 110032.
6. OECD. (2022). *Global Waste Outlook 2022: From Pollution to Resource.* Paris: OECD Publishing.
7. Panepinto, D., Genon, G., & Brizio, E. (2015). Energy recovery from waste: Technical and economic aspects. *Energy Procedia, 81*, 506–512.
8. World Bank. (2023). *What a waste 2.0: Global snapshot of solid waste management.* Washington, DC.
9. Zafar, S. (2019). Waste-to-energy: A key element for circular economy. *BioEnergy Consult.* Retrieved from https://www.bioenergyconsult.com