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Review

A strategic review on sustainable approaches in municipal solid waste management and energy recovery: Role of artificial intelligence, economic stability and life cycle assessment

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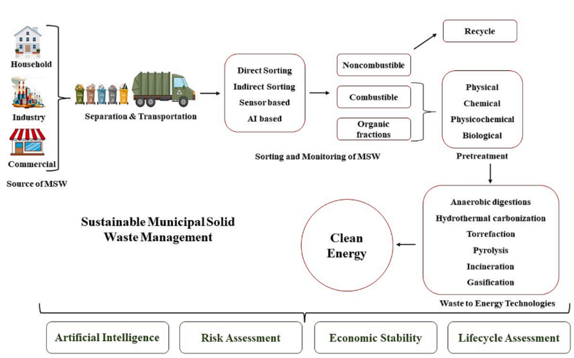
HIGHLIGHTS

- Waste-to-energy for municipal solid waste management have been presented.
- Effective waste management requires integrated technologies.
- Artificial intelligence helps to develop a sustainable waste management technique.
- Policy, economic and environmental impact analysis reduces the risk.

GRAPHICAL ABSTRACT



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ABSTRACT

The consumption of energy levels has increased in association with economic growth and concurrently increased the energy demand from renewable sources. The need under Sustainable Development Goals (SDG) intends to explore various technological advancements for the utilization of waste to energy. Municipal Solid Waste (MSW) has been reported as constructive feedstock to produce biofuels, biofuel carriers and biochemicals using energy-

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Risk assessment
Circular bioeconomy

efficient technologies in risk freeways. The present review contemplates risk assessment and challenges in sorting and transportation of MSW and different aspects of conversion of MSW into energy are critically analysed. The circular bioeconomy of energy production strategies and management of waste are also analysed. The current scenario on MSW and its impacts on the environment are elucidated in conjunction with various policies and amendments equipped for the competent management of MSW in order to fabricate a sustained environment.

1. Introduction

A recent concern is elevated due to the dramatic increase in the usage of fossil fuels that cause climate change (Ebrahimian et al., 2023). The International Energy Agency (IEA) has suggested the 2 °C scenario (2DS), which focuses on reducing carbon dioxide (CO_2) emissions by 70 % by 2060 relative to present levels (Oh et al., 2018). Researchers are continuously working towards establishing suitable alternative sustainable energy. Municipal solid waste (MSW) can be considered a potential raw source for the production of biofuels and energy. Prominently, worldwide MSW generation has grown dramatically, with predictions indicating that it will reach 3.4 billion tonnes by 2050 (Varjani et al., 2022). In the following decades, the rate of municipal solid waste generation will increase enormously. Extremely, handling and proper disposal of MSW is a critical issue, particularly in developing countries where it presents considerable risks to the environment and society (Varjani et al., 2022). Moreover, the conversion of MSW into energy should be critically analysed to tackle the barriers existing for the complete utilization towards sustainable energy production.

Wastes generated from municipalities and local authorities are categorised as municipal solid waste. This category includes trash originating from commercial and residential activities. MSW contains extremely diverse components such as plastics, papers, organic, glass kitchen waste and metals (Rajendran et al., 2021). Solid wastes have a high organic content (between 40 and 60 %), which presents a great possibility for energy recovery using the appropriate waste-to-energy technology (Varjani et al., 2022). Nevertheless, it should be emphasized that complexity and high organic contents might cause severe environmental pollution if the waste was not properly treated. Even though existing technologies related to the utilization of MSW as a source are well studied, such technologies continue to face difficulties due to the complicated designs of treatment facilities, inconsistent compositions of waste and emission of air pollution (Yang et al., 2021).

The incessant increase in MSW and the demand for fuel in the transportation field has led to the discovery of new technology called waste-to-energy technology (WTE-T) and it is a favourable technology for developing countries to convert their waste into energy (Hoang et al., 2022). Through the establishment of appropriate WTE technology, the handling of MSW could become a harsh process and simultaneously production of energy can be attained, which could directly reflect in severe circumstances of global warming and climate change situations. WTE-T has resulted in the production of biofuel from waste cooking oil, algae and other waste resources. Many communities all over the globe have recognized biofuel for providing energy security, thereby reducing the demand for fossil fuels. Government sectors have a strong mind to encourage an alternative to fossil fuels by applying a policy that supports biofuel technology and production, especially for biodiesel and ethanol. Several developed and developing countries are now investing in feasibility studies and drafting action plans for the effective implementation of WTE technology. Financial and geopolitical factors, including high fossil fuel prices, environmental impacts such as GHG emissions, and supply uncertainty from oil-producing countries have simplified the greater importance on renewable energy policy initiatives.

Recently, different strategies have been reviewed to escalate bioconversion yields from MSW through waste-to-energy technology. A review by Varjani et al. (2022) highlighted the technologies for transforming MSW into energy. Ebrahimian et al (2023) reviewed mechanisms, opportunities, and difficulties of pretreatment techniques for MSW and to improve biofuel yields. Despite the increase in review articles, a thorough analysis of the reports on waste-to-energy technology used for effective MSW conversion to biofuels is still lacking. Importantly, complex mechanisms and heterogeneous composition of MSW have hindered not only the performance of conventional pretreatment methods, such as anaerobic digestion, incineration, pyrolysis, composting and gasification but also management techniques and collection methods. These techniques have several drawbacks that are posing significant issues in the field of environment. Moreover, ineffective and inefficient MSW transportation strategies and routes require a lot of human, material, and financial resources and raise greenhouse gas emissions. In addition, the operating procedures of MSW management provide dangerous risk factors associated with human health and the environment (Cai et al., 2021). For sustainable MSW management, the aforementioned critical concerns with life cycle assessment, environmental impacts and economic stability should be addressed.

Recently, artificial intelligence (AI) techniques play an important role in providing alternative computational strategies to solve MSW problems. AI is used to manage problems, find the optimized solution and manage uncertainty. AI is linked to most the field to find and solve critical issues. In environmental engineering, AI is used in different applications such as solving environmental pollution issues, logistics, waste management, water treatment as well as planning MSW strategies (Abdallah et al., 2020). MSW treatment is a worldwide issue with economic losses and environmental impact. Most countries spend huge money on waste management and pollution indirectly crease socioeconomic problems. The economic and environmental impact analysis helps to find a sustainable MSW management technique with low emissions.

The present investigation critically analyses the exploitation of MSW towards energy production with current trends. Prominently, the role of AI towards with effective MSW management was discussed with risks associated factors. Later, environmental impacts consideration with economic stability connected with MSW management were projected. The delivered insights allow for the reduction of obstacles encountered during the implementation of various approaches to produce energy from MSW.

2. Review methodology

This literature study was conducted to identify the current trends in waste-to-energy technology used for MSW to bioenergy conversion, the risk associated with the different waste management techniques, policies in waste management techniques, and economic and environmental impacts were discussed and conclude the critical points in this sector. This literature covered the MSW characterizations, collections techniques, waste to energy technologies, AI technologies in MSW management, advantages of integrated technologies, Socio-economic and environmental risk were discussed, and critical points were reviewed.

3. Distinctive attributes of municipal solid waste

The leading step in managing any sort of solid waste is waste characterization, which is followed by acquisition, transportation, storage, processing, and disposal. Broadly, MSW can be classified into liquid, solid, gaseous and semi-solid waste. The primary benefits of characterisation are to limit or decrease waste and use proper recycling techniques to conserve resources. MSW varies in kind, source, content, and amount based on factors such as geography, economic status, culture, and so on. MSW comprises non-combustible components such as inorganics, glass, metals, etc and combustible components such as plastics, food waste, yard waste, agricultural waste, etc. (Mukherjee et al., 2020). MSW includes household trash, office waste, industrial waste, construction and demolition waste, agricultural waste, and urban garbage (Varjani et al., 2022).

MSW can also be characterized based on the physical, biological and chemical constituents. Moisture content, density and particle size are the important parameters used for the physical characterization of MSW. The chemical composition present in MSW includes phosphorous, potassium, nitrogen and carbon-to-nitrogen ratio. Understanding the composition and amount of waste generated leads to efficient waste management procedures and provides an estimate of how much energy can be produced from MSW. Most developing nations have a higher proportion of MSW generated by households (55–80 %), in contrast to the commercial sector's lesser contribution (10–30 %) (Llano et al., 2021). Both physicochemical characteristics and calorific value are essential to obtain an elevated yield of energy and safe residual from the treatment operations. Identifying the most effective processing and treatment options for MSW is quite difficult due to its heterogeneity nature (Varjani et al., 2022). Thus, pre-processing sorting is necessary for accurate evaluation and characterization, which may, in most situations, improve the effectiveness of the succeeding waste treatment procedure. Increased public knowledge, modifying behaviour of customers and community acceptability will make MSW sorting and separation easier to implement for improved MSW handling effectiveness.

4. Collection, transportation and pre-treatment of municipal solid waste

Primarily, MSW is removed from its source and transported to disposal sites, processing facilities, or transfer stations through employing collection and transportation procedures (Yadav and Karmakar, 2020). Pretreatment is an essential step for effective management of MSW that alters the characteristics of MSW to increase accessibility. Advances in collection, transportation and pretreatment are essential for implementing sustainable approaches to municipal solid waste management.

4.1. Significance of collection and transportation of MSW

The waste collection includes door-to-door, dumping in the specified location, pneumatic collection and entering the property (Zhang et al., 2022). The majority of researchers are concerned with the ultimate treatment, whereas just a few focus on the expense and environmental impact of collection and transportation. In practice, collection and transportation of MSW accounted for 50–75 % of total expenses in developed nations due to high labour intensity and widespread use of transportation technologies, whereas in developing nations like India, this percentage even reached 70–90 % (Yadav and Karmakar, 2020). Developed countries have discrete MSW mechanical collecting devices. However, informal recycling, scavengers, or uncontrolled dumping are widespread practices employed in developing countries and result in a lot of human effort and expenses towards collection (Yadav and Karmakar, 2020). Importantly, negative environmental consequences were mostly caused by unmanaged GHG emissions and odour pollutants during transportation. Thus, enhancement of current collection and transportation methods for MSW are necessary for attaining sustainable MSW management.

4.2. Significance of sorting and pretreatment technologies

Collected sources separated or mixed MSW is further subjected to assist sorting, treatment and utilization of resources. Prior to sorting, crushing and bag breaking are crucial. Sorting can be performed by using direct methods such as screw press, air separator, hydro-cyclone, disc screen etc and indirect methods such as tracer-based sorting, X-ray sorting, laser-induced breakdown spectroscopy, Optical sorting, magnetic induction spectroscopy, etc (Zhang et al., 2022). Currently, sensor-based indirect automated sorting methods were addressed by (Signoret et al., 2020). Multi-sensor coupling for precise sorting, processing of signals, and sophisticated classification algorithms also offer significant potential for research and commercialization under the challenging circumstances of factory acquisition. Common pretreatment technologies of MSW can be classified as physical, chemical, physicochemical and biological methods. Selection of a suitable pretreatment method is based on the composition of MSW (Ebrahimian et al., 2023). Table 1 represents an overview of pretreatment technologies applied on organic fraction of MSW. Usually, compaction is a pretreatment technique that utilises pressure to minimise waste volume, increase the effectiveness of treatment, and lower greenhouse gas emissions.

5. Current trends of energy production from municipal solid waste

The major issue for hygienic conditions and long-term growth in any nation is the effective planning, management and disposal of waste. Utilization of MSW for the production of energy is an effective way to manage it. Management of MSW has a significant impact on the long-term viability of the nation's economy and environment (Wang et al., 2021). WTE technologies produce energy from renewable sources, such as MSW, reducing reliance on conventional energy sources and significantly lowering GHG emissions. Developed countries have successfully implemented WTE technologies using conventional methods. However, developing countries still face many burdens for the establishment of WTE technologies using MSW (Chand Malav et al., 2020). Table 2 represents current trends in energy production from municipal solid waste. More efficient and advanced techniques can create a potential pathway for the effective utilization of MSW and can assist the establishment of alternative sustainable energy production.

5.1. Anaerobic digestion

Anaerobic degradation (AD) is the process of biodegradable organic matter being broken down by a variety of anaerobic bacteria without the presence of oxygen via a number of biochemical reactions. AD involves mainly-four biochemical phases, such as hydrolysis, acidogenesis, acetogenesis, and methanogenesis. In these phases, methane and CO_2 are produced from organic matter with help of bacteria. The major factors such as feedstock type, process parameters, total solid, volatile fatty acid accumulations, C/N ratio imbalance, ammonia inhibition, and micronutrient deficiency influence AD. Sludge-related environmental issues may be solved sustainably by using AD, which also helps produce clean, renewable energy (Lee et al., 2021). MSW can be to be converted into useful by-products including fertilisers, and electrical and thermal energy through the employment of AD. However, difficulty in degradation, complex components and heterogeneous nature create a problematic burden to the successful implementation of AD on MSW. Further, the most problematic component present in MSW under anaerobic conditions is lignin which directly affects the performance of the AD process (Zamri et al., 2021).

Quality of MSW and engaged pretreatment methods are the another important factors involved in the performance of AD. Based on organic matter segregation, solubilization, and biodegradability conditions, the quality of MSW is evaluated (Cesaro and Belgiorno, 2014). Typically, pretreatment and activation are applied to the organic fraction of MSW feedstock in order to improve and maximise the digesting activity (Paudel et al., 2017). Other parameters such as pH, carbon:nitrogen (C:N) ratio, temperature, the organic loading rate, stirring and hydraulic

Table 1
Overview of pretreatment technologies applied on organic fraction of municipal solid waste.

Pretreatment	Conditions / requirements	Impact	Reference
Physical methods			
Grinding/ chopping	Ball mill	Reduction of particle size, more energy required, composition dependant	(Liu et al., 2022)
Irradiation	Power of microwave (440–500 W),time (1–10 min) and temperature (30 – 175 °C)	Decreased energy consumption, quick heating rate, quick response time, and high polar component selectivity	(Ahmed et al., 2021)
High pressure homogenization	High pressure of 60 MPa, homogenizer	Fine structural modification and increased accessibility	(Nabi et al., 2019)
Electro dialysis	Apparatus, anion and cation exchanger, electrolytes, pH adjustment	Recovery of toxic metals and separation of ionic metals	(Zhan and Kirkelund, 2021)
Chemical methods			
Acid treatment	1 % of H_2SO_4, 60 min and 130 °C.	Lignocellulosic structures are broken down, increasing the surface area and promoting biodegradability	(Mahmoodi et al., 2018a)
Alkali treatment	3 g/L NaOH, 30 min at 125 °C	Elimination of acetyl and lignin groups, devoid of carbohydrate loss and sugar reduction, biogas production	(Ahmed et al., 2022)
Organic solvents	Acetic acid (1 %), ethanol (85 %) for 30 at 120 °C	Degrades lignocellulose fraction, increased enzymatic hydrolysis	(Ebrahimian and Karimi, 2020)
Physicochemical treatment			
Steam explosion	Pressured steam (3.5 MPa) at high temperature 240 °C, followed by a quick pressure drop to ambient conditions	Shear stress leads to break the glycosidic link, disrupts the organic structure, increased enzymatic hydrolysis possibilities	(Yu et al., 2022)
Hydrothermal pretreatment	Water under high pressure for 30 min at 160–260 °C	Water molecules penetration, degradation of lignin, hydrolysis of hemicellulose,	(Mahmoodi et al., 2018b)
Biological methods			
Fungal pretreatment	Moisture content (10 %), fungal species of *Trichoderma viride* with incubation period	Delignification can be performed using various species, prolonged time is required, additional nutrients are required.	(Kainthola et al., 2021)

Table 2
Overview of techniques for energy production from municipal solid waste.

S. No.	Technique	Overview of process	Advantages	Disadvantages	Reference
1	Anaerobic digestion	Decomposition using heat without the presence of oxygen	Produce clean, renewable energy and biofertilizer	Long operation time, operating problems and difficulty in degrade	(Lee et al., 2021)
2	High-solids anaerobic digestion	Same as anaerobic digestion but can handle high organic contents	Devoid of clogging problem, less water utilization and production of high-quality digestate	Difficult in operating parameter	(Ting et al., 2020)
3	Hydrothermal carbonization	High pressures and temperatures about 200–260 °C with subcritical water	Hydrolysis, dehydration and decarboxylation occurs, reduction of OH CO and COOH groups, production of biogas and char	Handling problems with organic fraction of MSW	(Gupta et al., 2021)
4	Torrefaction	Gradual heating of biomass between 200 and 300 °C in an oxygen-free or inert atmosphere	Lower moisture content, higher energy density decreased O/C ratio and increased heating value	Loss of energy, difficulties in process control	(Gouws et al., 2021)
5	Pyrolysis	External energy applied to disrupt chemical bonds, heating upto 1000 °C without the presence of oxygen	Can handle mixed MSW, production of syngas, char and pyrolysis oil	Toxic gases emission, low performance, elevated cost	(Lee et al., 2020)
6	Plasma pyrolysis	High temperature, almost oxygen-free breakdown of waste component's molecular bonds into slag and gases	Requirement of low area, very quick process, supply of oxygen is not essential, waste volume reduction, production of fuel hydrogen, syngas, less toxic emission	Requirement of high energy and maintenance	(Bhatt et al., 2022)
7	Incineration	Direct Combustion with an Adequate Supply of Air and Oxygen	Quicker than biological processes, heat is released	Release of toxic substances, SOx, CO_2, NOx, elevated cost	(Wang et al., 2022)
8	Gasification	Requirement of heat and a low oxygen environment	Syngas production, accumulation of char and tar	Release of toxic compounds, elevated cost	(Valizadeh et al., 2022)

retention time have an influence on the performance of AD of MSW (Zamri et al., 2021). Several researchers have concentrated on pretreatment, co-digestion, additions of conductive materials, and enzymatic procedures towards the enhancement of AD performance (Ahmed et al., 2021).

Increased biomethane/biogas production can be obtained using notable techniques. Usually, the organic fraction of MSW contains both liquid and solid fractions. Polyhydroxyalkanoate production was reported from the liquid portion of the organic fraction of MSW. When compared with AD employed on OFMSW, which increased energy recovery from the solid portion of MSW (Papa et al., 2022). But the problems associated with low energy production should be considered when additional processing is engaged, which directly reflects on commercialization.

Rate-limiting step in AD is inadequate hydrolysis because of the rigid structure of extracellular polymeric molecules. Additionally, the carbon to nitrogen (C/N) ratio was less, AD hindrance occurs due to the accumulation of ammonia. To overcome this phenomenon, Jiang et al. (2022) attempted the co-digestion of municipal waste with vegetable waste which resulted in reduced humidification after co-digestion. Simultaneously, low levels of total ammonia nitrogen accumulated after co-digestion (Jiang et al., 2022). Thus, anaerobic co-digestion can be beneficial for resource recovery and the synergistic disposal of organic wastes.

5.2. High-solids anaerobic digestion

Due to its inherent benefits for digesting organic fractions of MSW, high-solids anaerobic digestion (HSAD) has received significant attention (Ting et al., 2020). HSAD systems work with organic solid wastes that have greater total solids contents (usually 20–40 % TS) than wet-type anaerobic digesters (normally with 10 % TS concentration) (Fagbohungbe et al., 2015). However, the fundamental biological processes of HSAD remain the same as the wet type. In typical wet-type AD systems, high solid contents and heterogeneity organic MSW may lead to clogging problems (Ting et al., 2020). Less water utilization, managing greater organic loading rates, reduced heating costs, and the production of high-quality digestate without the need for specialised dewatering techniques are some of the main advantages of HSAD systems (Fagbohungbe et al., 2015). Even though HSAD systems are regarded to be the most suitable for organic solid wastes, the problems associated with HSAD should be considered. Engagement of HSAD on MSW could result in substantial accumulations of volatile fatty acids and ammonia, which inhibited microbial growth and caused operational instability (Zhang et al., 2015). Operational variables such as the ratio of feedstock to inoculum, source of inoculum, and co-substrate mixing ratio need to be considered for the successful long-term functioning of HSAD (Lee et al., 2019).

Recently, the HSAD system was engaged for MSW containing organic fractions and the effect of percolate recirculation time (PRT) and ratio of feedstock to inoculum (F:I) were analysed (Dastyar et al., 2021). Importantly, F:I ratio has been reported to be more important than PRT and interestingly, the generation of volatile fatty acids at a F:I ratio of 3 kg volatile solids /kg volatile solid resulted in noticeably lower the production of methane (Dastyar et al., 2021). In contrast to wet-type digesters, the heterogeneous and changeable physicochemical properties of organic fraction MSW might still suffer from various restrictions like reduced biomethane production (Dastyar et al., 2021) and biochemical kinetics (Fagbohungbe et al., 2015). More studies related to the effect of process parameters on MSW using HSAD systems should be investigated.

5.3. Hydrothermal carbonization

Recent research has shown that hydrothermal carbonization (HTC) can be used as a viable option for the synergetic recovery of water and organic matter from digestate obtained from MSW (Motavaf et al., 2021). HTC is carried out at high pressures in enclosed vessels with various hydrothermal conditions (Huezo et al., 2021). Hydrolysis is the first step in the HTC process, accompanied by dehydration and decarboxylation (Reza et al., 2014). The application of HTC on wet biomass obtained from MSW can improve mechanical dewatering (Aragon-Briceño et al., 2022). The presence of OH groups is reduced due to dehydration and subsequently, a decrease in O/C ratio can be attained. Similarly, CO and COOH groups are reduced due to the process of decarboxylation (Funke and Ziegler, 2010). Conversion of biomass into carbon-rich solid fuel depends critically on operating conditions during HTC. To produce hydrochar with the required qualities, factors such as temperature, moisture rate, heating rate, residence time and filling ratio should be considered. Moreover, understanding how water interacts at higher temperatures is essential because the HTC process occurs with the presence of water (Wang et al., 2018).

Recently, an anaerobic digester of MSW was subjected to the HTC process and positively improved the dewatering process under the process conditions at 200 °C for 120 min (Aragon-Briceño et al., 2022). In another study, biomethane production was reported from combining AD of MSW with HTC under the process condition at 180 °C for 60 min. (Lucian et al., 2020). It created the potential of hydrothermal carbonization process towards promising valorization of MSW. The major barrier to the successful implementation of the HTC process is other than organic compounds should be separated from MSW (Wu et al., 2021b). Studies related to a combination of the anaerobic digester with HTC on MSW are not explored well. Importantly, extensive research needs to perform to acquire the influence of various parameters involved in the HTC process. The effluent obtained from HTC has a notable quantity of organic compounds and can be easily digested with other substrates. Furthermore, the HTC process can alter the inorganic fractions present in the biomass through the extraction of elements like phosphorous. Biogas production can be enhanced through the employment of the HTC process. In addition, biochar can be obtained as solid fuel from the leftover biomass (Aragon-Briceño et al., 2022).

5.4. Torrefaction

For the pre-treatment of a variety of biomass resources, such as MSW, forest wastes, non-woody, and woody wastes, multiple research have employed the promising, practical, and environmentally friendly thermochemical process known as torrefaction (He et al., 2019). Torrefaction is differentiated by its slow heating rate of under 50 °C/min and comparatively low reaction temperature, which ranges from 200 to 300 °C in an atmosphere devoid of oxygen (Mohd Fuad et al., 2019). Enhancing the calorific value or energy density of feedstock is the primary goal of torrefaction. By lowering oxygen-to-carbon, hydrogen-to-carbon ratios and moisture content of biomass and increasing fixed carbon, torrefaction improves the hydrophobic property of biomass (Abdulyekeen et al., 2022). The torrefaction process is greatly influenced by process parameters such as residence time, heating rate, biomass type, initial moisture content and particle size (Mohd Fuad et al., 2019). Recently, on the basis of mechanical fluidization, the feasibility of generating high calorific value solid fuel in a specialized fluidized bed reactor was reported (Abdulyekeen et al., 2022).

Due to reduced energy consumption and cost, flue gas torrefaction gained increasing interest as a unique oxidative torrefaction (Uemura et al., 2017). Nitrogen oxides were decreased and the fuel characteristics of distilled spirit lees were improved as proceeded with flue gas torrefaction (Zhu et al., 2021). All of these studies concentrated on biomass feedstock. However, MSW has a complicated composition when compared to biomass flue gas torrefaction of MSW likely faces various challenges. Remarkably, the torrefaction of MSW improved its fuel qualities (Rago et al., 2020). Recently, increased higher heating value and energy density were reported using flue gas torrefaction of MSW. Additionally, the effect of operating parameters for optimal flue gas torrefaction was analysed (Zhu et al., 2022).

5.5. Pyrolysis

Thermal breakdown of organic material without the presence of oxygen is known as pyrolysis, and results in gas, liquid, and solid by-products. The three main stages of pyrolysis are initiation, propagation, and termination. (Sipra et al., 2018). The pyrolysis process converts biomass contents present in MSW into syngas, pyrolysis oil and biochar and is usually operated at 400 – 1000 °C (Lee et al., 2020). Various kinds of MSW, including mixed, plastics and paper are thermally degraded by the permanent process of pyrolysis (Hasan et al., 2021). The yield and composition of the products produced by pyrolysis vary depending on a variety of factors, including temperature, reactor system, feedstock type, heating rate, residence time of the gas, contact time, pressure ranges, impact of any catalysts present and the presence of hydrogen gas or compounds that produce hydrogen (Sipra et al., 2018).

Pyrolysis can be classified into slow, fast, microwave-assisted and catalytic processes. Research has often been conducted using rapid pyrolysis due to the lower processing efficiency of slow pyrolysis (Sipra et al., 2018). Importantly, microwave-assisted pyrolysis eliminates the requirement for shredding by applying direct heat to the feedstock. Due to its affordable production, adaptable manufacturing technique, and simple equipment transportation, it can be utilised for large-scale commercialization. Table 3 presents the yield of pyrolysis products obtained from MSW. Significant amounts of organic waste such as wood, food and garden waste are included in MSW. When burnt, the trash produced by the photosynthetic process, such as wood waste, absorbs the same quantity of CO_2 from the atmosphere that it previously consumed. Hence, there is no overall impact (Grycová et al., 2016).

Table 3
Yield of pyrolysis products from various municipal solid wastes.

S. No.	Chief component of MSW	Reactor type	Pyrolysis process	Operating conditions	Yield of products Syngas	Biochar	Biooil	Reference
1	Mixed	Batch	Fast	At 450 °C, 30 min, 2 cm^2 of particle size with 10 °C /min heating rate	42 %	18 %	40 %	(Miandad et al., 2017)
2	Mixed	Batch	Fast	At 450 °C, 75 min, 2 cm^2 of particle size with 10 °C /min heating rate	69.9 %	5.1 %	25 %	(Miandad et al., 2017)
3	Plastic	Fixed bed	Slow	At 400 °C, 60 min, 5 – 10 cm of particle size	50 %	28.6 %	21.4 %	(Gandidi et al., 2018)
4	Paper	Fixed bed	Slow	At 600 °C, 60 min with 4 °C/min heating rate	22 %	27 %	48 %	(Sarkar and Chowdhury, 2016)
5	Mixed	Fixed bed	Catalytic	At 600–750 °C, 2 mm of particle size	56.6 %	32.4 %	10.8 %	(Tursunov, 2014)
6	Mixed	Continuous	Microwave assisted	At 750 °C, 2.45 GHz of frequency, 3 kW of microwave power	45.5 %	74.9 %	1.2 %	(Zhou et al., 2022)
7	Organic	Fluidized bed	Microwave assisted	At 650 °C	35 %	54 %	35 %	(Liu et al., 2020)

A thorough investigation of the product yield from the pyrolysis of organic MSW was reported by Yang et al. (2018). After being crushed, the collected MSW was dried at variable moisture percentages between 12.7 and 45.8 %. In an auger screw reactor, the pyrolysis was executed at variable temperatures of 450–850 °C with a set feeding rate of 300 g/h. At a temperature of 700 °C, about 40 % bio-oil, 22 % biochar, and 38 % syngas were produced. The production of syngas and bio-oil showed a divergent pattern with temperature increase. The moisture content had very little impact compared to the pyrolysis temperature. Lastly, in order to maximise the production of bio-oil and minimise energy consumption, MSW with a low moisture content should be utilised in the pyrolysis process (Yang et al., 2018). Although the by-products generated by a pyrolysis process often have characteristics comparable to fuels, pyrolysis on MSW is primarily intended to produce energy. Importantly, households can utilise MSW as a source of energy by using the pyrolysis process and larger-scale pyrolysis facilities could operate more efficiently to the energy products produced during the process.

5.6. Plasma pyrolysis

Plasma technologies provide a viable approach for handling waste due to the efficient utilisation of electrons and ions and the resultant high energy densities (Sanito et al., 2023). Very high temperatures and a lack of oxygen, or a nearly complete lack of oxygen, are required for the plasma pyrolysis process (Bhatt et al., 2022). The solid waste particles are converted to hydrocarbons, non-leachable solid residue and syngas at high temperatures. Plasma technologies also provide advantages related to fast start-up and shutdown mechanisms without the need of fuels or oxidants (Pei et al., 2020). Another beneficial aspect of plasma pyrolysis is the tremendous decrease in the enormous quantity of waste (Bhatt et al., 2022). In contrast to other biological processes, it can also handle all major forms of waste including MSW and quick treatment time with less area for the process (Mašláni et al., 2021). Recently, plasma pyrolysis was successfully applied to various waste streams such as polymer waste, petrochemical waste, polypropylene and waste tires (Bhatt et al., 2022). Only a few studies were engaged to investigate plasma pyrolysis on MSW. As most of the components in MSW may be related to one or more of the aforementioned other wastes, MSW can also be effectively treated by utilising plasma pyrolysis to produce syngas. As a safe solution for the environment, plasma pyrolysis may cure MSW without causing any harm.

5.7. Incineration

Incineration involves the presence of adequate air and the complete burning of solid waste at temperatures ranging from 980 to 2000 °C, which effectively converts chemical energy contained in MSW into heat energy and produces power using a turbine-generator system (Wang et al., 2022). Incineration is primarily dependent on the characterization of MSW and is greatly influenced by variations in demography, seasons and sociocultural activities (Sebastian et al., 2019). However, the major difficulties associated with MSW incineration are variations in operation conditions, the uncertainty of input composition of MSW and long-time operation with optimized conditions. More importantly, inert waste and moisture content lower the calorific value of MSW and have an impact on its combustibility (Prajapati et al., 2021). Drying incineration, recovery of energy from combustion, and exhaust gas purification are the steps involved in the incineration process. As heterogeneous operating conditions are practised in MSW incineration, complications exist related to practising simulation software. Hence, diverse simulation conditions need to be developed for the successful execution of MSW incineration. Customized mathematical simulations near the real operating process are obligatory. When it concerns the safety and prolonged usage of incineration units, the appropriate simulation may be utilised to validate the optimum control algorithm designed offline.

5.8. Gasification

Gasification is a thermochemical technique that transforms carbonaceous material such as biomass using heat and a low-oxygen environment (Valizadeh et al., 2022) Gasification converts MSW into a blend consisting of carbon monoxide, hydrogen, carbon dioxide and trace quantities of methane, known as synthetic gas (syngas) and might be used to generate power in fuel cells or as fuel in motors and turbines after cleaning (Lee, 2022). The chief by-product of gasification is syngas, however, additional gases such as CH_4, CO_2, and other products ash particles, char and tar are also produced (Ramos et al., 2020). Depending on the reaction parameters, the H_2 and CO content of the gasification processes can be changed. In addition, syngas can be utilised in catalytic conversion to produce liquid fuels, intermediates of chemicals and a wide range of final products (Guran, 2018).

Currently, investigations related to gasification from MSW were concentrated on novel catalyst development, improving reaction conditions and chemical looping gasification. The quality of syngas from MSW was enhanced by altering the process conditions such as interactions between volatiles and the production of chars reported. Importantly, raising the temperature, including additional char, and decreasing air flow rate enhanced gas productivity (Veses et al., 2020). Catalytic gasification of MSW using a Ni-CaO catalyst was reported. Novel catalysts were synthesised by dc melting plasma with TiO_2 to improve stability and successfully converted the generated CO_2 to H_2 for the improvement of high-quality syngas. Subsequently, H_2 concentration was improved from 35.1 % to 57.7 % using a Ni-CaO catalyst (Irfan et al., 2019).

5.9. Composting and vermicomposting

Composting and vermicomposting are commonly used techniques to manage MSW and organic fertilizer. Composting is an aerobic degradation of organic waste using microbes under the optimum condition. Bacteria, fungi and actinomycetes are widely used for aerobic composting. Aerobic composting is performed in two methods pre- and post-fermentations. MSW is commonly used post-fermentation (Saravanan et al., 2022). Some previous studies show the heat energy recovery from the composting process. The energy recovery from the commercial-scale composting unit was investigated. The temperature of compost vapor between 51 and 66 °C resulted in recovery rates of 17,700–32,940 kJ/h (Smith and Aber, 2018). Vermicomposting and aerobic composting are used to treat different types of MSW (Bhattacharya et al., 2016). Vermicomposting is an eco-friendly and economic method to convert solid waste residues into value-added products using earthworms. *Eisenia fetida* is commonly used in the vermicomposting process (Mondal et al., 2020; Paul et al., 2019). Vermicomposting is used as an energy recovery for the regeneration of soils, and energy as liquid and combustible gases. The end-product of vermicomposting is called vermi-wash which contains large amounts of humic acid used for electricity production in microbial fuel cells technology (Khan et al., 2022).

5.10. Integrated technologies

In order to address respective limitations and properly use the process energy and resources, numerous researchers have recently attempted to integrate technologies applied to MSW. The employment of pyrolysis on digestate obtained from AD resulted in fruitful outcomes of increased overall energy efficiency (Chen et al., 2021). Alternatively, products obtained from pyrolysis majorly contain organic materials in bio-oil such as C_2-C_6 sugars, hydroxy acids, oligomers, and water-soluble phenols. These substances can be employed as substrates for AD to produce biogas to help offset the energy needed in pyrolysis (Feng and Lin, 2017). Wu et al. (2021a) integrated bacterial cellulose production and vermicomposting with the AD process. The biochar from vermicomposting is used in the AD process to improve digestion. Earthworm biomass, vermicompost and bacterial cellulose were produced from kitchen waste. The multi-product approach helps to develop sustainable technology (Wu et al., 2021a).

Recently, AD coupled with pyrolysis was reported in MSW which was proved to be eco-friendly in process circumstances. Simultaneously, it resulted in increased production of energy and subsequently may lead to reduced solid digestate emission (Wang et al., 2021). In another study, Panepinto et al. (2015) evaluated the processing of MSW gasification, pyrolysis, and incineration and concluded that gasification might be a competitive technique when syngas production is taken into account in aspects of valorisation of energy as well as the flexibility of design (Panepinto et al., 2015).

HTC of MSW can be combined with pelletization to increase hydrochar production, as rising temperature and prolonged time leads to affect (Bhakta Sharma et al., 2021). HTC often results in hydrochars with limited surface areas, which makes it less suitable for soil additions and other plans to valorize solid carbon. Biochars derived wastes like lignocellulose biomass have larger surface areas (Volpe et al., 2018). Nevertheless, if biochar can be utilised as a soil amendment, fertilisers need to be added due to the poor nutritional content of most pyrolyzed biomasses. To address these drawbacks, a thermochemical process consisting of HTC combined pyrolysis was reported in which hydrochar produced from cow manure was used to enrich nutrients of biochar and simultaneously biooil can be produced (Lin et al., 2021). Such an integrated system of MSW can lead to upgrading value-added products such as biofertilizers.

Biofuels such as bioethanol, biobutanol and biohydrogen were produced from MSW using the co-cultivation of fungal species such as *Mucor indicus* and *Clostridium acetobutylicum*. By-products such as succinic acid, acetic acid and acetone were applied for the pretreatment of MSW (Ebrahimian et al., 2022). Employing an organic fraction of MSW as a low-cost feedstock and producing biofuels and necessary chemicals like acetic acid and acetone for pretreatment, using a biorefinery framework, led to a successful bioprocess that may circumvent the main bottlenecks of biofuel manufacturing processes as well as MSW management. Thus, there is a high possibility for integrated technologies on MSW in future. More studies taking into account integrated technology duration, plant size and purification technique are required to examine the sustainability of proper utilization of MSW.

6. Municipal solid waste management

6.1. Global scenario on municipal solid waste management

Globally, the concept of WTE-T from MSW is a debated issue and postulated method to divert MSW from active landfills. Due to land availability, landfill continues to be the traditional and most economically feasible alternative for the global MSW stream (Mukherjee et al., 2020). Although there are many technologies for MSW treatment available to produce energy, there is a significant gap in the use of WTE-T policy. This is primarily because creating durable facilities is quite expensive and has financial risks. However, the economic benefits of treating MSW and energy production should be considered with environmental impact for successful implementation. Many techno-socioeconomic impact elements are required for the adoption of WTE technology from MSW. The essential technological variables are the MSW's composition, energy content and volume as well as the plant's operating parameters with regard to thermodynamics, chemistry and total energy output efficiency. Critically, advanced knowledge of innovative technologies like AI can improve the effectiveness of MSW management activities towards WTE technology. Risk assessment strategies related to the management of MSW create an absolute impression.

6.2. Role of Artificial intelligence towards prosperous municipal solid waste management

AI has quickly risen to become among the most game-changing innovations in recent times (Andeobu et al., 2022). AI is being utilized in many industries and is quickly becoming the foundational technology that organisations and governments need to enhance their operational efficiency and financial success (Cugurullo, 2020). Many countries have chances to continue to be prosperous and globally competitive thanks to AI. Future AI development will be significantly shaped by how civilizations use and interact with it.

The top five AI technologies used for modelling and solid waste management process optimization are as follows: Artificial neural networks (ANN), support vector machines (SVM), decision trees (DT), linear regression (LR) and genetic algorithms (GA) (Guo et al., 2021). Planning and a strategic roadmap for execution are necessary for effectively managing the accumulation of MSW. Prediction of accurate MSW accumulation using AI is a crucial prerequisite for effective waste management (Yigitcanlar and Cugurullo, 2020). AI technology can be used by waste management organizations to monitor trash containers all over the city (Ortega-Fernández et al., 2020). The sorting process is where AI plays another significant role in MSW management (Gundupalli et al., 2017). The use of AI in intelligent sorting involves autonomously scanning MSW with cameras, analysing the data using deep learning algorithms, and providing compositional analysis to assist SWM management facilities (Gundupalli et al., 2017). Fig. 1 represents the role of AI towards the sustainable management of MSW.

For many cities, the cost of garbage collection often accounts for between 70 and 85 % of total SWM expenses. Unplanned collection patterns and inadequate truck allocation lead to unneeded traffic jams and delays, which also raises operational expenses. (Singh and Satija, 2018). Whilst the technology for smart garbage collection is still in its

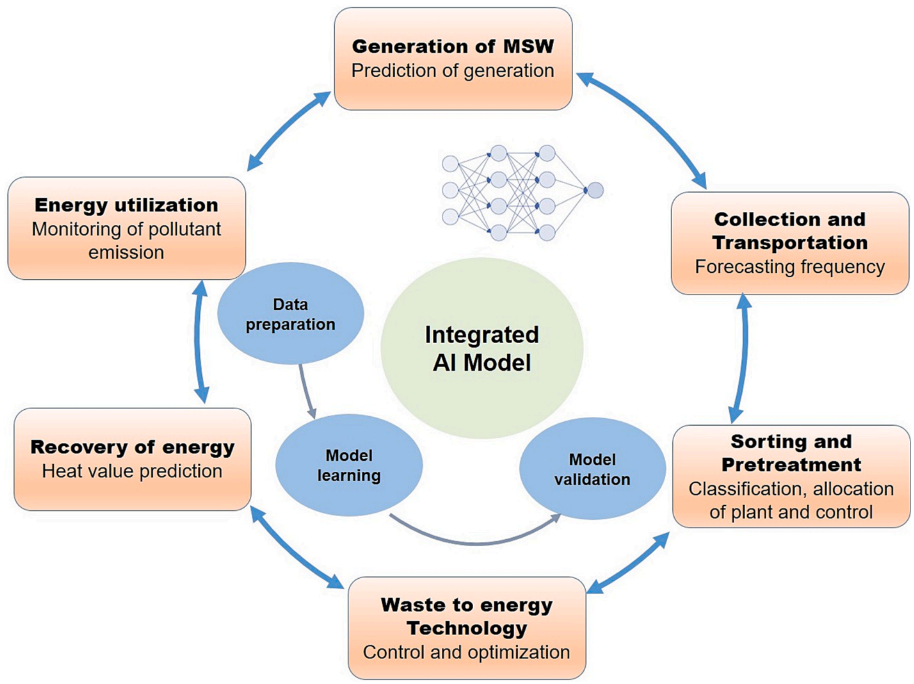

Fig. 1. Role of AI towards sustainable management of municipal solid waste.

early stages of development, new approaches are being developed and practised. ANN models can be used to forecast the necessary frequency of collection at various sites. Optimization of waste collection routes using a geographic information system and waste prediction model using ANN was reported (Vu et al., 2019). The analysis showed how the characteristics of waste items' composition impact the distance, time and air emissions of an optimum truck route.

Prediction of process output and process parameters are used to explore the use of AI models in MSW management. It is crucial to quantify both safe and harmful byproducts, including leachate and other pollutants, as well as helpful byproducts like energy and biogas. (Andeobu et al., 2022). Many research have been reported to use AI models for forecasting the volume and make-up of various by-products produced by solid waste (Andeobu et al., 2022). However, studies related to MSW are not well explored and need to be analysed in future. Recently, ANN was employed to optimize the process conditions involved in the production of energy from landfill waste components. Factors such as pressure and temperature were successively optimized by ANN model (Alrbai et al., 2022).

The design and operation of waste-to-energy technology are reliant on process variable modelling and optimization. A few research have been looking at the application of AI to estimate the process variables of MSW management. The genetic algorithm was used to predict nitrogen losses and maturity during composting of waste materials. Additionally, estimating nitrogen losses across all reactors was done using a both linear and nonlinear approaches based on a cascaded forward neural network. The genetic algorithm was used to identify the ideal parameter values for the composting process (Kabak et al., 2022).

Recently, an admirable work was reported using ANN, gradient boosting tree (GBT) and random forest (RF) for the prediction of hydrothermal carbonization parameters. Municipal sludge composition was analyzed for carbon recovery, energy production and increased heating value (Zhu et al., 2023). This study showed municipal sludge as a potential candidate for energy production. Studies related to the utilization of mixed MSW combined with AI tools should be engaged. Table 4 highlights the potential AI techniques used for sustainable MSW management. More analysis needs to be investigated in the future and subsequently such AI techniques can be expanded further to take into account additional MSW treatment techniques combined with energy production. This will result in a more conceptual system that will precisely direct the management of MSW in the most efficient and sustainable way possible to increase the reduction of carbon emissions in the waste recycling industry. Thus, an appropriate AI tool can be utilised as a valid and reliable tool for forecasting energy production, and by improving this tool, parameter values that would result in successful MSW management.

6.3. Risk assessment in management of municipal solid waste

Adopting a planned strategy and ensuring risk management are the primary goals of risk assessment (Yang et al., 2020). The process of identifying hazards that might result in long-term harm detection is connected to risk assessment. Transporting and processing of MSW includes a number of risks, including chemical, mechanical, and biological threats and health issues (Chowdhury et al., 2019).

6.3.1. Chemical risk factors associated with management of municipal solid waste

In the informal handling of MSW, direct contact with chemicals existing leads to higher chemical risk and particularly, blood and skin infections are more likely to occur as a consequence of skin irritation and intoxication (Rincón et al., 2019). Any kind of exposure, including skin contact or inhalation, may result in dermatitis, renal failure, liver damage, and central nervous system disorders. Inadequate disease classification, lack of awareness and a long time before the impact become apparent are major chemical risks directly associated with negative consequences (Ma et al., 2018). Unsegregated MSW contains old batteries and waste electrical components from radios, TVs, fluorescent lights, phones, and computers. It might lead to MSW containing lead, mercury, and cadmium (Udofia et al., 2017). Chronic exposure to heavy metals may have negative consequences that can lead to cancer and harm to the digestive system. Acute inhalation of any metal dust affects the respiratory system, leading to pulmonary inflammation (Shi et al., 2020). By considering the consequences of chemical risks associated with MSW, a proper management system should be engaged.

Table 4
Role of Artificial Intelligence towards management of municipal solid waste.

Stage of MSW management	Potential AI technique	Input factors	Benefits	Output	Performance indicator	Restrictions	Reference
Sorting of MSW	Multi-Layer Perceptron (MLP)	Images of collected waste	Simple to set up and train, supports adaptive learning, useful for huge data sets and effective for solving prediction issues	Types and volume of MSW can be predicted	Accuracy and sensitivity	Inappropriate for difficult tasks, complexity in computing and duplication problems	(Islam et al., 2014)
Classification of MSW	Deep convolutionalneural network (DCNN)	Images of collected waste	Architecture is adaptive to new issues, features are consequently decided	Classification of waste	Operative with accuracy, sensitivity and error rate	Large amounts of data are required, and the complicated structure makes it difficult to train and interpret.	(Altikat et al., 2022)
Generation of MSW	Artificial neural network (ANN)	Socioeconomic variables like general public budget expenditure, GDP per capita, disposable income	Contains distributed memory system, hold data on the whole network, responding to noise, generating output even with malfunction.	Prediction of quantity MSW generated	Root mean square value, correlation coefficients	Additional processors requirements, network behavior cannot be explained, Inability to define the right network structure	(Qin et al., 2021)
	Support vector machines (SVM)	Unit family, population, employment data	Effective memory management, function with maximum marginal separation and nonlinear data handling	MSW projections and future forecasts	Root mean square value, correlation coefficients	Requires characteristics scaling, unsuitable for huge data, Unsatisfactory for noise	(Ayeleru et al., 2021)
	Decision tree	Variables of demography and socioeconomy	Easy to understand and interpret, less effort for the preparation and cleaning of the data, devoid of normalization of data	Quantification of MSW	Root mean square value, correlation coefficients	Influenced by noise, requires additional training time	(Kannangara et al., 2018)
	Genetic algorithm (GA)	Variables of demography	Readily adaptable to various issues, simple to interpret, supportive of multiple optimization goals	Assessment of environmental impacts	Root mean square value, correlation coefficients	More time and effort are needed for computation, and gradients cannot be used.	(Pourreza Movahed et al., 2020)
	Linear regression	Values of independent variables	Quick and simple understanding, minimal computing expenses	Predicting recovery of compositions	Correlation coefficients and root mean square	Inappropriate for nonlinear data modelling	(Hosseinzadeh et al., 2020)

6.3.2. Mechanical risk factors associated with management of municipal solid waste

Piercing, metal cuts, scraping and bruising from coming into touch with sharp waste cause MSW in terms of mechanical safety in many places. The additional threats, including glass bottle fragments, landfill fires, sharp-edged containers, etc., provide certain safety issues for the local workforce. An incident involving a safety-related injury is a serious problem. Personal protective equipment, personal protective clothing and safety warnings all refer to various methods that are associated with the reduction of mechanical risks while handling MSW. To handle a greater degree of complexity of smoke and dust, personal protective equipment such as dust masks and respirators are required (Wassiem et al., 2021).

6.3.3. Biological risk factors associated with management of municipal solid waste

Biological agents, such as viruses and bacteria, which cause waste contamination and are often derived through the breakdown of waste materials and eventually result in diseases, might infect personnel during the management of MSW (Fei et al., 2018). The proliferation of flies and mosquitoes from sites MSW is a critical biological risk that also includes water-borne illnesses (Lima et al., 2018). Propagation of hazardous materials through leaching from unregulated MSW management sites could contaminate water supplies and can cause severe health problems. Close communication with MSW including animal feeding waste may cause blood and skin infections (Kasemy et al., 2021). Prolonged-term exposure to contaminated air may result in allergy illnesses.

6.3.4. Health risk factors associated with management of municipal solid waste

Risk to human health occurs with the collection of MSW from an unregulated region that contains biological waste that has degraded or compounds that are contaminated with pathogens (Istrate et al., 2020). Risks of improper MSW disposal in terms of soil, water, and air pollution, as well as the resulting health consequences on people living nearby, have been emphasised by the World Health Organization (Vinti et al., 2021). If municipal solid waste (MSW) is not properly handled via separation, collection, transport, processing, and removal or recycling and reuse, it creates a hazard to human health. Due to a lack of readily available healthcare resources, the accumulated waste in various locations that are subjected to adequate collection and reuse techniques poses a variety of health risks that may be difficult to address. Health threats include infections spread by mice, fliers, and cockroaches, and an increase in odours (Istrate et al., 2020). Still, opportunities exist to analyse the prudent strategy related to health risk factors associated with the management of MSW.

6.3.5. Ergonomic risks factors associated with management of municipal solid waste

In order to dispose of MSW, the personnel responsible for handling and acquiring waste must not exceed the advised limits, deviations in this phenomenon could lead to making harmful effects. Repetitive motions, carrying large loads, shovelling, managing heavy objects, and being exposed to extreme temperatures are some examples of ergonomic risks. These activities may also lead to muscular and bone disorders. Even hearing loss can occur due to loud noises exposures. The greatest ergonomic risk is caused by uncomfortable postures, forced exertions, heavy loads, bent arms and wrists, and stress from interactions (Park et al., 2020).

6.4. Policy and amendments in municipal solid waste

To highlight the overlaps and differences between existing policies of management of MSW towards WTE-T of various nations, representative examples were chosen. Bioeconomy Strategy, Renewable Energy Directive and EU Action Plan for the Circular Economy are executed by European Union towards the successful implementation of MSW (Mak et al., 2020). The majority of the EU Union have the infrastructure for MSW handling and biogas facilities according to EU regulation. Consequently, the EU is regarded as the world's top producer of biomethane, with a capacity of 2.4 billion m^3 (Jin et al., 2021). California's Low Carbon Fuel Standard and the United States (US) EPA Renewable Fuel Standard are currently the most implemented and possibly significant policies in the US. These policies ensure the incentives to encourage facilities for the recovery of energy and resources from MSW in order to meet the worldwide objectives for lowering GHG emissions (Dalke et al., 2021).

China has one of the biggest factories with a processing capability of 365 thousand tonnes per year and a biogas production of 28 million m^3 per year. It is mainly due to China's long-term renewable energy strategy. Appreciatively, China has a mixed collection system for MSW as of now. According to the Chinese government's 13th Five-Year Plan (2020), all municipalities, cities, and provincial capitals must prepare for about 100 % safe disposal of MSW from all regions of the country (Khalid et al., 2020). Specifically, The Chinese government provided guidelines on how to properly dispose of MSW through the use of advanced WTE technology (Khalid et al., 2020).

In the UK, a notable amount of MSW is transferred to AD plants as a result of the Waste Resources Action Plan, Feed-in-Tariff (FIT) and Renewable heat incentive (RHI) initiatives that are aimed towards enhancing renewable power (Ackrill and Abdo, 2020). The FIT programme in Canada supports renewable natural gas from AD. Between 2010 and 2017, this initiative resulted in the installation of AD plants throughout Canada (Norouzi and Dutta, 2022). Other Asian nations are also making significant efforts in converting traditional waste management systems to WTE-T. The National Environmental Agency of Singapore has just begun exploring the potential of running co-digest food waste with sewage sludge to achieve energy neutrality in treating wastewater. If this strategy is effective, they intend to expand it to all sewage treatment facilities (Dalke et al., 2021).

While drafting the management of MSW policies, difficulties and concerns related to MSW management should be addressed. Both short-term and long terms views of environmental impacts, economic aspects and benefits as well as financial sources must be included in the account of policy drafting. There is still a lack of worldwide uniformity in the laws and regulations governing the handling of organic waste streams. However, all laws and regulations have a heavy focus on conserving and protecting the environment. In recent years, cities from developed countries have developed numerous biogas facilities as a waste management technique, particularly from landfilled MSW (Norouzi and Dutta, 2022). However, still, many developing countries are facing issues in implementation of WTE-T from MSW. In the near future, many countries may implement integrated waste management plans with incentives for the management of MSW and enhanced WTE technology.

7. Importance of waste to energy using circular economy

Circular economy (CE) is a system of regenerative in which discharges, waste and energy losses are reduced through delaying, shutting, and decreasing material and energy channels (Chakraborty et al., 2023). Integrating CE principles into systems for managing MSW could assist the growth of the economy. The CE system aims to combine the three pillars of sustainable development (social, economic and environmental) using a synergistic approach to produce energy and materials from waste (Venkata Mohan et al., 2020). The value-added usage of MSW as a potential resource remains an attractive alternative that complements the circular economy plan. Biorefineries are very energy-efficient, allowing for zero-waste operation and enabling businesses to generate environmentally beneficial materials on a long-term basis. Biorefineries promote the conception of a circular economy by employing biodegradable resources and producing bioproducts that may be returned to nature without harming the environment at the end of their lifespans (Chakraborty et al., 2023). The opinions provided in this study favour a circular economy and make obvious the resource potential of MSW.

8. Life cycle assessment and environmental impacts on sustainability of municipal solid waste management

Computer-based life-cycle assessment (LCA) is used to estimate and compile the input, output, and environmental effects that occur throughout the course of a product's life (Morya et al., 2022). Europe and Asia have both seen widespread adoption of the LCA technique. All waste-to-energy methods generate energy, which lessens the environmental effect by easing the pressure on the energy system. The significance of life-cycle assessment combined with environmental impacts is crucial for making decisions on the most advanced, pedagogical, and environmentally friendly technologies. For the majority of waste streams, gasification and AD delivered positive environmental consequences (Arafat et al., 2015). However, determining a suitable method which is more eco-friendly for treating MSW continues to be a significant difficulty.

Using LCA, four waste management strategies were evaluated for the developing country (India). It has been highlighted that appropriate sorting of MSW and recovery could assist sustainable management of MSW (Khandelwal et al., 2019). Assessment of energetic and environmental sustainability was reported using LCA for the management of MSW. Among the scenarios of the production of materials and fuel through the engagement of WTE technology, the production of fuel was reported to be better energetic (Barracco et al., 2023). Various WTE technologies have benefits and drawbacks in regard to the environment. LCA of MSW was reported in connection with hydrogen production using gasification and fermentation and compared with the conventional method. With MSW gasification and dark fermentation, the carbon footprint of producing hydrogen was approximately-one-third and a half of the conventional method (Lui et al., 2022). Thus, the LCA of MSW provides an applicable method for decarbonizing waste disposal and hydrogen generation. Such fascinating new research directions are required to concentrate on improving energy production from MSW for the adaptation of WTE technology.

Thermochemical processes like HTL and HTC have been proven to work better when it comes to reduction in volume and product transformation of various organic wastes and biomass. The lack of a feedstock drying requirement and a greater heat value are the benefits of HTL (Lachos-Perez et al., 2022). However, the HTC method has a major threat due contamination of heavy metals and organic micropollutants. Zhu et al. (2023) reported through the employment of appropriate AI tools carbon recovery can be maximized during HTC technology. Importantly, reduced energy utilization and increased production of energy from the organic fraction of MSW could enhance environmental impact (Ladakis et al., 2022). Thus, more technical and scientific findings are being published that reveal significant findings for widespread applications and workable pollution management.

Value chemical production may lead to economic viability, but process integration advancements and technological advancements are the only ways to lead to environmental improvement as evaluated by LCA. In addition to the availability of resources, community engagement, knowledge and skill development, safe and healthy living circumstances, consumer savings, accountability for technology usage, and the provision of infrastructure for the technologies, LCA examination of possible essential aspects including cost, economics, environmental effect, and competitive advantage will develop innovative greener, carbon–neutral technologies.

9. Challenges and outlook on municipal solid waste management

MSW can be recognized as renewable energy and may be utilised to produce energy in the form of fuel, heat and electricity. As compared to other renewable energy sources, MSW is the most economical and environmentally beneficial feedstock. Many studies have been performed to date on various methods for using MSW to produce energy. Unfortunately, the research conducted so far has not identified any practical strategies for energy production on an industrial scale. With the aid of the analytical Hierarchy process, obstacles to the quick development of biogas technology from MSW were rated. The top five impediments include a lack of segregated facilities, waste characteristics that vary, inconsistent feedstock supply, the necessity for pretreatment, and expensive installation costs (Yadav et al., 2022). Despite the fact that certain energy production units are running on an industrial scale, all of them are in the trial or observation phase. Hence, to translate laboratory findings to commercial and bigger-scale energy generation, a significant study is required. Importantly, prominent methods are available for producing energy from MSW. However, more expensive and less efficient are the major challenges to implementing in huge commercial aspects. Thus, further research is required to develop rapid and cost-effective energy generation methods.

While pyrolysis has the potential to convert MSW into liquid fuels, the heterogeneous composition of MSW presents a technological difficulty. Hence pyrolysis products must undergo extensive cleaning, sorting, and polishing in order to overcome techno-economic obstacles. To overcome these difficulties, certain approaches might be performed. Because of the renewable nature and nearly zero CO_2 content, bio-oil made from MSW could be utilized as a substitute for fossil fuels. However, the reactor, the main component of the pyrolysis system, is heated to high temperatures either by an internal or an external heater. In particular, the disintegration of MSW requires a lot of thermal energy. Such heating equipment is highly expensive and fuel consumption often results in significant CO_2 emissions that contribute to air pollution. Issues related to pyrolysis heating can be reduced by integrating the systems consisting of solar heating and pyrolysis. It allows for the effective utilization of solar energy with combustion heating systems. Combination approaches like solar-assisted pyrolysis is more eco-friendly and uses less energy.

Even though torrefaction encourages the fast growth of biomass-fired power facilities, torrefied biomass combustion is still difficult, nevertheless, for a number of reasons. Mostly ash-related concerns (particularly the slagging) and the viability of the economy are the major hurdles. The MSW pyrolyzer will have to handle the time-varying feed amount and compositions, but it may still result in proper treatment with end products of the highest market value while using the least amount of energy and emitting the fewest greenhouse gases. New process designs, new catalysts, and novel approaches to control the associated reactions are necessary for addition to the appropriate MSW treatment to remove non-combustible substances from the feedstocks to the pyrolyzer.

The great majority of current research are only concerned with one AI model. Nevertheless, integrated models (for instance, ANN/SVM/RF combined with GA) often exhibit greater prediction accuracy, reduced overfitting risk, and stronger flexibility than a single model, which may be preferable for resolving difficult OSW treatment issues. The treatment and recycling of OSW typically suffer from a lack of adequate data for model training. The following approaches might be thought of as potential means of overcoming data scarcity: Extrapolate new data from previous research; construct the experiment using the orthogonal test technique and response surface approach to increase AI effectiveness without expanding the sample size.

10. Economic stability of energy resources from municipal solid waste

WTE technology concentrates on sustainable energy production from MSW rather than discarding it as garbage. Producing energy at a lower price is crucial for sustainable production. The economic consideration of any waste utilisation comprises the estimation of capital cost, operational cost and profitability evaluation (Usmani et al., 2021). Despite the fact that many scientific studies on the effectiveness of various technologies towards the conversion of MSW into energy have been published, still improvement is required in terms of information on the economics of advanced techniques. The global market for biorefinery innovations is projected to increase at an 8.9 % CAGR during 2016–2021 to reach $714.6 billion as a result of the blooming technical progress in the next years (Shah et al., 2022). The commercial development of integrated WTE technology is hindered due to a lack of economic viability. As of now, the economic stability of the management of integrated MSW is still under process, due to the complex design of such systems, which raises expenses and makes such methods unfeasible economically.

11. Conclusions

A sustainable MSW management strategy must promote environmental protection and economic stability. This study reports various aspects of waste-to-energy technology using succeeding techniques. Developing smart MSW management systems would be an excellent way to manage the generated waste and to produce bioenergy. AI approaches have the capacity to anticipate environmental consequences and recognise the sustainability of energy production. Many novel techniques related with life cycle asssement and environmental analysis create a spectular pathway to reduce the restriction of fantastic technologies.

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.

Data availability

No data was used for the research described in the article.

References

Abdallah, M., Abu Talib, M., Feroz, S., Nasir, Q., Abdalla, H., Mahfood, B., 2020. Artificial intelligence applications in solid waste management: A systematic research review. Waste Manag. 109, 231–246. https://doi.org/10.1016/j.wasman.2020.04.057.

Abdulyekeen, K.A., Daud, W.M.A.W., Patah, M.F.A., Abnisa, F., 2022. Torrefaction of organic municipal solid waste to high calorific value solid fuel using batch reactor with helical screw induced rotation. Bioresour. Technol. 363, 127974 https://doi.org/10.1016/j.biortech.2022.127974.

Ackrill, R., Abdo, H., 2020. On-farm anaerobic digestion uptake barriers and required incentives: A case study of the UK East Midlands region. J. Clean. Prod. 264, 121727 https://doi.org/10.1016/j.jclepro.2020.121727.

Ahmed, B., Tyagi, V.K., Aboudi, K., Naseem, A., Álvarez-Gallego, C.J., Fernández-Güelfo, L.A., Kazmi, A.A., Romero-García, L.I., 2021. Thermally enhanced solubilization and anaerobic digestion of organic fraction of municipal solid waste. Chemosphere 282, 131136. https://doi.org/10.1016/j.chemosphere.2021.131136.

Ahmed, B., Kumar Tyagi, V., Kazmi, A.A., Khursheed, A., 2022. New insights into thermal-chemical pretreatment of organic fraction of municipal solid waste: Solubilization effects, recalcitrant formation, biogas yield and energy efficiency. Fuel (Lond.) 319, 123725. https://doi.org/10.1016/j.fuel.2022.123725.

Alrbai, M., Abubaker, A.M., Darwish Ahmad, A., Al-Dahidi, S., Ayadi, O., Hjouj, D., Al-Ghussain, L., 2022. Optimization of energy production from biogas fuel in a closed landfill using artificial neural networks: A case study of Al Ghabawi Landfill. Jordan. Waste Manag. 150, 218–226. https://doi.org/10.1016/j.wasman.2022.07.011.

Altikat, A., Gulbe, A., Altikat, S., 2022. Intelligent solid waste classification using deep convolutional neural networks. Int. J. Environ. Sci. Technol. (Tehran) 19, 1285–1292. https://doi.org/10.1007/s13762-021-03179-4.

Andeobu, L., Wibowo, S., Grandhi, S., 2022. Artificial intelligence applications for sustainable solid waste management practices in Australia: A systematic review. Sci. Total Environ. 834, 155389 https://doi.org/10.1016/j.scitotenv.2022.155389.

Arafat, H.A., Jijakli, K., Ahsan, A., 2015. Environmental performance and energy recovery potential of five processes for municipal solid waste treatment. J. Clean. Prod. 105, 233–240. https://doi.org/10.1016/j.jclepro.2013.11.071.

Aragon-Briceño, C., Pożarlik, A., Bramer, E., Brem, G., Wang, S., Wen, Y., Yang, W., Pawlak-Kruczek, H., Niedźwiecki, Ł., Urbanowska, A., Mościcki, K., Płoszczyca, M., 2022. Integration of hydrothermal carbonization treatment for water and energy recovery from organic fraction of municipal solid waste digestate. Renew. Energy 184, 577–591. https://doi.org/10.1016/j.renene.2021.11.106.

Ayeleru, O.O., Fajimi, L.I., Oboirien, B.O., Olubambi, P.A., 2021. Forecasting municipal solid waste quantity using artificial neural network and supported vector machine techniques: A case study of Johannesburg. South Africa. J. Clean. Prod. 289, 125671 https://doi.org/10.1016/j.jclepro.2020.125671.

Barracco, F., Demichelis, F., Sharifikolouei, E., Ferraris, M., Fino, D., Tommasi, T., 2023. Life cycle assessment for the production of MSWI fly-ash based porous glass-ceramics: Scenarios based on the contribution of silica sources, methane aided, and energy recoveries. Waste Manag. 157, 301–311. https://doi.org/10.1016/j.wasman.2022.12.013.

Bhakta Sharma, H., Panigrahi, S., Dubey, B.K., 2021. Food waste hydrothermal carbonization: Study on the effects of reaction severities, pelletization and framework development using approaches of the circular economy. Bioresour. Technol. 333, 125187 https://doi.org/10.1016/j.biortech.2021.125187.

Bhatt, K.P., Patel, S., Upadhyay, D.S., Patel, R.N., 2022. A critical review on solid waste treatment using plasma pyrolysis technology. Chem. Eng. Process. 177, 108989 https://doi.org/10.1016/j.cep.2022.108989.

Bhattacharya, S.S., Kim, K.-H., Ullah, M.A., Goswami, L., Sahariah, B., Bhattacharyya, P., Cho, S.-B., Hwang, O.-H., 2016. The effects of composting approaches on the emissions of anthropogenic volatile organic compounds: A comparison between vermicomposting and general aerobic composting. Environ. Pollut. 208, 600–607. https://doi.org/10.1016/j.envpol.2015.10.034.

Cai, Y., Zheng, Z., Schäfer, F., Stinner, W., Yuan, X., Wang, H., Cui, Z., Wang, X., 2021. A review about pretreatment of lignocellulosic biomass in anaerobic digestion: Achievement and challenge in Germany and China. J. Clean. Prod. 299, 126885 https://doi.org/10.1016/j.jclepro.2021.126885.

Cesaro, A., Belgiorno, V., 2014. Pretreatment methods to improve anaerobic biodegradability of organic municipal solid waste fractions. Chem. Eng. J. 240, 24–37. https://doi.org/10.1016/j.cej.2013.11.055.

Chakraborty, D., Chatterjee, S., Althuri, A., Palani, S.G., Venkata Mohan, S., 2023. Sustainable enzymatic treatment of organic waste in a framework of circular economy. Bioresour. Technol. 370, 128487 https://doi.org/10.1016/j.biortech.2022.128487.

Chand Malav, L., Yadav, K.K., Gupta, N., Kumar, S., Sharma, G.K., Krishnan, S., Rezania, S., Kamyab, H., Pham, Q.B., Yadav, S., Bhattacharyya, S., Yadav, V.K., Bach, Q.-V., 2020. A review on municipal solid waste as a renewable source for waste-to-energy project in India: Current practices, challenges, and future opportunities. J. Clean. Prod. 277, 123227 https://doi.org/10.1016/j.jclepro.2020.123227.

Chen, G., Zhang, R., Guo, X., Wu, W., Guo, Q., Zhang, Y., Yan, B., 2021. Comparative evaluation on municipal sewage sludge utilization processes for sustainable management in Tibet. Sci. Total Environ. 765, 142676 https://doi.org/10.1016/j.scitotenv.2020.142676.

Chowdhury, S., Kim, G.-H., Bolan, N., Longhurst, P., 2019. A critical review on risk evaluation and hazardous management in carcass burial. Process Saf. Environ. Prot. 123, 272–288. https://doi.org/10.1016/j.psep.2019.01.019.

Cugurullo, F., 2020. Urban artificial intelligence: From automation to autonomy in the smart city. Front. Sustain. Cities 2. https://doi.org/10.3389/frsc.2020.00038.

Dalke, R., Demro, D., Khalid, Y., Wu, H., Urgun-Demirtas, M., 2021. Current status of anaerobic digestion of food waste in the United States. Renew. Sustain. Energy Rev. 151, 111554 https://doi.org/10.1016/j.rser.2021.111554.

Dastyar, W., Mohammad Mirsoleimani Azizi, S., Dhadwal, M., Ranjan Dhar, B., 2021. High-solids anaerobic digestion of organic fraction of municipal solid waste: Effects of feedstock to inoculum ratio and percolate recirculation time. Bioresour. Technol. 337, 125335. https://doi.org/10.1016/j.biortech.2021.125335.

Ebrahimian, F., Denayer, J.F.M., Mohammadi, A., Khoshnevisan, B., Karimi, K., 2023. A critical review on pretreatment and detoxification techniques required for biofuel production from the organic fraction of municipal solid waste. Bioresour. Technol. 368, 128316 https://doi.org/10.1016/j.biortech.2022.128316.

Ebrahimian, F., Karimi, K., 2020. Efficient biohydrogen and advanced biofuel coproduction from municipal solid waste through a clean process. Bioresour. Technol. 300, 122656 https://doi.org/10.1016/j.biortech.2019.122656.

Ebrahimian, F., Denayer, J.F.M., Karimi, K., 2022. Efficient coproduction of butanol, ethanol, and biohydrogen from municipal solid waste through a cocultivated biorefinery. Energy Convers. Manag. 255, 115303 https://doi.org/10.1016/j.enconman.2022.115303.

Fagbohungbe, M.O., Dodd, I.C., Herbert, B.M.J., Li, H., Ricketts, L., Semple, K.T., 2015. High solid anaerobic digestion: Operational challenges and possibilities. Environ. Technol. Innov. 4, 268–284. https://doi.org/10.1016/j.eti.2015.09.003.

Fei, F., Wen, Z., Huang, S., De Clercq, D., 2018. Mechanical biological treatment of municipal solid waste: Energy efficiency, environmental impact and economic feasibility analysis. J. Clean. Prod. 178, 731–739. https://doi.org/10.1016/j.jclepro.2018.01.060.

Feng, Q., Lin, Y., 2017. Integrated processes of anaerobic digestion and pyrolysis for higher bioenergy recovery from lignocellulosic biomass: A brief review. Renew. Sustain. Energy Rev. 77, 1272–1287. https://doi.org/10.1016/j.rser.2017.03.022.

Funke, A., Ziegler, F., 2010. Hydrothermal carbonization of biomass: A summary and discussion of chemical mechanisms for process engineering. Biofuel. Bioprod. Biorefin. 4, 160–177. https://doi.org/10.1002/bbb.198.

Gandidi, I.M., Susila, M.D., Mustofa, A., Pambudi, N.A., 2018. Thermal – Catalytic cracking of real MSW into Bio-Crude Oil. J. Energy Inst. 91, 304–310. https://doi.org/10.1016/j.joei.2016.11.005.

Gouws, S.M., Carrier, M., Bunt, J.R., Neomagus, H.W.J.P., 2021. Co-pyrolysis of coal and raw/torrefied biomass: A review on chemistry, kinetics and implementation. Renew. Sustain. Energy Rev. 135, 110189 https://doi.org/10.1016/j.rser.2020.110189.

Grycová, B., Koutník, I., Pryszcz, A., 2016. Pyrolysis process for the treatment of food waste. Bioresour. Technol. 218, 1203–1207. https://doi.org/10.1016/j.biortech.2016.07.064.

Gundupalli, S.P., Hait, S., Thakur, A., 2017. A review on automated sorting of source-separated municipal solid waste for recycling. Waste Manag. 60, 56–74. https://doi.org/10.1016/j.wasman.2016.09.015.

Guo, H.-N., Wu, S.-B., Tian, Y.-J., Zhang, J., Liu, H.-T., 2021. Application of machine learning methods for the prediction of organic solid waste treatment and recycling processes: A review. Bioresour. Technol. 319, 124114 https://doi.org/10.1016/j.biortech.2020.124114.

Gupta, D., Mahajani, S.M., Garg, A., 2021. Hydrothermal carbonization of household wet waste - characterization of hydrochar and process wastewater stream. Bioresour. Technol. 342, 125972 https://doi.org/10.1016/j.biortech.2021.125972.

Guran, S., 2018. Sustainable waste-to-energy technologies: Gasification and pyrolysis, in: Sustainable Food Waste-To-Energy Systems. Elsevier, pp. 141–158. https://doi.org/10.1016/b978-0-12-811157-4.00008-5.

Hasan, M.M., Rasul, M.G., Khan, M.M.K., Ashwath, N., Jahirul, M.I., 2021. Energy recovery from municipal solid waste using pyrolysis technology: A review on current status and developments. Renew. Sustain. Energy Rev. 145, 111073 https://doi.org/10.1016/j.rser.2021.111073.

He, Q., Ding, L., Gong, Y., Li, W., Wei, J., Yu, G., 2019. Effect of torrefaction on pinewood pyrolysis kinetics and thermal behavior using thermogravimetric analysis. Bioresour. Technol. 280, 104–111. https://doi.org/10.1016/j.biortech.2019.01.138.

Hoang, A.T., Varbanov, P.S., Nižetić, S., Sirohi, R., Pandey, A., Luque, R., Ng, K.H., Pham, V.V., 2022. Perspective review on Municipal Solid Waste-to-energy route: Characteristics, management strategy, and role in circular economy. J. Clean. Prod. 359, 131897 https://doi.org/10.1016/j.jclepro.2022.131897.

Hosseinzadeh, A., Baziar, M., Alidadi, H., Zhou, J.L., Altaee, A., Najafpoor, A.A., Jafarpour, S., 2020. Application of artificial neural network and multiple linear regression in modeling nutrient recovery in vermicompost under different conditions. Bioresour. Technol. 303, 122926 https://doi.org/10.1016/j.biortech.2020.122926.

Huezo, L., Vasco-Correa, J., Shah, A., 2021. Hydrothermal carbonization of anaerobically digested sewage sludge for hydrochar production. Bioresour. Technol. Rep. 15, 100795 https://doi.org/10.1016/j.biteb.2021.100795.

Irfan, M., Li, A., Zhang, L., Javid, M., Wang, M., Khushk, S., 2019. Enhanced H2 Production from Municipal Solid Waste Gasification Using Ni–CaO–TiO2 Bifunctional Catalyst Prepared by dc Arc Plasma Melting. Ind. Eng. Chem. Res. 58, 13408–13419. https://doi.org/10.1021/acs.iecr.9b01999.

Islam, M.S., Hannan, M.A., Basri, H., Hussain, A., Arebey, M., 2014. Solid waste bin detection and classification using Dynamic Time Warping and MLP classifier. Waste Manag. 34, 281–290. https://doi.org/10.1016/j.wasman.2013.10.030.

Istrate, I.-R., Iribarren, D., Gálvez-Martos, J.-L., Dufour, J., 2020. Review of life-cycle environmental consequences of waste-to-energy solutions on the municipal solid waste management system. Resour. Conserv. Recycl. 157, 104778 https://doi.org/10.1016/j.resconrec.2020.104778.

Jiang, X., Xie, Y., Liu, M., Bin, S., Liu, Y., Huan, C., Ji, G., Wang, X., Yan, Z., Lyu, Q., 2022. Study on anaerobic co-digestion of municipal sewage sludge and fruit and vegetable wastes: Methane production, microbial community and three-dimension fluorescence excitation-emission matrix analysis. Bioresour. Technol. 347, 126748 https://doi.org/10.1016/j.biortech.2022.126748.

Jin, C., Sun, S., Yang, D., Sheng, W., Ma, Y., He, W., Li, G., 2021. Anaerobic digestion: An alternative resource treatment option for food waste in China. Sci. Total Environ. 779, 146397 https://doi.org/10.1016/j.scitotenv.2021.146397.

Kabak, E.T., Cagcag Yolcu, O., Aydın Temel, F., Turan, N.G., 2022. Prediction and optimization of nitrogen losses in co-composting process by using a hybrid cascaded prediction model and genetic algorithm. Chem. Eng. J. 437, 135499 https://doi.org/10.1016/j.cej.2022.135499.

Kainthola, J., Podder, A., Fechner, M., Goel, R., 2021. An overview of fungal pretreatment processes for anaerobic digestion: Applications, bottlenecks and future needs. Bioresour. Technol. 321, 124397 https://doi.org/10.1016/j.biortech.2020.124397.

Kannangara, M., Dua, R., Ahmadi, L., Bensebaa, F., 2018. Modeling and prediction of regional municipal solid waste generation and diversion in Canada using machine learning approaches. Waste Manag. 74, 3–15. https://doi.org/10.1016/j.wasman.2017.11.057.

Kasemy, Z.A., Rohlman, D.S., Abdel Latif, A.A., 2021. Health disorders among Egyptian municipal solid waste workers and assessment of their knowledge, attitude, and practice towards the hazardous exposure. Environ. Sci. Pollut. Res. Int. 28, 30993–31002. https://doi.org/10.1007/s11356-021-12856-3.

Khalid, H., Zhang, H., Liu, C., Li, W., Abuzar, M.K., Amin, F.R., Liu, G., Chen, C., 2020. PEST (political, environmental, social & technical) analysis of the development of the waste-to-energy anaerobic digestion industry in China as a representative for developing countries. Sustain. Energy Fuels 4, 1048–1062. https://doi.org/10.1039/c9se00692c.

Khan, A.H., López-Maldonado, E.A., Khan, N.A., Villarreal-Gómez, L.J., Munshi, F.M., Alsabhan, A.H., Perveen, K., 2022. Current solid waste management strategies and energy recovery in developing countries - State of art review. Chemosphere 291, 133088. https://doi.org/10.1016/j.chemosphere.2021.133088.

Khandelwal, H., Thalla, A.K., Kumar, S., Kumar, R., 2019. Life cycle assessment of municipal solid waste management options for India. Bioresour. Technol. 288, 121515 https://doi.org/10.1016/j.biortech.2019.121515.

Lachos-Perez, D., César Torres-Mayanga, P., Abaide, E.R., Zabot, G.L., De Castilhos, F., 2022. Hydrothermal carbonization and Liquefaction: differences, progress, challenges, and opportunities. Bioresour. Technol. 343, 126084 https://doi.org/10.1016/j.biortech.2021.126084.

Ladakis, D., Stylianou, E., Ioannidou, S.-M., Koutinas, A., Pateraki, C., 2022. Biorefinery development, techno-economic evaluation and environmental impact analysis for the conversion of the organic fraction of municipal solid waste into succinic acid and value-added fractions. Bioresour. Technol. 354, 127172 https://doi.org/10.1016/j.biortech.2022.127172.

Lee, D.-J., 2022. Gasification of municipal solid waste (MSW) as a cleaner final disposal route: A mini-review. Bioresour. Technol. 344, 126217 https://doi.org/10.1016/j.biortech.2021.126217.

Lee, E., Bittencourt, P., Casimir, L., Jimenez, E., Wang, M., Zhang, Q., Ergas, S.J., 2019. Biogas production from high solids anaerobic co-digestion of food waste, yard waste and waste activated sludge. Waste Manag. 95, 432–439. https://doi.org/10.1016/j.wasman.2019.06.033.

Lee, D.-J., Lu, J.-S., Chang, J.-S., 2020. Pyrolysis synergy of municipal solid waste (MSW): A review. Bioresour. Technol. 318, 123912 https://doi.org/10.1016/j.biortech.2020.123912.

Lee, J.T.E., Ok, Y.S., Song, S., Dissanayake, P.D., Tian, H., Tio, Z.K., Cui, R., Lim, E.Y., Jong, M.-C., Hoy, S.H., Lum, T.Q.H., Tsui, T.-H., Yoon, C.S., Dai, Y., Wang, C.-H., Tan, H.T.W., Tong, Y.W., 2021. Biochar utilisation in the anaerobic digestion of food waste for the creation of a circular economy via biogas upgrading and digestate treatment. Bioresour. Technol. 333, 125190 https://doi.org/10.1016/j.biortech.2021.125190.

Lima, P.D.M., Colvero, D.A., Gomes, A.P., Wenzel, H., Schalch, V., Cimpan, C., 2018. Environmental assessment of existing and alternative options for management of municipal solid waste in Brazil. Waste Manag. 78, 857–870. https://doi.org/10.1016/j.wasman.2018.07.007.

Lin, J.-C., Mariuzza, D., Volpe, M., Fiori, L., Ceylan, S., Goldfarb, J.L., 2021. Integrated thermochemical conversion process for valorizing mixed agricultural and dairy waste to nutrient-enriched biochars and biofuels. Bioresour. Technol. 328, 124765 https://doi.org/10.1016/j.biortech.2021.124765.

Liu, X.-L., Dong, C., Leu, S.-Y., Fang, Z., Miao, Z.-D., 2022. Efficient saccharification of wheat straw pretreated by solid particle-assisted ball milling with waste washing liquor recycling. Bioresour. Technol. 347, 126721 https://doi.org/10.1016/j.biortech.2022.126721.

Liu, Y., Song, Y., Ran, C., Siyal, A.A., Chtaeva, P., Dai, J., Jiang, Z., Deng, Z., Zhang, T., Ao, W., Fu, J., 2020. Pyrolysis of furfural residue in a bubbling fluidized bed reactor: Biochar characterization and analysis. Energy (Oxf.) 211, 118966. https://doi.org/10.1016/j.energy.2020.118966.

Llano, T., Arce, C., Finger, D.C., 2021. Optimization of biogas production through anaerobic digestion of municipal solid waste: a case study in the capital area of Re ykjavik. Iceland. J. Chem. Technol. Biotechnol. 96, 1333–1344. https://doi.org/10.1002/jctb.6654.

Lucian, M., Volpe, M., Merzari, F., Wüst, D., Kruse, A., Andreottola, G., Fiori, L., 2020. Hydrothermal carbonization coupled with anaerobic digestion for the valorization of the organic fraction of municipal solid waste. Bioresour. Technol. 314, 123734 https://doi.org/10.1016/j.biortech.2020.123734.

Lui, J., Sloan, W., Paul, M.C., Flynn, D., You, S., 2022. Life cycle assessment of waste-to-hydrogen systems for fuel cell electric buses in Glasgow. Scotland. Bioresour. Technol. 359, 127464 https://doi.org/10.1016/j.biortech.2022.127464.

Ma, W., Tai, L., Qiao, Z., Zhong, L., Wang, Z., Fu, K., Chen, G., 2018. Contamination source apportionment and health risk assessment of heavy metals in soil around municipal solid waste incinerator: A case study in North China. Sci. Total Environ. 631–632, 348–357. https://doi.org/10.1016/j.scitotenv.2018.03.011.

Mahmoodi, P., Karimi, K., Taherzadeh, M.J., 2018a. Efficient conversion of municipal solid waste to biofuel by simultaneous dilute-acid hydrolysis of starch and pretreatment of lignocelluloses. Energy Convers. Manag. 166, 569–578. https://doi.org/10.1016/j.enconman.2018.04.067.

Mahmoodi, P., Karimi, K., Taherzadeh, M.J., 2018b. Hydrothermal processing as pretreatment for efficient production of ethanol and biogas from municipal solid waste. Bioresour. Technol. 261, 166–175. https://doi.org/10.1016/j.biortech.2018.03.115.

Mak, T.M.W., Xiong, X., Tsang, D.C.W., Yu, I.K.M., Poon, C.S., 2020. Sustainable food waste management towards circular bioeconomy: Policy review, limitations and opportunities. Bioresour. Technol. 297, 122497 https://doi.org/10.1016/j.biortech.2019.122497.

Mašláni, A., Hrabovský, M., Křenek, P., Hlína, M., Raman, S., Sikarwar, V.S., Jeremiáš, M., 2021. Pyrolysis of methane via thermal steam plasma for the production of hydrogen and carbon black. Int. J. Hydrogen Energy 46, 1605–1614. https://doi.org/10.1016/j.ijhydene.2020.10.105.

Miandad, R., Barakat, M.A., Aburiazaiza, A.S., Rehan, M., Ismail, I.M.I., Nizami, A.S., 2017. Effect of plastic waste types on pyrolysis liquid oil. Int. Biodeterior. Biodegradation 119, 239–252. https://doi.org/10.1016/j.ibiod.2016.09.017.

Mohd Fuad, M.A.H., Hasan, M.F., Ani, F.N., 2019. Microwave torrefaction for viable fuel production: A review on theory, affecting factors, potential and challenges. Fuel (Lond.) 253, 512–526. https://doi.org/10.1016/j.fuel.2019.04.151.

Mondal, A., Goswami, L., Hussain, N., Barman, S., Kalita, E., Bhattacharyya, P., Bhattacharya, S.S., 2020. Detoxification and eco-friendly recycling of brick kiln coal ash using Eisenia fetida: A clean approach through vermitechnology. Chemosphere 244, 125470. https://doi.org/10.1016/j.chemosphere.2019.125470.

Morya, R., Raj, T., Lee, Y., Kumar Pandey, A., Kumar, D., Rani Singhania, R., Singh, S., Prakash Verma, J., Kim, S.-H., 2022. Recent updates in biohydrogen production strategies and life-cycle assessment for sustainable future. Bioresour. Technol. 366, 128159 https://doi.org/10.1016/j.biortech.2022.128159.

Motavaf, B., Dean, R.A., Nicolas, J., Savage, P.E., 2021. Hydrothermal carbonization of simulated food waste for recovery of fatty acids and nutrients. Bioresour. Technol. 341, 125872 https://doi.org/10.1016/j.biortech.2021.125872.

Mukherjee, C., Denney, J., Mbonimpa, E.G., Slagley, J., Bhowmik, R., 2020. A review on municipal solid waste-to-energy trends in the USA. Renew. Sustain. Energy Rev. 119, 109512 https://doi.org/10.1016/j.rser.2019.109512.

Nabi, M., Zhang, G., Zhang, P., Tao, X., Wang, S., Ye, J., Zhang, Q., Zubair, M., Bao, S., Wu, Y., 2019. Contribution of solid and liquid fractions of sewage sludge pretreated by high pressure homogenization to biogas production. Bioresour. Technol. 286, 121378 https://doi.org/10.1016/j.biortech.2019.121378.

Norouzi, O., Dutta, A., 2022. The current status and future potential of biogas production from Canada's organic fraction municipal solid waste. Energies 15, 475. https://doi.org/10.3390/en15020475.

Oh, Y.-K., Hwang, K.-R., Kim, C., Kim, J.R., Lee, J.-S., 2018. Recent developments and key barriers to advanced biofuels: A short review. Bioresour. Technol. 257, 320–333. https://doi.org/10.1016/j.biortech.2018.02.089.

Ortega-Fernández, A., Martín-Rojas, R., García-Morales, V.J., 2020. Artificial Intelligence in the Urban Environment: Smart Cities as Models for Developing Innovation and Sustainability. Sustain. Sci. Pract. Policy 12, 7860. https://doi.org/10.3390/su12197860.

Panepinto, D., Tedesco, V., Brizio, E., Genon, G., 2015. Environmental performances and energy efficiency for MSW gasification treatment. Waste Biomass Valorization 6, 123–135. https://doi.org/10.1007/s12649-014-9322-7.

Papa, G., Pepe Sciarria, T., Scaglia, B., Adani, F., 2022. Diversifying the products from the organic fraction of municipal solid waste (OFMSW) by producing polyhydroxyalkanoates from the liquid fraction and biomethane from the residual solid fraction. Bioresour. Technol. 344, 126180 https://doi.org/10.1016/j.biortech.2021.126180.

Park, J., Lee, J., Lee, M.-S., 2020. Occupational health injuries by job characteristics and working environment among street cleaners in South Korea. Int. J. Environ. Res. Public Health 17, 2322. https://doi.org/10.3390/ijerph17072322.

Paudel, S.R., Banjara, S.P., Choi, O.K., Park, K.Y., Kim, Y.M., Lee, J.W., 2017. Pretreatment of agricultural biomass for anaerobic digestion: Current state and challenges. Bioresour. Technol. 245, 1194–1205. https://doi.org/10.1016/j.biortech.2017.08.182.

Paul, S., Choudhury, M., Deb, U., Pegu, R., Das, S., Bhattacharya, S.S., 2019. Assessing the ecological impacts of ageing on hazard potential of solid waste landfills: A green approach through vermitechnology. J. Clean. Prod. 236, 117643 https://doi.org/10.1016/j.jclepro.2019.117643.

Pei, S.-L., Chen, T.-L., Pan, S.-Y., Yang, Y.-L., Sun, Z.-H., Li, Y.-J., 2020. Addressing environmental sustainability of plasma vitrification technology for stabilization of municipal solid waste incineration fly ash. J. Hazard. Mater. 398, 122959 https://doi.org/10.1016/j.jhazmat.2020.122959.

Pourreza Movahed, Z., Kabiri, M., Ranjbar, S., Joda, F., 2020. Multi-objective optimization of life cycle assessment of integrated waste management based on genetic algorithms: A case study of Tehran. J. Clean. Prod. 247, 119153 https://doi.org/10.1016/j.jclepro.2019.119153.

Prajapati, K.K., Yadav, M., Singh, R.M., Parikh, P., Pareek, N., Vivekanand, V., 2021. An overview of municipal solid waste management in Jaipur city, India - Current status, challenges and recommendations. Renew. Sustain. Energy Rev. 152, 111703 https://doi.org/10.1016/j.rser.2021.111703.

Qin, L.W., Ahmad, M., Ali, I., Mumtaz, R., Zaidi, S.M.H., Alshamrani, S.S., Raza, M.A., Tahir, M., 2021. Precision measurement for industry 4.0 standards towards solid waste classification through enhanced imaging sensors and deep learning model. Wirel. Commun. Mob. Comput. 2021, 1–10. https://doi.org/10.1155/2021/9963999.

Rago, Y.P., Collard, F.-X., Görgens, J.F., Surroop, D., Mohee, R., 2020. Torrefaction of biomass and plastic from municipal solid waste streams and their blends: Evaluation of interactive effects. Fuel (Lond.) 277, 118089. https://doi.org/10.1016/j.fuel.2020.118089.

Rajendran, N., Gurunathan, B., Han, J., Krishna, S., Ananth, A., Venugopal, K., Sherly Priyanka, R.B., 2021. Recent advances in valorization of organic municipal waste into energy using biorefinery approach, environment and economic analysis. Bioresour. Technol. 337, 125498 https://doi.org/10.1016/j.biortech.2021.125498.

Ramos, A., Berzosa, J., Espí, J., Clarens, F., Rouboa, A., 2020. Life cycle costing for plasma gasification of municipal solid waste: A socio-economic approach. Energy Convers. Manag. 209, 112508 https://doi.org/10.1016/j.enconman.2020.112508.

Reza, M.T., Andert, J., Wirth, B., Busch, D., Pielert, J., Lynam, J.G., Mumme, J., 2014. Hydrothermal carbonization of biomass for energy and crop production. Appl. Bioenergy 1. https://doi.org/10.2478/apbi-2014-0001.

Rincón, C.A., De Guardia, A., Couvert, A., Le Roux, S., Soutrel, I., Daumoin, M., Benoist, J.C., 2019. Chemical and odor characterization of gas emissions released during composting of solid wastes and digestates. J. Environ. Manage. 233, 39–53. https://doi.org/10.1016/j.jenvman.2018.12.009.

Sanito, R.C., Bernuy-Zumaeta, M., Wang, W.-C., Yang, H.-H., You, S.-J., Wang, Y.-F., 2023. Optimization of metals degradation and vitrification from fly ash using Taguchi design combined with plasma pyrolysis and recycling in cement construction. J. Clean. Prod. 387, 135930 https://doi.org/10.1016/j.jclepro.2023.135930.

Saravanan, A., Kumar, P.S., Nhung, T.C., Ramesh, B., Srinivasan, S., Rangasamy, G., 2022. A review on biological methodologies in municipal solid waste management and landfilling: Resource and energy recovery. Chemosphere 309, 136630. https://doi.org/10.1016/j.chemosphere.2022.136630.

Sarkar, A., Chowdhury, R., 2016. Co-pyrolysis of paper waste and mustard press cake in a semi-batch pyrolyzer—optimization and bio-oil characterization. Int. J. Green Energy 13, 373–382. https://doi.org/10.1080/15435075.2014.952423.

Sebastian, R.M., Kumar, D., Alappat, B.J., 2019. A technique to quantify incinerability of municipal solid waste. Resour. Conserv. Recycl. 140, 286–296. https://doi.org/10.1016/j.resconrec.2018.09.022.

Shah, A.V., Singh, A., Sabyasachi Mohanty, S., Kumar Srivastava, V., Varjani, S., 2022. Organic solid waste: Biorefinery approach as a sustainable strategy in circular bioeconomy. Bioresour. Technol. 349, 126835 https://doi.org/10.1016/j.biortech.2022.126835.

Shi, Y., Li, Y., Yuan, X., Fu, J., Ma, Q., Wang, Q., 2020. Environmental and human health risk evaluation of heavy metals in ceramsites from municipal solid waste incineration fly ash. Environ. Geochem. Health 42, 3779–3794. https://doi.org/10.1007/s10653-020-00639-7.

Signoret, C., Caro-Bretelle, A.-S., Lopez-Cuesta, J.-M., Ienny, P., Perrin, D., 2020. Alterations of plastics spectra in MIR and the potential impacts on identification towards recycling. Resour. Conserv. Recycl. 161, 104980 https://doi.org/10.1016/j.resconrec.2020.104980.

Singh, D., Satija, A., 2018. Prediction of municipal solid waste generation for optimum planning and management with artificial neural network—case study: Faridabad City in Haryana State (India). Int. J. Syst. Assur. Eng. Manag. 9, 91–97. https://doi.org/10.1007/s13198-016-0484-5.

Sipra, A.T., Gao, N., Sarwar, H., 2018. Municipal solid waste (MSW) pyrolysis for bio-fuel production: A review of effects of MSW components and catalysts. Fuel Process. Technol. 175, 131–147. https://doi.org/10.1016/j.fuproc.2018.02.012.

Smith, M.M., Aber, J.D., 2018. Energy recovery from commercial-scale composting as a novel waste management strategy. Appl. Energy 211, 194–199. https://doi.org/10.1016/j.apenergy.2017.11.006.

Ting, H.N.J., Lin, L., Cruz, R.B., Chowdhury, B., Karidio, I., Zaman, H., Dhar, B.R., 2020. Transitions of microbial communities in the solid and liquid phases during high-solids anaerobic digestion of organic fraction of municipal solid waste. Bioresour. Technol. 317, 123951 https://doi.org/10.1016/j.biortech.2020.123951.

Tursunov, O., 2014. A comparison of catalysts zeolite and calcined dolomite for gas production from pyrolysis of municipal solid waste (MSW). Ecol. Eng. 69, 237–243. https://doi.org/10.1016/j.ecoleng.2014.04.004.

Udofia, E.A., Gulis, G., Fobil, J., 2017. Solid medical waste: a cross sectional study of household disposal practices and reported harm in Southern Ghana. BMC Public Health 17. https://doi.org/10.1186/s12889-017-4366-9.

Uemura, Y., Sellappah, V., Trinh, T.H., Hassan, S., Tanoue, K.-I., 2017. Torrefaction of empty fruit bunches under biomass combustion gas atmosphere. Bioresour. Technol. 243, 107–117. https://doi.org/10.1016/j.biortech.2017.06.057.

Usmani, Z., Sharma, M., Awasthi, A.K., Sivakumar, N., Lukk, T., Pecoraro, L., Thakur, V. K., Roberts, D., Newbold, J., Gupta, V.K., 2021. Bioprocessing of waste biomass for sustainable product development and minimizing environmental impact. Bioresour. Technol. 322, 124548 https://doi.org/10.1016/j.biortech.2020.124548.

Valizadeh, S., Hakimian, H., Farooq, A., Jeon, B.-H., Chen, W.-H., Hoon Lee, S., Jung, S.-C., Won Seo, M., Park, Y.-K., 2022. Valorization of biomass through gasification for green hydrogen generation: A comprehensive review. Bioresour. Technol. 365, 128143 https://doi.org/10.1016/j.biortech.2022.128143.

Varjani, S., Shahbeig, H., Popat, K., Patel, Z., Vyas, S., Shah, A.V., Barceló, D., Hao Ngo, H., Sonne, C., Shiung Lam, S., Aghbashlo, M., Tabatabaei, M., 2022. Sustainable management of municipal solid waste through waste-to-energy technologies. Bioresour. Technol. 355, 127247 https://doi.org/10.1016/j.biortech.2022.127247.

Venkata Mohan, S., Hemalatha, M., Chakraborty, D., Chatterjee, S., Ranadheer, P., Kona, R., 2020. Algal biorefinery models with self-sustainable closed loop approach: Trends and prospective for blue-bioeconomy. Bioresour. Technol. 295, 122128 https://doi.org/10.1016/j.biortech.2019.122128.

Veses, A., Sanahuja-Parejo, O., Callén, M.S., Murillo, R., García, T., 2020. A combined two-stage process of pyrolysis and catalytic cracking of municipal solid waste for the production of syngas and solid refuse-derived fuels. Waste Manag. 101, 171–179. https://doi.org/10.1016/j.wasman.2019.10.009.

Vinti, G., Bauza, V., Clasen, T., Medlicott, K., Tudor, T., Zurbrügg, C., Vaccari, M., 2021. Municipal solid waste management and adverse health outcomes: A systematic review. Int. J. Environ. Res. Public Health 18, 4331. https://doi.org/10.3390/ijerph18084331.

Volpe, M., Goldfarb, J.L., Fiori, L., 2018. Hydrothermal carbonization of Opuntia ficus-indica cladodes: Role of process parameters on hydrochar properties. Bioresour. Technol. 247, 310–318. https://doi.org/10.1016/j.biortech.2017.09.072.

Vu, H.L., Bolingbroke, D., Ng, K.T.W., Fallah, B., 2019. Assessment of waste characteristics and their impact on GIS vehicle collection route optimization using ANN waste forecasts. Waste Manag. 88, 118–130. https://doi.org/10.1016/j.wasman.2019.03.037.

Wang, J., Okopi, S.I., Ma, H., Wang, M., Chen, R., Tian, W., Xu, F., 2021. Life cycle assessment of the integration of anaerobic digestion and pyrolysis for treatment of municipal solid waste. Bioresour. Technol. 338, 125486 https://doi.org/10.1016/j.biortech.2021.125486.

Wang, Y.-N., Shi, H., Wang, Q., Wang, H., Sun, Y., Li, W., Bian, R., 2022. Insights into the landfill leachate properties and bacterial structure succession resulting from the colandfilling of municipal solid waste and incineration bottom ash. Bioresour. Technol. 361, 127720 https://doi.org/10.1016/j.biortech.2022.127720.

Wang, T., Zhai, Y., Zhu, Y., Gan, X., Zheng, L., Peng, C., Wang, B., Li, C., Zeng, G., 2018. Evaluation of the clean characteristics and combustion behavior of hydrochar derived from food waste towards solid biofuel production. Bioresour. Technol. 266, 275–283. https://doi.org/10.1016/j.biortech.2018.06.093.

Wassiem, A., Zaki, G.R., Charl, F., El-Gazzar, R., 2021. Biochemical changes among municipal solid waste sorting workers: implications for personal protective equipment availability and use. Int. J. Occup. Saf. Ergon. 27, 1028–1038. https://doi.org/10.1080/10803548.2019.1674504.

Wu, M., Hu, J., Shen, F., Huang, M., Zhao, L., Tian, D., Zhang, Y., Liu, Y., Zeng, Y., Deng, S., 2021a. Conceptually integrating a multi-product strategy for the valorization of kitchen waste towards a more sustainable management. J. Clean. Prod. 306, 127292 https://doi.org/10.1016/j.jclepro.2021.127292.

Wu, Z., Liu, Y., Yao, J., Zheng, X., Wandera, S.M., Dong, R., Li, Y.-Y., Qiao, W., 2021b. The materials flow and membrane filtration performance in treating the organic fraction of municipal solid waste leachate by a high solid type of submerged anaerobic membrane bioreactor. Bioresour. Technol. 329, 124927 https://doi.org/10.1016/j.biortech.2021.124927.

Yadav, V., Karmakar, S., 2020. Sustainable collection and transportation of municipal solid waste in urban centers. Sustain. Cities Soc. 53, 101937 https://doi.org/10.1016/j.scs.2019.101937.

Yadav, P., Yadav, S., Singh, D., Shekher Giri, B., Mishra, P.K., 2022. Barriers in biogas production from the organic fraction of municipal solid waste: A circular bioeconomy perspective. Bioresour. Technol. 362, 127671 https://doi.org/10.1016/j.biortech.2022.127671.

Yang, Y., Heaven, S., Venetsaneas, N., Banks, C.J., Bridgwater, A.V., 2018. Slow pyrolysis of organic fraction of municipal solid waste (OFMSW): Characterisation of products and screening of the aqueous liquid product for anaerobic digestion. Appl. Energy 213, 158–168. https://doi.org/10.1016/j.apenergy.2018.01.018.

Yang, Y., Liew, R.K., Tamothran, A.M., Foong, S.Y., Yek, P.N.Y., Chia, P.W., Van Tran, T., Peng, W., Lam, S.S., 2021. Gasification of refuse-derived fuel from municipal solid waste for energy production: a review. Environ. Chem. Lett. 19, 2127–2140. https://doi.org/10.1007/s10311-020-01177-5.

Yang, Q., Zuo, C., Liu, X., Yang, Z., Zhou, H., 2020. Risk response for municipal solid waste crisis using ontology-based reasoning. Int. J. Environ. Res. Public Health 17, 3312. https://doi.org/10.3390/ijerph17093312.

Yigitcanlar, T., Cugurullo, F., 2020. The Sustainability of Artificial Intelligence: An Urbanistic Viewpoint from the Lens of Smart and Sustainable Cities. Sustain. Sci. Pract. Policy 12, 8548. https://doi.org/10.3390/su12208548.

Yu, Y., Wu, J., Ren, X., Lau, A., Rezaei, H., Takada, M., Bi, X., Sokhansanj, S., 2022. Steam explosion of lignocellulosic biomass for multiple advanced bioenergy processes: A review. Renew. Sustain. Energy Rev. 154, 111871 https://doi.org/10.1016/j.rser.2021.111871.

Zamri, M.F.M.A., Hasmady, S., Akhiar, A., Ideris, F., Shamsuddin, A.H., Mofijur, M., Fattah, I.M.R., Mahlia, T.M.I., 2021. A comprehensive review on anaerobic digestion of organic fraction of municipal solid waste. Renew. Sustain. Energy Rev. 137, 110637 https://doi.org/10.1016/j.rser.2020.110637.

Zhan, X., Kirkelund, G.M., 2021. Electrodialytic remediation of municipal solid waste incineration fly ash as pre-treatment before geopolymerisation with coal fly ash. J. Hazard. Mater. 412, 125220 https://doi.org/10.1016/j.jhazmat.2021.125220.

Zhang, Y., Li, H., Liu, C., Cheng, Y., 2015. Influencing mechanism of high solid concentration on anaerobic mono-digestion of sewage sludge without agitation. Front. Environ. Sci. Eng. 9, 1108–1116. https://doi.org/10.1007/s11783-015-0806-x.

Zhang, X., Liu, C., Chen, Y., Zheng, G., Chen, Y., 2022. Source separation, transportation, pretreatment, and valorization of municipal solid waste: a critical review. Environ. Dev. Sustain. 24, 11471–11513. https://doi.org/10.1007/s10668-021-01932-w.

Zhou, C., Deng, Z., Zhang, Y., Li, X., Liu, Y., Fu, J., Chen, L., Yuan, Y., Jin, Y., Dai, J., Yu, M., Zhang, C., Liu, C., Ao, W., Li, Y., 2022. Pyrolysis of typical solid wastes in a continuously operated microwave-assisted auger pyrolyser: Char characterization, analysis and energy balance. J. Clean. Prod. 373, 133818 https://doi.org/10.1016/j.jclepro.2022.133818.

Zhu, X., Zhou, S., Zhang, Z., Zhang, Y., Li, J., Ahmed, S., Yan, B., Chen, G., Li, N., 2021. Flue gas torrefaction of distilled spirit lees and the effects on the combustion and nitrogen oxide emission. Bioresour. Technol. 342, 125975 https://doi.org/10.1016/j.biortech.2021.125975.

Zhu, X., Li, S., Zhang, Y., Li, J., Zhang, Z., Sun, Y., Zhou, S., Li, N., Yan, B., Chen, G., 2022. Flue gas torrefaction of municipal solid waste: Fuel properties, combustion characterizations, and nitrogen /sulfur emissions. Bioresour. Technol. 351, 126967 https://doi.org/10.1016/j.biortech.2022.126967.

Zhu, X., Liu, B., Sun, L., Li, R., Deng, H., Zhu, X., Tsang, D.C.W., 2023. Machine learning-assisted exploration for carbon neutrality potential of municipal sludge recycling via hydrothermal carbonization. Bioresour. Technol. 369, 128454 https://doi.org/10.1016/j.biortech.2022.128454.