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Review article

Strategies of managing solid waste and energy recovery for a developing country – A review

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A R T I C L E I N F O

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A B S T R A C T

Solid waste is considered one of the major pollutants of both water and surface worldwide. The growing global population, urban expansion, and industrial growth are the main reasons for solid waste generation. This has become a major challenge with both regional and worldwide consequences. The yearly generation of municipal solid wastes around the world is 2.01 BT (billion tons) among which about 33 % are not ecologically handled. To address this, proper solid waste management, especially recycling waste products, is crucial to achieving sustainability. High-income countries are able to recycle 51 % of their waste, while low-income countries only recycle 16 % of their waste. Inadequate solid waste management practices can only compound environmental and social problems. To handle these issues thermochemical and biochemical methods are used to convert solid waste to energy. Thermochemical method is suitable for developing countries though it is energy extensive. This review provides a detailed analysis of developing countries' solid waste management and energy recovery. It explores energy recovery technologies, including thermochemical and biochemical waste conversion processes.

1. Introduction

The growth in urbanization and financial development has resulted in a growing quantity of municipal solid waste (MSW). By the year of 2050, global MSW production is projected to spread around 3.4 billion metric tons per year [1]. The growth in waste production is largely attributed to population growth, which poses a major concern for ecological sustainability [1]. Asia produces one-third of the total waste globally, where China produces 0.44–4.3 kg of waste person/day [1]. Out of the two billion metric tons of waste produced annually, 33 % are not managed properly.

Low-income countries (HICs) are able to recycle 51 % of their waste, while low-income countries (LICs) only recycle 16 % of their waste. LICs dispose of 93 % of their waste in open dumps, whereas HICs only dispose of 2 % of their waste in open dumps, indicating a lack of proper solid waste management (SWM) practices in LICs, which pose a hazard not only to human health but also the

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environment, and livelihoods [2]. The poor SWM practices in the past decades have led to major health crises during pandemics, storms, earthquakes, and floods [3]. The increasing quantity and difficulty of managing the wastes is a significant concern for society and has numerous negative environmental and societal implications [4–6]. Landfilling and inadequate waste dumping have also been causes of economic, well-being, and security concerns [7–10].

In figuring out the environmental and socioeconomic effects of solid waste, environmentally friendly waste management methods are crucial to develop [11,12]. The formation of new elements from scratch requires significant energy and resources. Recycling and reusing materials can significantly decrease the need for extracting new assets and minimize the ecological impact related to resource extraction and processing. Improper waste disposal can pose health risks to humans and wildlife [13]. Improperly disposed waste can attract pests and vermin, contaminate drinking water sources, and contribute to the spread of diseases. Environmentally friendly waste management practices help to ensure the proper handling and disposal of waste, protecting public health and reducing the risk of environmental contamination. Within these strategies, waste-to-energy (WTE) has been seen as a promising approach for waste generation as it works as an effective source while reducing emissions and land use [14]. Resource recovery is a realistic solution of reducing feedstock consumption, reducing greenhouse gas (GHG) emissions, and reducing the amount of garbage disposed [15]. Beginning with this method, organic material is decomposed by naturally occurring soil microbes, creating fertilizer, a rich source of plant nutrients. This technology has been extensively studied, and its effectiveness has been documented by numerous researchers, including Kabir, Kumar [16]; Mankad, Kennedy [17]; Dos Santos and Maranho [18]; O'Brien, DeSutter [19]; Zimmer and Braganca [20]; Sindhu, Gnansounou [21]. The first stage of degradation is through physical disintegration by earthworms and soil insects, followed by the action of microorganisms in breaking down the organic material [22–24].

The purpose of this paper is to review the production and management of municipal solid waste (MSW) in developing countries and find a suitable one for energy recovery. The discussion covers a description of the features of MSW, the importance of recovering energy from it, and the potential for producing valuable products from MSW. Additionally, the paper explores the recent technological advancements in generating energy from MSW and highlights the limitations and unintended consequences of these technologies. This review will provide insight into the technological approaches for recovering energy and vital products and support a long-term strategy for turning MSW into end products.

2. Current scenario and handling of MSW

The yearly generation of MSW around the world is 2.01 BT among which about 33 % are not ecologically handled [25]. In addition to the classification of MSW in different countries, the management of MSW provides a small insight into the way SWM methods are implemented in municipal areas with a significant population growth and waste production [26]. These similar conditions happened in several countries among them China, Africa, Mexico, Czech Republic are common [27–30]. However, the SWM has changed progressively [31]. Fig. 1 shows municipal solid waste generation of different countries in Asia. In this figure it is shown that the MSW generation is higher in Japan and lowest in Bhutan. Bangladesh also produces a significant amount of waste.

The composition of MSW can differ greatly, based on the country's level of development and the specific local municipality [33]. For instance, some regions of East Asia and the Pacific produce higher amounts of organic waste in MSW, accounting for 62 % of the waste, compared to North Africa and the Middle East, which have around 61 % organic waste content (Fig. 2). Organic materials

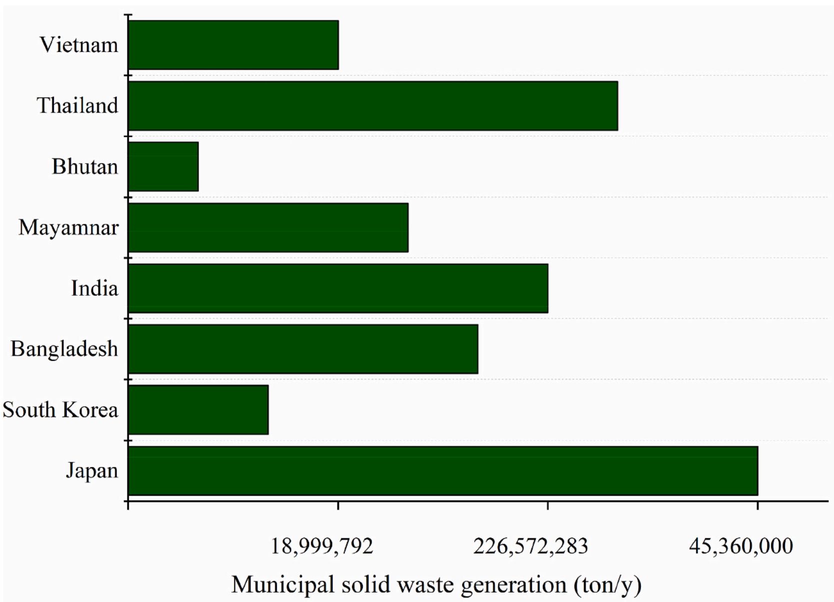

Fig. 1. MSW generation of different countries in Asia [32].

contain a substantial amount of energy; 65–80 % of the power found in these materials can be harnessed for use as heat in energy facilities [33]. Therefore, there is a considerable amount of composed waste in many developing countries that is disposed of through unlined landfills or open disposal, leading to a number of negative consequences [34]. These can include air pollution, contamination of groundwater, health consequences, soil and land pollution, financial damage, and garbage fires. Open dumping of waste or the use of unlined landfills can have serious health consequences, including respiratory issues, skin and eye infections, and elevated blood lead levels from open burning [35]. This type of waste management can also result in contaminated groundwater and soil, leading to the spread of waterborne illnesses such as diarrhea, dysentery, typhoid, malaria, hepatitis, yellow fever, and cholera [34].

In a study, it was shown that about 143449 MT (Metric Ton) of MSW are generated every single day, from which 111000 MT are collected and about 35602 MT are processed [38]. The problem arises due to the onward waste products, the growth of the population, and municipal development [39]. Collection, storage, and transfer are the three main steps for treating and managing of MSW [40]. In Ghana, garbage from urban areas is collected for a fee by municipal or private entities; in addition, open dumping is used for the rural areas [41,42]. The rate of SW is increasing very fast, day by day. Consequently, the huge variety of components present in the waste materials needed to be taken under management technique. The solid waste of urban areas comes in different ways and from various sources. According to a study of Boateng, Amoako [40] shows that about 78 % of the inhabitants, both in rural and urban areas of Ghana, practiced open dumping. The production of waste in urban areas in China per capita is about 1 kg/day [43].

In an another study of Patwa, Parde [43] shows in Iran, Shaharmahal and Bakhtiari (24 villages and 64 households) produced around 0.513 kg/day per capita of SW, with the inhabitants of around 82,562 [44]. The solid wastes are mainly 57 % cow dung, 32 % agricultural residue, and 8 % human excreta [43]. Recorded densities of the lowest solid waste were 432 kg per m^3 and 407 kg per m^3, respectively [43]. Another study by Kumar and Agrawal [26] shows the putrescible waste generation in different monsoons. The rate was 43.4 % in summer, 33.6 % in fall, 38.1 % in spring, and 42.0 % in winter [26]. Therefore, the rate of waste growth also increased in India. In 2001, the rate was 0.24 kg/day per capita, and in 2018, the rate was 0.85 kg/day per capita, which is much higher than previous years because of lifestyle, income, and so many other things [26]. Moreover, the rate has also increased in Bangladesh.

2.1. *Physical characteristics of solid waste*

MSW in developing nations is typically characterized by low calorific value, high organic matter content, and high moisture content [45]. MSW in developing nations typically comprises a high percentage of OM, such as yard waste, food waste, and paper products [46]. This is due to a number of factors, including high population densities, low levels of income, and limited access to waste disposal services. The organic content of MSW in developing countries is typically around 60–70 % [47]. MSW in developing countries also tends to have a high moisture content [48]. The moisture content of MSW in developing countries is typically around 20–30 % [49]. This is due to a number of factors, including the high organic matter content, the tropical climate, and the lack of waste collection and disposal systems. MSW in developing countries typically has a low calorific value, which means that it does not burn well [50]. This is owing to the high moisture content and the high OM content. The amount of garbage produced worldwide is expected to reach roughly twenty-seven billion tons by the year 2050, with Asia contributing one-third of the total waste [51]. China generates around 0–0.49 kg of waste person/day, while India generates 0.50–0.90 kg of waste per person per day [43,52,53]. The increase in global waste production, particularly in dismantling, construction, and commercial waste, is estimated to be 7 to 10 billion tons yearly [54,55]. The World Bank has compared the current condition to future projections and predicts that by 2050, local waste production in lower-middle income nations will more than quadruple from 2016, which ranged from 90 to 600 gm to 160–790 gm, while in

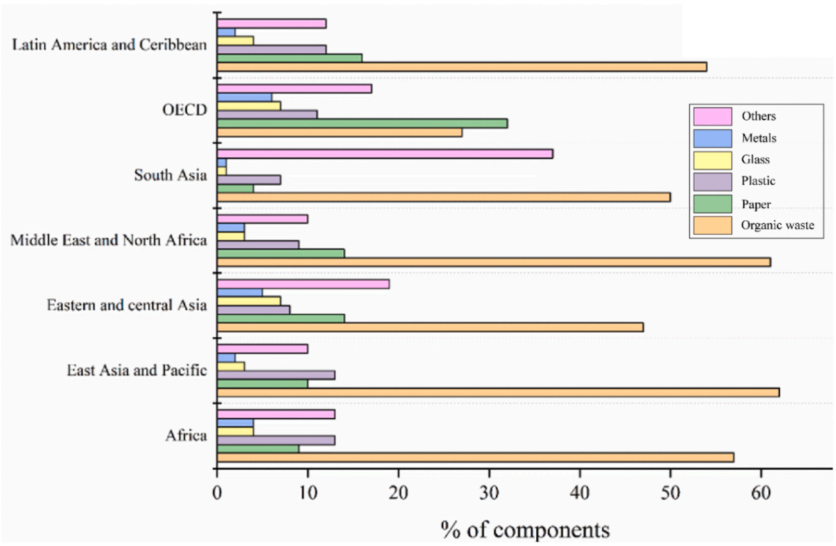

Fig. 2. Different types of solid waste around the world [36,37].

upper-middle income countries, it will increase from 100 to 1200 gm to 100–2200 gm [24]. The amount of municipal solid waste generated is impacted by various factors such as culture, geography, agriculture, financial situations, and urbanization. In Bangladesh, rubber and plastic has low calorific value; in addition, composite waste is higher compared to other waste fractions, while the values of glass and metal are zero [44,56]. Increased industrialization has resulted in increased financial and commerce activity [57]. Moreover, the percentage of the urban population has increased from 23.6 % to 37.4 % from 2000 to 2019, respectively [44]. The informal sector is primarily responsible for reusing plastics, metals, and glass, while non-government organizations (NGOs) are in charge of composting organic waste [58]. Fig. 3 highlights the energy generation from different solid waste materials. This figure shows that plastic waste produces more energy (32000×10^{-6}) compared to wood, textile, food waste and rubber waste.

Despite these efforts, the large amount of natural waste generated remains a significant concern [59]. The Bangladesh government and private NGOs have taken measures to convert waste into energy through techniques like anaerobic degradation (AD), gasification, hydrothermal carbonization (HTC), and pyrolysis. Among these methods, HTC is more financially and environmentally friendly. Proper management of MSW requires proper collection, loading, and shipment [40]. In many countries, local governments or the private sector take responsibility for collecting waste. The increasing population in most countries is leading to a rise in solid waste generation.

3. Production and management of MSW

The increasing inhabitants and development around the world are a result of an excessive increase in MSW [60]. However, many countries, including Bangladesh, Africa, Asia, the Czech Republic, China, Latin America, and the Caribbean, struggle with proper SWM strategies; moreover, in urban areas, the population and waste generation density is higher, but waste management is limited [27–30, 61,62]. The current predicament necessitates further action to address this escalating issue, which amplified waste production has exacerbated due to population growth and urbanization [39]. The accumulation, preservation, and carrying of waste is a critical aspect of SWM and treatment and needs careful consideration [63,64]. The differentiation of waste has become increasingly vital, as the proper disposal of various waste types requires unique methods of treatment [65]. Uncontrolled MSW is causing serious problems [66], and there is still much work to be done to manage solid waste effectively [67,68].

The high consumption patterns and urbanization in Bangladesh have led to a sharp growth in waste generation, creating a challenge for urban governments and organizations to manage [44]. The rate of urbanization in Bangladesh has risen rapidly, from 28.97 % in 2008 to 36.63 % in 2018 [44]. With a growing population of 164,802,127 and a yearly growth rate of 1.01 %, the country produces more waste each year [44]. In the year 2012, the frequency of waste production was 0.41 kg person/day, resulting in a total of 22.4 million tons of waste generated [44]. It is projected that this amount will rise to 47,064 tons per day, with a generation rate of 0.602 kg per capita per day, because of the growth of the people and the rise in per-person waste production. The typical effectiveness of rubbish collection in cities is around 55 %, with a range of 37 %–77 % [44,69]. Six significant cities in Bangladesh create roughly 7690 tons of solid waste daily, which consists of 74.4 % organic compound, 9.1 % paper, 0.8 % parchment and rubber, 3.5 % plastic, 1.9 % fabric and timber, 1.5 % iron, 0.8 % glass, and 8 % other waste [70]. The reasons that contribute to waste generation include population growth, seasonal changes in fruit production, way of life, weather, financial conditions, and waste management practices [71].

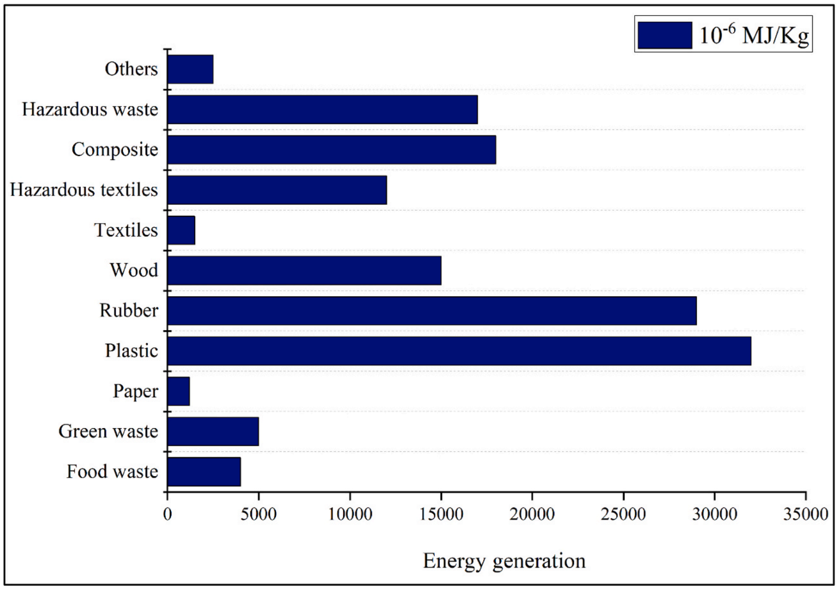

Fig. 3. Energy generation from different solid waste material [44].

4. Environmental impact of solid waste

One of the most significant contributors to climate change from solid waste is the generation of methane gas. Organic waste scraps undergo anaerobic decomposition in waste sites, producing CH_4. CH_4 is a powerful greenhouse gas that traps much more heat than carbon dioxide in the short term. Decomposing solid waste emits CH_4, a greenhouse gas with 25 times the warming potential of CO_2. CH_4 is a major provider to global warming, and it is estimated. Solid waste can also pollute the air and water. Combustion of solid waste releases harmful air pollutants, including particulate matter, nitrogen oxides, and sulfur dioxide. These pollutants can trigger respiratory problems, heart disease, and cancer. Solid waste can also leach pollutants into the water supply, contaminating consuming water and harming aquatic life [72]. Open burning of MSW releases toxic gases into the air and pollute soil and groundwater through its porosity [73,74]. The organic matter (OM) present in MSW is a significant source of methane, and burning organic waste can result in the release of substantial amounts of methane, contributing to global warming and changing the environment [75]. Additionally, OM in MSW can also harbor microbial pathogens that can cause infections in the workers and nearby communities [5,76]. Studies have found that the burning of MSW can lead to various health problems, as well as respiratory issues, gastrointestinal problems, skin irritation, eye and nose irritation, psychological disorders and allergies [77,78]. Fig. 4 highlights the environmental and health problems due to MSW. Other health risks linked to MSW include cancer, chemical toxic condition, low birth rates, nausea and vomiting congenital malformations, and neurological diseases [79], which occur when hazardous and electronic waste are mixed with solid waste.

Fig. 4. Effect of SW on environment and human health.

5. Waste-to-energy conversion technologies

Managing solid waste in rural areas is comparatively more accessible compared to urban areas due to minimum industrial waste. A significant portion of rural solid waste can be reused because of a lower generation rate, with organic waste forming the majority, followed by limited inorganic waste and no harmful waste [2]. Adequate composting and digesting technologies can be utilized to compost organic waste, while recyclable inorganic waste can be sold to federal recyclers. Table 1 presents a list of technologies that are used for generating energy from waste. Every process has its own limitations and conditions for energy production. In developing countries, separating waste can improve energy recovery and bring other benefits. Incorporating waste management techniques can result in several advantages, such as electricity generation, material recycling, and reduced requirements for waste disposal land. Municipal solid waste contains energy stored in chemical bonds that can be accessed by disruption, which can then be utilized as a fuel source or can be transformed into gas or liquid forms through thermochemical and biochemical conversions.

5.1. Thermochemical conversion

The thermochemical conversion process utilizes the concept of breaking down organic waste through heat [85,86]. The process leads to the alteration of biomass into biofuels [87]. The thermochemical transformation method often does not involve any chemical additions and can be used in a variety of feedstocks over a given period. This process encompasses methods like incineration, pyrolysis, and gasification, among others (as shown in Fig. 5).

5.1.1. Incineration for potential energy recovery

Incineration is a widely adopted method for converting waste into heat energy [88]. During the process, waste materials are burned at elevated temperatures (above 800 °C), releasing thermal energy, gases, and ash [89]. Utilizing heat, this energy can be transformed into steam to generate electricity [90,91]. Several factors influence the accomplishment of garbage incineration, including compactness, composition, water content, and the presence of inert elements in the waste [92]. The ash produced from incineration can produce building materials and cement [93]. However, the operation of incineration plants requires monitoring and treating exhaust gases, resulting in increased costs, which is a significant drawback of this method [94]. Trindade, Palacio [95] conducted a study to evaluate the potential for energy recovery and analyze the environmental impact of MSW incineration plant. Table 2 shows the general description of the incineration process. The table indicates the efficiency range of this process varies from 60 % to 90 % and several byproducts such as fly ash, bottom ash etc. are found in this process. India [96], Vietnam [97], Thailand [98] used this technique for waste management.

They evaluated the progressive exergy and ecological effect of MSW undergoing the vapor sequence in the plant, as well as energy regaining for electricity production. They determined the mechanisms and magnitude of energy demolition by determining thermodynamic performance indicators. Their findings showed that by improving the efficiency of plant components responsible for energy destruction, total energy destruction could be potentially reduced by 8.4 % [82].

5.1.2. Energy recovery by gasification

Gasification is a method that converts MSW into synthetic gas (syngas) through thermochemical conversion [103,104]. High temperatures are combined with a gasifying agent to create syngas during this process [105]. The composition of the syngas can differ based on the feedstock and conditions of the gasification process and typically contains a mixture of CO, H_2, CH_4, CO_2, and trace contaminants such as water vapor, sulfur compounds, H_2S, and NH_3 [106]. Table 3 Shows the features of different types of gasifiers. The entrained flow gasifier mainly operated in 1300–1500 °C and circulating bed gasifier operated in 750–950 °C however, the capacity is $>$ 1 MW and 1 MW or even higher for entrained flow gasifier and circulating bed gasifier respectively [87].

The gasification process comprises several stages, including moisture removal through drying, volatile components release through pyrolysis during devolatilization, and the reaction of carbon with the gasifying agent (air, oxygen, or steam) at temperatures between 760 and 1200 °C [109]. The type of gasifying agent used can affect the syngas' composition. For instance, pure oxygen gasification produces a combination of CO and hydrogen with little nitrogen, whereas utilizing air produces fuel gas with a high nitrogen concentration and little heating power [110]. Indirect gasification with steam produces a syngas dense in hydrogen and CO [111].

Table 1
Technologies used of MSW management.

Processes	Energy production	Limitations	Main products	References
Incineration	Utilizing heat	Ash production, air pollution	Heat, bottom ash, fly ash	[80]
Gasification	Utilizing syngas	Significant initial expenditure	Heat, syngas, tar	[81]
Pyrolysis	Utilizing pyrolysis and raw components	Significant initial expenditure	Heat, biochar, bio-oil	[43]
Composting	Utilizing heat	Requires a substantial time investment	Heat, compost	[82]
Dark fermentation	Utilizing microorganisms	Low energy conversion efficiency	Hydrogen gas (H_2), carbon dioxide (CO_2), and volatile fatty acids (VFAs)	[83]
Anaerobic digestion	Utilizing biogas	Significant energy expenditure	Biogas	[84]

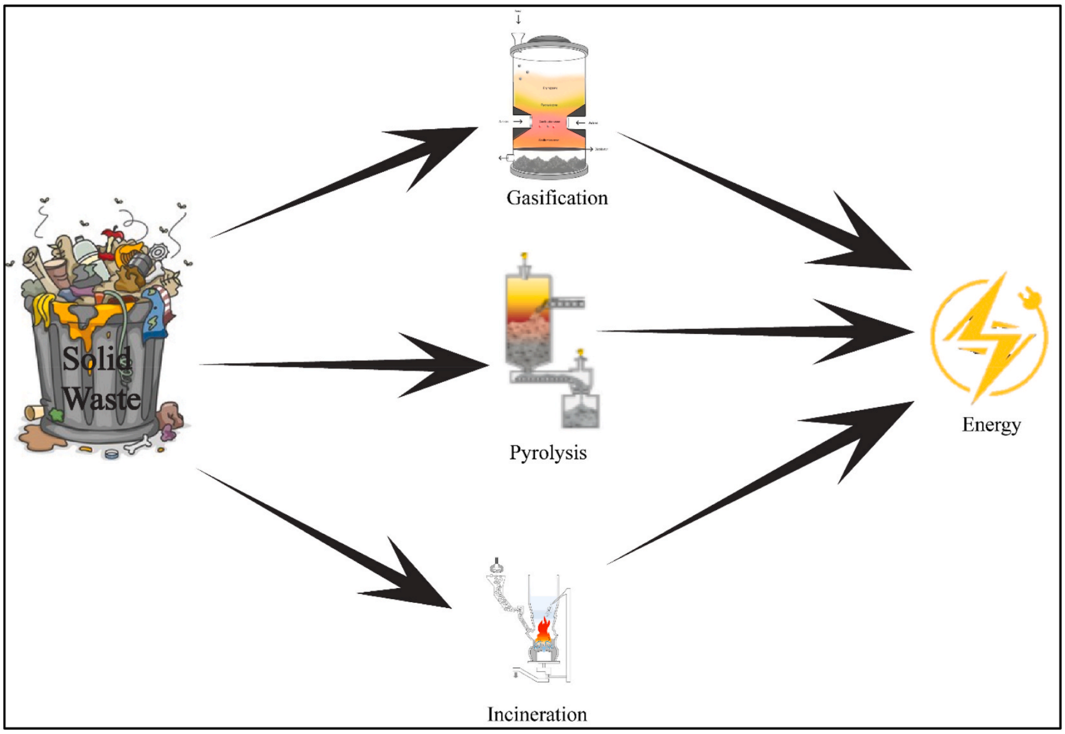

Fig. 5. Energy generation through thermochemical processes.

Table 2
General description of incineration process.

Parameter	Description	Reference
Production	181 million tons of MSW combusted annually in over 600 WTE facilities worldwide.	[99]
Emission	Dioxins, furans, heavy metals, and particulate matter are released into the air during incineration.	[100]
Efficiency	The efficiency of incineration plants varies depending on the design and operating conditions, but typically ranges from 60 % to 90 %.	[101]
Byproduct	Fly ash, bottom ash, and flue gas desulphurization (FGD) sludge are produced as byproducts of incineration.	[102]

Table 3
Characteristics of different types of gasifiers [107,108].

Gasifier type	Temperature Range	Suitable for capacities	Feed size	Scale-up potential
Updraft gasifiers	800-1400 °C	Up to 250 kW	10–100 mm	Limited scale-up
Downdraft gasifiers	800-1400 °C	20–200 kW	10–100 mm	Limited scale-up
Bubbling bed gasifier	750-950 °C	Up to 1 MW or even higher	0–20 mm	Good scale-up
Entrained flow gasifiers	1300-1500 °C	>1 MW	0.1–1 mm	Very good scale-up
Circulating bed gasifier	750-950 °C	up to 1 MW or even higher	0–20 mm	Very good scale-up

Gasification offers many benefits, such as versatility in using syngas for electricity, fuel, and chemical production and controlling the product's composition [112]. However, challenges still need to be addressed, such as simplifying the operation, scaling up to larger capacities, and making it more flexible and modular [113].

5.1.3. Pyrolysis process for conversion of waste to energy

Pyrolysis is breaking down waste through thermal decomposition without any exposure to air. Consequently, three major products are produced: liquid (bio-oil), non-condensable gases, and solid carbon residues (biochar). These pyrolysis products' production and composition are influenced by several variables, such as the reactor's composition, design, and kind of feedstock. A study explored the generation of syngas from MSW using pyrolysis with dolomite as a catalyst [114–116]. The results showed that the production of syngas ranged from 47 to 67 mol% and that the use of dolomite had a significant impact on its yield and composition [117]. It was also noted that higher temperatures lead to higher yields. According to a study of Santagata, Ripa [114]; Sharma, Dangi [115]; Singh and Kumari [116] the pyrolysis process produces nitrogen oxides (NO_x) and sulfur oxides (SO_x) due to its inert atmosphere compared to traditional MSW incineration. Japan [118], South Korea [119] use pyrolysis for their waste management. Table 4 highlights the thermochemical plants of different countries. The figure shows gasification is more effective compared to incineration and pyrolysis.

5.2. Biochemical conversion

The utilization of biomass through biochemical conversion is achieved by utilizing microorganisms, enzymes associated with various chemicals [123–125]. However, the productivity of this process is limited, and a productivity improvement requires increased capital investment, such as installing larger reactors. The process typically yields limited product diversity, requiring additional microbial cultures and enzymes for enhancement [126]. It is sensitive to temperature changes and can be negatively affected by exposure to sunlight in some cases [127,128]. Biomass sludge is often found as a by-product after the process. Table 5 shows the advantages and disadvantages of biological conversion processes.

5.2.1. Composting process for waste management

Composting is a traditional technique that is commonly used to break down organic compounds biologically through the actions of bacteria, fungi, worms and other organisms in controlled environments [129]. Although it is widely utilized, composting makes up a small portion of waste management practices, where landfilling accounting for approximately 52 % and incineration accounting for approximately 45 % [130]. One of the significant challenges associated with composting is the low yield of the final product, which often has low nutrient content and high levels of heavy metals [131]. Waste treatment facilities have become more prevalent, with 890 plants in existence by 2015 [130]. However, only a tiny fraction of these plants use composting as their treatment method.

Composting is a highly efficient way to change kitchen waste into fertilizer and can also serve as a pre-treatment step to improve biogas production. The compost can also be used as a soil or water conditioner. Nevertheless, the quality of compost from MSW is often inadequate due to a deficiency of appropriate waste sorting and the presence of impurities [26]. This can result in environmental pollution and adverse effects on human health.

5.2.2. Dark fermentation method for energy recovery

Dark fermentation is a biological energy process that can occur either in the presence or absence of light [132]. Organic matter is primarily utilized to produce hydrogen with the aid of living organisms [133]. This process converts biological energy into other forms of energy, and bioreactors are often utilized in dark fermentation due to their low cost [134]. The method offers several benefits, including the production of hydrogen from organic waste and the control and management of biological waste, which can have adverse effects on the environment [135]. Dark fermentation can also be used to produce hydrogen from wastewater, thus contributing to wastewater treatment [136,137]. The cost of production is low due to the abundant and inexpensive availability of organic waste compared to other hydrogen-producing materials. However, a drawback of dark fermentation is its lower capacity per unit of capital investment compared to other methods [138]. Additionally, as this process generates less hydrogen and emits fewer pollutants, it is considered an environmentally friendly method.

5.2.3. Anaerobic digestion technique for waste to gas conversion

Anaerobic digestion (AD) is a biological process in which microorganisms degrade organic waste in the absence of oxygen, producing methane-rich biogas and useable digestate [139]. The traditional method of anaerobic digestion of sludge is not efficient due to its long digestion period and high energy consumption [140]. To address these issues, several pre-treatment techniques such as mechanical, chemical, microbiological, and physio-chemical procedures have been employed, leading to an increase in methane generation and energy output of the AD process [141,142]. AD has several benefits, including low energy consumption during operation, fertilizer production, and the ability to generate electricity [143]. It can handle various organic waste and control unpleasant odors [144,145]. The organic fraction of Municipal Solid Waste (OFMSW) is suitable for AD since it is easily accessible and has a large amount of moisture [146]. However, the methane generated by anaerobic sludge digestion is lower than that produced by other organic waste [147]. Co-digestion, which involves adding a high methane-yielding co-substrate to the sludge, has been proposed [148,149]. This process adjusts factors like pH, C/N ratio, moisture, nutrient availability, etc. Eventually, waste organic matter and nutrients become digested, which can be used in agriculture [150]. A study by Fan, Klemes [142] found that pre-treating MSW with microwaves prior decreases energy usage and carbon emissions.

6. Perspectives and challenges

Developing a waste management method that conserves useable property and prioritizes resource recovery over waste dumping is

Table 4
Thermochemical plants of different countries.

Technology	Temperature	Capacity	Electricity efficiency	Heating efficiency	Plant location	Reference
Incineration	850 °C	450,000 t/a	24 %	6 %	Milan, Italy	[120,121]
Pyrolysis	500 °C	100,000 t/a	22 %	–	Hamm, Germany	[120,121]
Gasification	850–900 °C	250,000 tons	27 %	61 %	Finland	[121,122]

Table 5
Advantages and disadvantages of biological conversion processes.

Technology	Advantages	Disadvantages
Composting	• Nutrient-rich soil amendment • Waste reduction • Carbon sequestration • Cost-effective • Environmental benefits	• Time-consuming process • Space requirements • Odor and pest issues • Variability in end-product quality • Limited energy recovery potential
Dark fermentation	• Production of bioenergy • Utilization of diverse feedstocks • Reduced waste generation • Versatility in end-products • Potential for high-value byproducts	• Low energy efficiency • Sensitivity to process conditions • End-product inhibition • Limited scalability • Technically complex
Anaerobic digestion	• Biogas production • Waste management • Nutrient-rich digestate • Energy recovery • Reduction in greenhouse gas emissions	• High capital investment • Technical complexity • Long start-up and adaptation period • Limited feedstock flexibility • Potential for operational challenges

crucial. Waste management must be improved in developing nations as appropriate methods for collecting and disposing of MSW [151]. Waste segregation at the source and specialized processing plants for recyclable materials can lead to cleaner production. Thermochemical process is suitable for the developing countries though it is energy extensive. There is a shortage of knowledgeable, skilled people, community involvement, and responsibility in waste handling of the developing countries [152,153]. Improper collection and waste segregation, combined with a lack of recycling and treatment facilities, is a significant challenge in MSW management. The ultimate goal should be resource recovery for cleaner production, given the impact of landfilling on energy technology. Energy recovery from trash is becoming more effective and financially viable because of developments in thermodynamic and microbiological technology [154,155]. However, the adoption of innovative technology for converting trash into goods is hampered by a lack of education and awareness, as well as a lack of desire [156–158]. To drive the effectiveness of solid waste management, implementing user costs, fines, and reimbursement programs may be advantageous. Utilizing cutting-edge technology such as GIS, IoT, and information-based education and communication systems can help increase public knowledge and understanding. Effective collaboration with private entities, non-profit organizations, community organizations, and relevant government departments will be key to the future success and profitability of solid waste management in Bangladesh.

7. Conclusion

This study delves into the problems associated with solid waste management in developing nations where the expanding population burdens the municipal budget for waste disposal. Many nations have turned to open dumping sites to handle the increasing amount of solid waste. The paper summarizes various cost-effective methods for transforming waste into energy, including thermochemical methods (incineration, pyrolysis, and gasification) and biochemical methods (bio-composting). Despite these available technologies, there remains a need for sustainable waste management practices in these nations. Thermochemical method is suggested for the waste to energy conversation for the developing countries. Future research should focus on lowering the energy extensiveness of the thermochemical process. The study highlights the need for a collective effort between the public, stakeholders, and government and non-government organizations to enhance waste management facilities. AI (artificial intelligence) models like artificial neural networks (ANN), expert systems, genetic algorithms (GA), and fuzzy logic (FL) possess the capacity to address ambiguous problems, establish intricate mappings, and make predictions. Thus, AI can be used to solve solid waste management (SWM) problems.

Data availability statement

The authors declare that the data is included in the article and no additional data is available.

Additional information

No additional data and information are available for this paper.

CRediT authorship contribution statement

Shaik Muntasir Shovon: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Faysal Ahamed Akash:** Validation, Methodology, Conceptualization. **Wahida Rahman:** Writing – review & editing, Writing – original draft, Resources. **Md Abdur Rahman:** Writing – original draft, Visualization, Resources, Conceptualization. **Prosenjeet Chakraborty:** Writing – review & editing, Resources. **H.M. Zakir Hossain:** Writing – review & editing, Visualization, Validation. **Minhaj Uddin Monir:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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