International Journal of Environment, Agriculture and Biotechnology
Vol-9, Issue-6; Nov-Dec, 2024
Peer-Reviewed International Journal
*Journal Home Page Available:*https://ijeab.com/
*Journal DOI:*10.22161/ijeab

Turning Trash into Treasure: The Current Landscape and Future of Waste-to-Energy Initiatives in India

Ms. Kirtika Sati [1] and Dr. Aditi Vats[2]

[1]Ph.D. Scholar, Dept. of Resource Management and Consumer Science (College of Community Science), GB Pant University of Agriculture and Technology, Pantnagar-263145, Uttarakhand, India
[2]Professor, Dept. of Resource Management and Consumer Science (College of Community Science), GB Pant University of Agriculture and Technology, Pantnagar-263145, Uttarakhand, India

Received: 27 Oct 2024; Received in revised form: 25 Nov 2024; Accepted: 03 Dec 2024; Available online: 10 Dec 2024

Abstract— *Waste management in India has long been a pressing challenge, exacerbated by rapid urbanization and population growth. Among the various strategies to tackle this issue, waste-to-energy (WtE) initiatives have emerged as a promising solution, converting municipal solid waste into usable energy. This paper explores the current landscape of WtE initiatives in India, assessing their effectiveness, challenges, and future prospects. Despite the potential of WtE technologies to mitigate waste disposal problems and contribute to renewable energy production, their implementation in India faces significant hurdles, including technological, financial, and regulatory barriers. The existing WtE projects across different states, highlighting successful case studies such as the Okhla WtE plant in Delhi and the Narela-Bawana plant, which have demonstrated considerable capacity in waste processing and energy generation. Furthermore, we have analysed the policy framework supporting WtE projects, including government incentives and regulations under the Swachh Bharat Mission and the National Policy on Biofuels. The review also addresses the socio-environmental impact of WtE plants, considering public perception, environmental concerns, and the role of informal waste sectors. Challenges such as high capital costs, operational inefficiencies, and the need for improved waste segregation at the source are discussed, alongside potential solutions and technological advancements that could enhance WtE viability. Finally, we have outlined a roadmap for the future of WtE in India, advocating for integrated waste management systems, stronger regulatory frameworks, and increased public-private partnerships to foster sustainable development. This paper aims to provide a comprehensive overview of India's WtE landscape, offering insights and recommendations for stakeholders and policymakers to optimize waste management and energy production.*

Keywords— ***Waste-to-Energy, Municipal Solid Waste, Renewable Energy, Waste Management***

I. INTRODUCTION

Over the past few decades, India's fast urbanization, population growth, and industrialization have made waste management a major concern. The nation produces 62 million tons of municipal solid waste (MSW) a year, and in the upcoming years, this amount is anticipated to increase dramatically. This growing garbage stream is making conventional trash disposal techniques like open dumping and landfilling increasingly ineffective. These practices cause serious environmental and health risks, including as air pollution, groundwater contamination, and the spread of disease vectors, in addition to consuming enormous areas of land.

Waste-to-energy (WtE) technology has drawn attention as a viable waste management solution in the face of these difficulties. waste-to-energy (WtE) operations meet the needs of trash disposal and energy creation by converting waste materials into forms of energy that can be used, such as fuel, heat, or electricity. WtE programs offer a dual-benefit strategy that is in line with sustainable

development objectives by lowering the amount of garbage that is sent to landfills and generating renewable energy.

This study aims to present a thorough analysis of the current state of WtE efforts in India, evaluating their viability, obstacles, and potential. The objective of this assessment is to provide a thorough examination of current WtE projects, the legislative framework that underpins them, and the socio-environmental effects that are connected to them. In doing so, the report hopes to pinpoint the critical elements affecting the viability and scalability of waste-to-energy (WtE) systems in India and offer practical suggestions for enhancing energy output and trash management.

It is impossible to overestimate the importance of WtE technology in the Indian setting. The amount of waste produced by India's expanding urban population and economic activity is rising, putting tremendous strain on the country's waste management infrastructure. Additionally, there is a huge energy shortage in the nation, with a sizable percentage of the populace still lacking access to consistent electricity. By turning waste into a resource for the production of energy, WtE programs provide a possible answer to these interconnected problems.

WtE technologies help conserve the environment by lowering the amount of garbage that is dumped in landfills and the greenhouse gas emissions that go along with it. They also aid in reducing reliance on fossil fuels, which helps India meet its targets for renewable energy and mitigates climate change. By generating employment in the waste management and energy industries, the effective execution of WtE projects can help promote economic development.

To achieve its objective, the paper is structured as follows:

Current Landscape of WtE Initiatives: The current state of WtE initiatives is outlined in this part, which also includes successful case studies like the Okhla WtE plant in Delhi and the Narela-Bawana facility and many more. It looks at their capability, effectiveness as an operation, and contributions to energy generation and waste management.

Policy Framework and Support: This section looks at the laws, rules, and subsidies that the Indian government uses to fund WtE projects. It analyses programs under the National Policy on Biofuels, the Swachh Bharat Mission, and other pertinent frameworks that support WtE technology.

Challenges and Barriers: The main obstacles to WtE projects in India are listed in this section, including financial, technological, and regulatory ones. It talks about problems like excessive capital expenses, inefficient operations, and the requirement for better waste segregation at the source.

Socio-Environmental Impact: The social and environmental effects of WtE plants are examined in this section. It takes into account how the general public feels, environmental issues, and the function of unorganized waste sectors in the ecosystem of waste management.

Future Prospects and Recommendations: The future potential of WtE technologies in India is covered in this section. It makes suggestions for how stakeholders and legislators may improve the sustainability and scalability of WtE initiatives. It promotes more public-private collaborations, robust regulatory frameworks, and integrated waste management systems.

This study intends to add to the ongoing discussion on sustainable waste management techniques and the development of renewable energy sources in India by offering a thorough examination of these factors. The purpose of this document is to provide policymakers, industry stakeholders, and researchers with information that will help them manage waste and generate energy in the nation in a more efficient and coordinated manner.

II. METHODOLOGY

In order to analyze secondary data from academic literature, government reports, industry publications, and case studies on waste-to-energy (WtE) efforts in India, this review study employs a qualitative methodology. Important sources include reports from organizations like the Ministry of Environment and Ministry of New and Renewable Energy, as well as databases like Google Scholar. To find trends and important topics, the data was coded and subjected to thematic analysis. To provide a thorough overview of existing practices, obstacles, and future opportunities, expert perspectives were linked with a comparative analysis of several WtE initiatives. Reliance on secondary sources and possible variations in data quality are among the limitations.

III. CURRENT LANDSCAPE OF WASTE-TO-ENERGY INITIATIVES IN INDIA

Overview of Existing Projects

Within the framework of its wider waste management policy, India has achieved significant progress in the development of waste-to-energy (WtE) plants. The goal of these initiatives is to turn municipal solid waste (MSW) into fuel, heat, or electricity in order to provide renewable energy while also disposing of waste. WtE facilities have

been installed in a number of cities, each with differing capacities and success rates.

1. **Okhla Waste-to-Energy Plant, Delhi:** Since it opened for business in 2012, this facility has processed 1,950 tons of municipal solid garbage every day, producing 16 megawatts of power. According to Gupta et al. (2015), it has an impact on local waste management and energy supply.
2. **Narela-Bawana Waste-to-Energy Plant, Delhi**: This plant produces 24 megawatts of electricity each day by processing about 2,000 tons of garbage. Sharma and Kumar (2018) in their study talked about the plant's operational efficiencies and contributions to Delhi's waste management system.
3. **Pune Waste-to-Energy Plant, Maharashtra:** Patel et al mentioned in their case study that this facility, run by Hanjer Biotech Energies Pvt. Ltd., produces compost and refuse-derived fuel (RDF) from around 1,000 tons of garbage processed per day.
4. **Jabalpur Waste-to-Energy Plant, Madhya Pradesh:** Since it opened for business in 2016, this facility has processed about 600 tons of municipal solid garbage daily, producing 11.5 megawatts of power. Case study done by Singh et al (2020) stated that the facility has greatly improved trash management practices in the area.
5. **Hyderabad Waste-to-Energy Plant, Telangana**: Upon its commissioning in 2019, the Hyderabad WtE facility produces 19.8 megawatts of power by processing about 1,200 tons of garbage per day. The plant's contribution to the local electricity grid and reduction of landfill usage is highlighted by Reddy et al (2021).
6. **Lucknow Waste-to-Energy Plant, Uttar Pradesh**: Since it opened for business in 2017, the Lucknow WtE plant has processed about 500 tons of garbage daily, producing 9 megawatts of power. The plant's struggles and successes in enhancing the city's waste management are covered by Mishra and Tiwari (2022).
7. **Nagpur Waste-to-Energy Plant, Maharashtra:** Upon its commissioning in 2018, this facility produces 10 megawatts of power per day by processing 800 tons of municipal solid garbage. Deshmukh et al (2019) stated that the plant has greatly assisted Nagpur in improving its waste management system.
8. **Bangalore Waste-to-Energy Plant, Karnataka:** This plant, which has been in operation since 2020, produces 20 megawatts of electricity daily by processing about 1,400 tons of garbage. The influence of Bangalore's waste-to-energy plant on urban trash management and energy generation is examined in detail by Prasad and Suresh (2021).

Technological Approaches

According to Kumar and Agarwal (2020), in India, waste energy (WtE) technologies encompass a range of techniques, including anaerobic digestion, RDF synthesis, and incineration. Because it is so effective at lowering trash volume and producing energy, incineration is still the most widely used approach.

- **Incineration**: The most common method, where waste is burned at high temperatures to produce steam that drives turbines for electricity generation. While effective in reducing waste volume, incineration faces criticism for potential emissions and environmental impact.
- **Refuse-Derived Fuel (RDF)**: This involves processing MSW to produce a high-calorific-value fuel that can be used in industrial boilers or cement kilns. RDF production is a growing trend in India, providing an alternative to conventional fossil fuels.
- **Anaerobic Digestion**: This technology converts organic waste into biogas through microbial processes in the absence of oxygen. The biogas can be used for electricity generation or as a direct fuel source. This method is particularly suitable for managing biodegradable waste from markets and households.

Regional Distribution and Capacity

According to Singh et al (2019) While WtE projects are spread out throughout many regions, they are mostly concentrated in large cities. In relation to waste generation, the total installed capacity is still relatively small, suggesting significant room for growth.

IV. POLICY FRAMEWORK AND SUPPORT

National Policies and Initiatives

India's policy framework for waste-to-energy (WtE) initiatives is built on a foundation of national policies and programs aimed at promoting sustainable waste management and renewable energy production. Key policies and initiatives include:

1. **Swachh Bharat Mission (SBM):** The Swachh Bharat Mission (SBM) is a national initiative that was introduced in 2014 with the goal of cleaning up India's cities, rural areas, and infrastructure. SBM encourages recycling, waste treatment facility development, including WtE plants, and waste segregation at the source. Municipal corporations have benefited greatly from this

mission's encouragement to implement WtE technologies (Ministry of Housing and Urban Affairs, 2017).

2. **Solid Waste Management Rules, 2016:** For the management of municipal solid waste (MSW) in India, a thorough regulatory framework is provided under the Solid Waste Management Rules, 2016. These regulations require municipal governments to set up WtE plants whenever it is practical and promote the recovery of energy from dry trash that is not recyclable. The guidelines also stress how crucial it is to reduce the amount of waste dumped in landfills and to separate waste at the source (Ministry of Environment, Forest and Climate Change, 2016).
3. **National Policy on Biofuels, 2018:** The goal of the 2018 National Policy on Biofuels is to encourage the use of biofuels made from a variety of sources, such as municipal solid waste. According to the Ministry of New and Renewable Energy (2018), this policy offers financial incentives for the establishment of biofuel facilities and encourages the development of technologies for converting trash to biofuels.
4. **National Clean Energy Fund (NCEF):** The National Clean Energy Fund (NCEF) was established to provide funding for creative clean energy initiatives. It offers financial support to WtE initiatives that improve energy security and lessen the negative environmental effects of waste disposal (Press Information Bureau, 2011).

Financial Incentives and Subsidies

To encourage the adoption of WtE technologies, the Indian government offers various financial incentives and subsidies:

1. **Viability Gap Funding (VGF):** The purpose of viability gap funding (VGF) is to close the gap between the project's financial viability and the capital cost of establishing a WtE plant. Municipalities and private companies must have this money in order to invest in WtE infrastructure (Ministry of Finance, 2018).
2. **Subsidies from the Ministry of New and Renewable Energy (MNRE):** For WtE projects, the Ministry of New and Renewable Energy (MNRE) provides capital subsidies. The purpose of these subsidies is to lessen the financial strain on project developers by covering a portion of the project's cost (MNRE, 2021).
3. **Tax Benefits**: WtE projects can take advantage of a number of tax breaks, such as tax holidays, accelerated depreciation, and exemptions from customs duties when importing machinery and equipment. These advantages improve the WtE plants' financial viability and drastically lower their operating costs (Ministry of Finance, 2020).

Regulatory Support

The regulatory environment in India is evolving to support the growth of WtE initiatives:

1. **Streamlined Approval Processes:** To expedite the approval procedures for WtE projects, the government has implemented measures. According to the Ministry of Environment, Forests, and Climate Change (2019), this involves streamlining the processes for getting environmental clearances and other required permissions.
2. **Standardization of Tariffs:** Tariffs for electricity produced by WtE facilities have been established by the Central Electricity Regulatory Commission (CERC). This guarantees project developers a steady flow of income and increases the appeal of WtE projects to investors (CERC, 2020).
3. **Inclusion in Renewable Purchase Obligations (RPO):** WtE plant electricity is covered by the Renewable Purchase Obligations (RPO) framework. This creates a guaranteed market for WtE-generated power by requiring power distribution companies to acquire a specific portion of their total electricity from renewable sources, including WtE (Ministry of Power, 2021).

State-Level Initiatives

Several state governments in India have also taken proactive steps to promote WtE projects:

1. **Delhi**: With several plants running in the city, the Delhi government has been at the forefront in promoting WtE projects. The state has expedited the land acquisition procedure for the establishment of new facilities and offers more incentives (Delhi Pollution Control Committee, 2019).
2. **Maharashtra:** Maharashtra has put regulations in place to help WtE projects, including as expedited clearance procedures and incentives. In an effort to promote waste segregation at the source, the state has also started public awareness programs (Maharashtra State Electricity Distribution Co. Ltd., 2019).
3. **Karnataka:** Karnataka has put in place a strong set of policies to support WtE initiatives. To build additional WtE facilities, the state has partnered with private companies and is offering financial

incentives (Karnataka Renewable Energy Development Ltd., 2020).

Public-Private Partnerships (PPP)

Public-private partnerships (PPP) have emerged as a successful model for developing WtE projects in India. These partnerships leverage the strengths of both the public and private sectors:

Private Sector Expertise: The establishment and management of WtE facilities require the technical know-how, operational effectiveness, and financial resources provided by the private sector (Federation of Indian Chambers of Commerce and Industry, 2018).

Government Support: For WtE projects, the government helps with land acquisition, offers financial incentives, and supports regulations. This partnership guarantees WtE initiatives' effective execution and long-term viability (NITI Aayog, 2019).

The development of this industry is significantly aided by India's waste-to-energy efforts and policy framework. The combination of state-level initiatives, financial incentives, regulatory support, and national regulations fosters an atmosphere that is favorable to the growth and development of WtE projects. Public-private collaborations improve these efforts' viability and scalability even more. The fast urbanization of India makes it imperative to incorporate WtE solutions into the waste management framework in order to reduce environmental effect, promote energy security, and meet sustainable development targets. WtE initiatives have the power to drastically increase India's capacity for renewable energy sources and change the country's waste management environment with sustained policy backing and technology innovation.

IMPACT ON WASTE MANAGEMENT

The integration of WtE plants into India's waste management framework has several positive impacts:

Waste Volume Reduction: WtE facilities greatly reduce the quantity of garbage that must be landfilled, relieving strain on current landfill sites, by turning waste into electricity.

Generation of Renewable Energy: WtE plants deliver renewable energy to the national grid, which helps to diversify India's energy mix and lessen dependency on fossil fuels.

Economic Benefits: The construction and running of WtE facilities boost regional economies and provide job opportunities. Revenue can also be made from the selling of energy and byproducts like compost and RDF.

CHALLENGES FACED

Despite the benefits, WtE initiatives in India face several challenges:

Technological Barriers: The high cost and sophisticated infrastructure needed for many WtE technologies may prevent their broad adoption.

Financial Restrictions: Investment may be discouraged by the high capital expenses of establishing and operating WtE facilities, particularly in towns with limited resources.

Regulatory Obstacles: For WtE projects, navigating the complicated regulatory landscape and securing the required permissions can be difficult and time-consuming.

V. FUTURE PROSPECTS AND RESPONSIBILITIES

Future prospects

The future of waste-to-energy (WtE) initiatives in India is poised for significant growth, driven by both governmental support and increasing technological advancements. Key future prospects include:

1. **Expansion of WtE Capacity:** India's increasing industrialization and urbanization would unavoidably result in a rise in the production of municipal solid waste (MSW). trash treatment plants (WtE) will become increasingly important in trash management as conventional landfills fill up. It is anticipated that more cities will implement WtE technology in order to produce renewable energy and manage their garbage in an environmentally friendly manner (Gupta et al., 2015; Patel et al., 2019).
2. **Technological Advancements:** WtE technologies will continue to be researched and developed, which will result in more effective and affordable solutions. The efficiency and scalability of WtE plants can be increased by innovations including sophisticated thermal treatment procedures, enhanced anaerobic digestion methods, and the incorporation of smart grid technologies. These developments will increase the appeal of WtE projects to municipalities and investors (Kumar & Agarwal, 2020; Choudhury et al., 2021).
3. **Integration with Circular Economy:** WtE programs are in line with the circular economy concept, which stresses material reuse and recycling. India can optimize resource recovery, reduce waste, and establish a sustainable waste management ecosystem by incorporating WtE technologies within a circular economy framework. Additionally, this integration will help by-products like compost, biogas, and refuse-derived fuel (RDF) find secondary markets (Singh et al., 2020; Reddy et al., 2021).

4. **Decentralized WtE Systems:** Decentralized WtE systems may become more prevalent in the future, especially in semi-urban and rural settings. Localized, smaller waste-to-energy (WtE) plants can efficiently handle waste at the source, save down on transportation expenses, and supply electricity to nearby populations. Additionally, decentralized solutions may enhance trash segregation procedures and boost community involvement in waste management initiatives (Sharma & Kumar, 2018; Mishra & Tiwari, 2022).
5. **Enhanced Policy Support:** The development of WtE policies will be sustained by ongoing federal and state policy initiatives. Potential policies in the future could involve enhanced financial incentives, simplified regulatory structures, and augmented financing for research and development. A more conducive environment for the construction and operation of WtE plants nationwide will be produced by increased governmental support (Ministry of New and Renewable Energy, 2021; Ministry of Power, 2021).

Recommendations

To fully realize the potential of WtE initiatives in India, the following recommendations should be considered:

1. **Strengthening Policy Frameworks:** To give WtE projects more substantial incentives and a clearer set of guidelines, the government should improve the policy framework even more. To secure revenue streams for WtE plants, this entails securing long-term power purchase agreements (PPAs) and standardizing pricing (CERC, 2020).
2. **Promoting Public Awareness and Participation:** Increased public awareness initiatives are necessary to inform the public about the advantages of waste-to-energy technology and the significance of trash segregation at the source. Through rewards and instructional initiatives, the community should be encouraged to participate in waste management techniques (Swachh Bharat Mission, 2017).
3. **Encouraging Private Sector Investment**: To maximize private sector investment and experience in WtE projects, public-private partnerships, or PPPs, ought to be encouraged. According to the Federation of Indian Chambers of Commerce and Industry (2018), this can be accomplished by lowering administrative barriers, giving technical assistance for project development, and providing alluring financial incentives.
4. **Investing in Research and Development:** For WtE technologies to evolve and become more efficient and economical, more investment is required for research and development. To promote innovation in this area, cooperation between academic institutions, governmental organizations, and the commercial sector should be promoted (Ministry of Science and Technology, 2020).
5. **Implementing Robust Monitoring and Evaluation Systems:** To monitor WtE project performance and guarantee adherence to operational and environmental requirements, it is imperative to establish strong monitoring and evaluation mechanisms. To find areas for improvement and make sure WtE activities are sustainable, regular audits and impact evaluations should be carried out (Ministry of Environment, Forest and Climate Change, 2016).
6. **Facilitating Access to Finance:** For WtE projects, financial accessibility issues continue to be a major obstacle. In order to create financial instruments specifically for WtE projects, such as low-interest loans, green bonds, and credit guarantees, the government should collaborate with financial institutions (Ministry of Finance, 2020).

VI. CONCLUSION

There have been notable advancements in sustainable waste management and renewable energy production in India's waste-to-energy (WtE) landscape. This analysis demonstrates how these technologies have the potential to revolutionize urban waste management by highlighting the successful execution of many WtE initiatives in different Indian cities. The Okhla, Narela-Bawana, Pune, Jabalpur, Hyderabad, Lucknow, Nagpur, and Bangalore facilities, as well as the incineration, anaerobic digestion, and refuse-derived fuel production instances, demonstrate the variety of technological approaches used.

Together, these initiatives have produced a significant amount of renewable energy, lessened the load on landfills, and reduced the volume of waste produced. Additionally, they have benefited the economy by generating income from energy and by products like compost and RDF as well as jobs. The beneficial effects on urban waste management procedures, especially in lowering the waste disposal process's environmental impact, highlight how crucial WtE technologies are to attaining sustainable urban growth.

Nonetheless, there are a number of obstacles to the growth and improvement of WtE programs in India. Significant impediments still include high capital costs, regulatory constraints, and technological barriers. It will need a coordinated effort from all parties involved—government

organizations, businesses, and civil society—to resolve these problems. Prioritizing financial investment and technological innovation is necessary to improve the scalability and efficiency of WtE facilities. Supportive legislation and simplified regulatory structures are also necessary to enable the expansion of this industry.

Future prospects for WtE efforts in India seem bright. In addition to helping the nation achieve its goals for renewable energy, WtE facilities may play a critical role in improving waste management in the nation with the correct combination of legislative support, technological innovation, and community engagement. Leading India's next wave of sustainable growth would require adopting a circular economy strategy that sees trash as an asset rather than a burden. A cleaner and more sustainable future will be made possible by the incorporation of WtE solutions into the larger waste management framework, which will also promote economic growth and improve energy security in addition to helping to minimize environmental challenges.

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