Harnessing Renewable Energy for Food Waste Management in Developing Countries

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Integration of renewable energy and waste management is becoming increasingly important as the world faces the dual challenges of climate change and growing waste production. Together, these two fields offer significant opportunities to reduce environmental impact, improve energy security, and promote a circular economy. Here's an exploration of how renewable energy can play a crucial role in modern waste management practices, and how waste management can support the growth of renewable energy. Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves, and geothermal heat. Waste management involves the collection, transportation, processing, recycling, and disposal of waste materials. Effective waste management practices are crucial for reducing pollution, conserving natural resources, and protecting public health. However, as urban populations grow and consumption increases, waste management systems worldwide face increasing challenges. Traditional methods such as landfill disposal and incineration can contribute to air pollution, groundwater contamination, and significant carbon emissions. Before addressing food waste management, it's essential to understand what food waste is. It generally refers to food suitable for human consumption that is not eaten, either because it spoils or is discarded unnecessarily. While some waste occurs naturally at retail and consumption stages, much of it results from carelessness or deliberate disposal. Food waste also involves the misuse of resources like energy, water, and land, and contributes significantly to environmental degradation. The FAO defines food waste as food appropriate for human consumption being discarded, whether it's kept beyond its expiry date or left to spoil. Food waste management encompasses a range of strategies across the stages of prevention, recovery, recycling, and final disposal, including food waste tracking and prevention, redistribution through food banks, use as animal feed, renewable energy generation via anaerobic digestion, composting, and, as a last resort, disposal in landfills. This article highlights the management strategies and future prospects of food waste management in India, emphasizing the need for detailed waste characterization and improved treatment methods for efficient handling.

Potential of Food Waste in India

According to the most recent data collected by FSSAI (2021), India is the world's second-largest producer of food, accounting for nearly 10.1% of total global food production. Despite such values, India has nearly 196 million undernourished people, the second-highest number in the world, as India has been interpreted to house 25% of the world's hungry people, and statistical studies (primarily conducted and reported by the FAO) have revealed that as of 2021, the amount of food waste generated in India accounts for nearly 40% of its total food production (by weight), which includes household waste, with each individual throwing away approximately 50 kg of food per year (Roe *et al.* 2021). Indian families waste 50 kg of food per capita per year, the lowest figure in South Asia. In 2019, 931 million tonnes of food were wasted worldwide, with households wasting the most (570 million tonnes), followed by the food service and retail sectors (Pal and Bhatia 2022). The generation of food waste (FW) is progressively increasing due to evolving lifestyles and the rapid urbanization of the global population. This waste originates from a variety of sources, including industrial, agricultural, commercial, domestic, and other sectors. Moreover, the accumulation of FW results in the considerable depletion of essential resources such as water, land, labor, and energy. As illustrated in Figure 1, major contributors to FW include food processing industries, agricultural by-products, and both commercial and household kitchens (Sharma *et al.* 2020; Saber *et al.* 2022).

Types of food waste and their sustainable utilization

Food waste (FW) is classified as wet waste and typically consists of kitchen scraps, including both cooked and uncooked food, eggshells, bones, flower and fruit residues like juice peels, houseplant waste, green waste from fruit and vegetable vendors or shops, and refuse from food and tea stalls. Major contributors

to food waste in India include hotels, hostels, restaurants, cafés, supermarkets, residential complexes, airline catering services, and food processing industries (Paritosh *et al.* 2017). Food waste has become increasingly common in India. While a portion is composted for fertilizer or buried in the ground, these practices can lead to soil contamination and strain on natural resources. Composting is an efficient method for managing food waste in developing countries. In India, over 70 facilities process mixed municipal solid waste, recycling about 5.90% of total food waste to produce more than 4.3 million tonnes of compost each year. Bioethanol production from food waste in Greater Noida, Uttar Pradesh, was tested in the lab using dried and shredded waste (Sahoo *et al.*, 2024). An overview of food waste management and the valorization process is presented in Fig. 1.

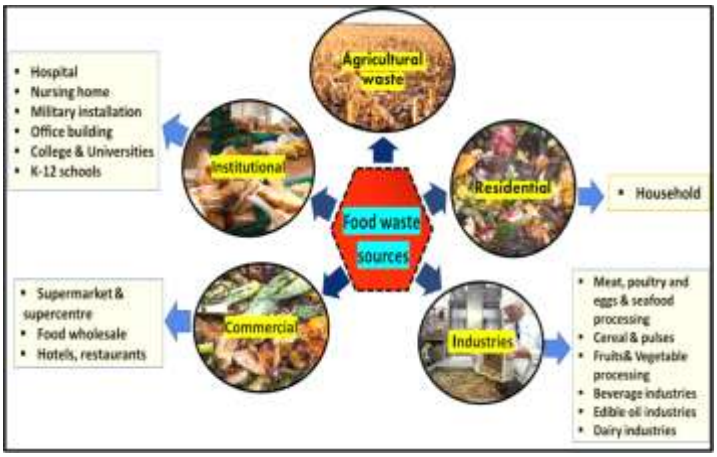

Fig. 1 Different sources of food waste

Common food waste treatment process

Food waste management practices in developing and underdeveloped countries differ according to the availability of resources, existing infrastructure, and prevailing local customs. There are some common food waste treatment methods widely employed in developing nations, namely animal foods, fertilizer production, anaerobic assimilation, incineration, landfill disposal. Dumping and landfills are accountable for 90 % waste disposal. On the other hand, composting is responsible for 1 %–6 % of disposal process across different areas. Landfills and open dumps remain the main food waste disposal methods in developing countries, despite their environmental and health risks. This highlights the need for greater investment in sustainable alternatives like composting and anaerobic digestion. In contrast, anaerobic digestion contributes under 0.6 %, and animal feeding, incineration are seldom practiced for managing food waste in these regions as shown in Fig.2 (Rahman *et al.*, 2024).

Fig. 2 Types of food waste and their sustainable utilization

Fig.3 Food waste treatment process

Conclusion

Given the seriousness of food waste, a comprehensive approach to its management is essential. This article explores key issues, strategies, and future directions for food waste management in India, where waste primarily originates from domestic, commercial, agricultural, and industrial sources. Numerous studies focus on sustainably managing food waste. Techniques such as valorization, anaerobic digestion, composting, and landfilling are widely used both globally and in India for effective food waste management. Improper food waste disposal causes pollution, disease spread, and GHG emissions. Research on integrating processes for value-added products can improve waste management efficiency. The partnership between renewable energy and food waste management offers a path forward for more sustainable, efficient, and environmentally friendly

systems. Waste-to-energy technologies, biomass energy production, and the integration of renewable energy sources into waste management operations have the potential to reduce waste, lower carbon emissions, and create a more circular and resilient economy. As both sectors continue to evolve, the synergy between renewable energy and waste management will be a critical component of a sustainable future.

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