



# A Review on Waste Management Techniques for Sustainable Energy Production

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## ABSTRACT

Energy consumption worldwide is increasing due to increased populations, industrialization, and technological development, underlining the importance of efficient energy use. Waste-to-energy technologies are also known as waste-to-energy systems, whereby the production of energy and waste management are considered interrelated. This review summarizes the present trends and state-of-the-art waste management technologies, where renewable energy systems have been integrated into waste management infrastructure and how optimization algorithms help to improve waste management systems. Anaerobic digestion, pyrolysis, and gasification processes raise wastes and convert them into energy products like biogas and syngas, which follow material flow and recovery. Another important area covered in the study is implementing machine learning-optimized methods, genetic algorithms, and artificial neural networks for waste processing and energy recovery. These threats become as follows: high capital costs, feedstock fluctuations, and public perception are tackled alongside solutions like policy support or engagement of the communities involved. This review focuses on the importance of multi-disciplinary systems to achieve future sustainable Waste-to-Energy systems for both the global environment and energy objectives.

**Keywords:** Waste Recycling ▪ energy ▪ Organic resources ▪ Optimization ▪ Recycling ▪ Sustainable environment

## 1. INTRODUCTION

Global energy consumption has risen over several decades due to population growth, industrialization, and technological development. Conventional energy remains responsible for substantial environmental pollution through greenhouse-gas emissions and other pollutants. These challenges demonstrate the urgent need to tap into sustainable and renewable energy sources to meet energy requirements without worsening environmental impact [1].

Interest has therefore increased in shifting from fossil-based energy to renewable resources such as solar, wind, hydro, and biomass. Biomass is particularly important as a feedstock in waste-to-energy (WTE) systems, where organic and inorganic waste is converted into useful energy products. Effi-

cient waste management addresses the accumulation of waste stocks and contributes to resource utilization, including energy production [2].

Renewable energy refers to the availability of sufficient energy to meet present demand without exhausting resources needed by future generations. In energy-recovery waste management, this principle is linked to maintaining circular material flows by diverting waste from landfills and reducing emissions. However, to fully harness the capabilities of WTE systems, additional methods and approaches must be incorporated to achieve adequate results [3].

Optimization algorithms have become indispensable for improving the efficiency of waste-management and energy systems. These algorithms address issues such as process opti-

mization, cost reduction, and environmental-impact mitigation. With the help of optimization methods, stakeholders can make effective decisions on waste-processing technologies, logistics, and energy-recovery pathways [4].

Different optimization techniques, including linear programming, genetic algorithms, particle swarm optimization, and artificial neural networks, have been employed in waste-to-energy systems. Such methods support the modeling and simulation of alternative scenarios to identify efficient resource use, waste treatment, and energy-conversion strategies. Their integration helps align waste-management practices with economic, environmental, and social objectives [5].

Complementary renewable-energy technologies used in waste-management systems include anaerobic digestion, pyrolysis, and gasification. These processes transform waste material into energy-bearing products such as biogas, bio-oil, and syngas, which can be used for electricity production, heating, and automotive applications. Optimization algorithms complement these technologies by improving process parameters, minimizing costs, and increasing energy generation.

Despite these benefits, key issues remain, including high capital costs, public acceptance, and technical constraints. Addressing these points requires engineering effort, policy support, and community engagement. Resource-use optimization can also help overcome these challenges by identifying efficient solutions [6].

This review presents a synthesis of works related to waste management for sustainable energy production, with emphasis on optimization techniques. It indicates the current state of the field, the principal technologies used, and directions for further study. Overall, the review highlights how waste management, renewable energy, and optimization can be used together to support a more sustainable energy future.

## 2. LITERATURE REVIEW

This literature review concentrates on the advanced techniques and technologies that effectively address the most challenging problems in various sectors, such as energy management, sustainability, and material sciences. The reviewed works outline several ideas that support sustainable-development paradigms, including green synthesis methods, machine learning for optimization, integrated energy systems, and new conceptual paradigms of sustainable infrastructure. Therefore, this review synthesizes these studies' ideas to understand how cutting-edge practices in biodiesel manufacturing, microgrid control, wireless communications, and renewable energy systems support international environmental preservation and technological development objectives. The emphasis made toward optimization, resource usage, and sustainability is evidence that those innovations are vital in combating present-day issues. This section establishes the principles that explain how interdisciplinary strategies support advances toward efficient and sustainable solutions.

According to [7], the qualitative and quantitative factors in water resource issues like distribution, key water quality issues, water conditions, environmental effects and sustainable policies in water affairs are solved. The research considers the top surface water system of the Dez River from the Dez regulatory dam up to Band-e-Ghir by simulating current conditions with

the coupled model, which couples system components and defines efficient exploitation plans. A multi-objective particle swarm optimization algorithm is introduced to strike a balance between the goals of a higher supply fulfillment rate and lower water-quality deviation. Outcomes show that demand priorities receive higher satisfaction and pollution violation events are lower, especially at the agricultural withdrawal points without excluding near-standard river quality. These results demonstrate that qualitative-quantitative modeling and sophisticated optimization methods such as NSGA-II are applicable to sustainable water-resource management while considering stakeholder requirements and environmental impacts.

As mentioned in the paper [8], sustainability is now one of the most important concerns for companies and governments worldwide, discussing topics such as climate warming, decreased resources, decreased spaces for disposal, and increased water levels. This research focuses on how AI revolutionizes sustainable product developments by adopting resource-inefficient, wasteful processes. In the IT industry, artificial intelligence innovations, including dynamic workload scheduling, predictive system maintenance, and traffic control, aid in minimal power usage of servers and networks. The next generation of sophisticated algorithms enhances data efficiency, management and delivery, reducing the carbon footprint of data-conveyance procedures. In addition, AI enables renewable energy management, monitors carbon emission footprints, and provides recommendations for sustainable software and IT systems, organizational performance improvements, and global sustainable development initiatives. This study has highlighted the potential of AI in cutting down the environmental impact of IT systems while simultaneously achieving growth and performance goals.

According to [9], there is a growing demand for adequately treating industrial wastewater because of the continuous increase and diversification of pollutants produced by several industries. Compared to other treatment techniques, electrocoagulation (EC) has garnered interest due to its effectiveness in removing a wide range of pollutants including heavy metals, oils and suspended solids. However, high energy consumption and secondary waste generation make them less suitable. The relation between EC and hybrid treatment systems is studied by integrating EC systems with biological treatment, filtration, adsorption and AOPs to improve treatment efficiency and sustainability. This integration enhances the ability to remove pollutants, decrease energy consumption, and minimize the sludge formed. Continuous monitoring and control systems enhance these processes, making them variable to the wastewater composition. The paper presents the EC hybrid system case studies as a cost-effective means of operating complex industrial effluents with lower operational costs, chemical use reduction, and resource recovery potential, making this approach sustainable.

Based on the works stated in [10], the electrocoagulation process is considered one of the green processes used commercially in water treatment owing to its cost-effective, efficient and environmentally friendly mode of pollutant removal. Unlike chemical coagulation, EC uses an electrical energy source to generate coagulants on site, thus minimizing the need for external chemicals and secondary pollution. By tar-

getting and handling pollutants, including heavy metals, oils, dyes and pathogens, the tech is best suited for industrial, agricultural and municipal use. New developments in electrode materials, integration of renewable energy sources and hybrid systems reduced its carbon emissions and operation cost, thereby increasing its sustainability. As such, applications include water reuse, pre-treatment for seawater desalination, and nutrient recovery, contributing to promoting a circular water economy that underpinned every sustainable development and climate action. Further work focuses on developing large-scale EC systems, fine-tuning the operating variables and enhancing electrode lifetime, underlining its applicability as a more sustainable approach to water management and backing the tenets of the United Nations' Sustainable Development Goals.

In the study conducted in [11], the authors describe *Suaeda aegyptiaca* as a halophytic plant with strong prospects for industrial use, including bioremediation of saline land, pharmaceuticals, bioactive compounds, and biofuel production. Habitat suitability for large-scale cultivation of *S. aegyptiaca* in saline areas is assessed using species distribution models (SDMs) and machine-learning algorithms such as Random Forest (RF) and Support Vector Machine (SVM). The research was undertaken in Bushehr Province, Iran and employed 72 field-recorded events and 18 environmental variables to build ecosystem models. With 70% of the data used for training and 30% for validation, the RF model demonstrated superior predictive accuracy (AUC = 0.965) compared with the SVM model (AUC = 0.886). Habitat suitability was determined to be highly dependent on elevation and slope. The findings support that the RF model is viable for ecological planning to mitigate soil salinization issues and encourage salt-resistant crop production to improve food production/processing industries and agribusiness ventures in salinity-affected zones. This research also proves the usefulness of methods like RF or SVM from machine learning techniques as tools for situations like ecological modeling or managing biodiversity concerns.

As described in [12], while MSW combustion for electricity production utilizing waste to energy is consistent with circular economy thinking, the concern of pollutant emission cannot be overemphasized because of the social and ecological implications. CC and CLC techniques for converting MSW into energy through incineration as a technology with options for carbon dioxide capture are considered here. Therefore, the multi-objective optimization of the proposed system is performed using NSGA-II, where total capital investment (TCI) and exergy efficiency (EE) are taken as the objectives. The things show that, even if CLC needs a TCI that is 23.41% more than that of CC, it gives 5.91 years shorter payback period and a carbon dioxide capture rate of 2,686 tons per year. Finally, an assessment of the financial, economic and energy performances points toward the desirability of CLC as a more sustainable approach and a better overall business case. These findings would be informative to policymakers and investors in choosing the right MSW incineration technologies for sustainable environmental improvement and practical implementation ability.

As in [13], carbonizing agro-industrial wastes for obtaining CNMs can become one of the most efficient and environ-

mentally friendly approaches to sustainable nanotechnology and waste reuse. This approach employs sustainable raw materials like agro-residues, food processing byproducts, and forestry residues ready for applications like pyrolysis, HTP and CVD to generate CNMs with desired properties and mouth feel. Microscopy, spectroscopic and computational methods characterize the nanomaterial morphology and function to enhance understanding for application in numerous fields. Potential uses of CNMs include energy storage, pollution treatment, catalysis, biomedical engineering and agriculture because they share properties like high surface area, chemical stability, mechanical strength and electrical conductivity originating from their agro-industrial waste origin. Examples are supercapacitors, water filtration, Pharmaceutical technology and agriculture. Consequently, the research continues concerning feedstock selection, cost reduction, and overcoming the barriers to large-scale production and regulatory compliance. This work has highlighted how CNMs can transform sectors such as waste management and encourage technology development, as well as how a shift towards the cornerstones of the circular economy – reduction and efficient utilization of resources- is possible through CNMs.

Following the method explained in [14], MoO<sub>3</sub> nanostructures were prepared by doping with different amounts of nickel, 1, 3, and 7 wt% to be accurate for energy storage and photocatalytic activity. XRD and FT-IR results confirmed the crystal structure of orthorhombic MoO<sub>3</sub> with successful nickel doping with Raman spectra and SEM images showing nanospheres of 80–90 nm diameters. The electrochemical test results of the 5 wt% nickel-doped MoO<sub>3</sub> demonstrated that the MoO<sub>3</sub> electrode had a very high specific capacitance of 1677.3 F g<sup>-1</sup> at 1 A g<sup>-1</sup>, that it has higher pseudo capacitance. It demonstrated excellent cyclic stability, where after 5000 cycles; it had dropped to 93.7% only. Photocatalytic tests proved the improvement with energy bandgap decrease to 2.80 eV and degradation efficiency of 95% of Rhodamine B within 70 min, which is four times more efficient than pure MoO<sub>3</sub>. These studies showed that nickel doping provided suitable alterations to the arrangement and forms of these nanostructures, leading to optimal electrochemical and photocatalytic activity, making them suitable materials for energy and water treatment technologies.

As described in [15], the principles of responsible consumption within spatial contexts and creating sustainable cities require developing approaches to designing and producing chemicals, including the biodegradability of new chemical entities. The current work reports the ability of ten sets of 3-D molecular descriptors to discriminate between compounds with fast biodegradation. These descriptors were obtained with the Merck molecular force field (MMFF94s) and the 3-D geometries of the compounds of a set of chemical molecules, which were selected and determined. Through cross-validated 5-fold AUC metrics, SVM and all tree-based methods (XGBOOST, GBM, and Random Forest) were tuned using a Bayesian algorithm for computational efficiency and relevancy. Our findings of cross-validated AUC averaged 0.962, demonstrating that these four methods are the most effective in classifying developmental PT and PTL. Of the descriptors considered, GETAWAY, 3-D autocorrelation, and 3-D-MoRSE were the most effective. For the SVM model

trained with 3-D autocorrelation descriptors, we obtained the highest prediction accuracy of 0.88, the AUC=0.93, sensitivity = 0.83, specificity=0.91, F1 Score = 0.82. PFI, SHAP, and PDP were applied to determine the model's most significant decision 3-D autocorrelation descriptors. Overall, the results demonstrate the importance of 3-D molecular descriptors, especially 3-D autocorrelations, for constructing accurate, transparent prediction models for biodegradability. This work contributes to designing green chemicals, SDGs 11 and 12 and promoting legal systems for sustainable chemical production that create sustainable cities and reduce environmental harm.

Self-powered or photovoltaic (PV) systems have specific efficiency and reliability issues concerning the environment, thermal control, and prognostics. Due to these concerns, the study [16] presents a new Digital Twin framework that comprises physical modeling in MATLAB Simulink, analytical equations, and Gradient Boosting Regression Trees. This work also involves the actual implementation of the framework using data obtained in real-time from a 2.88 kW on-grid PV system, further demonstrating the operational usefulness of the theoretical proposals made in this work. This approach goes beyond standard practices of monitoring and tracking equipment and plants by allowing absolute time control and actual operation in changing conditions with real-time projections for maintenance and operations. The framework obtained a predictive accuracy of 99.77%, thus laying out the possibility of improving system performance and flexibility. Therefore, the proposed framework will incorporate real-time data and state-of-the-art models to provide a low-cost PV energy-management system.

As pointed out in [17], current trends in microgrid energy management tend to concentrate on optimizing the dispatch of DERs based on the cost function while emissions considerations. To this end, the study introduces an incentive-based demand response (IBDR) that gives customers incentives for load shaving during peak hours, hence curtailing emissions and generation costs. The economic–environmental trade-off involves balancing operating cost and emissions. Six scenarios were chosen based on different levels of grid involvement, and the approach to the electricity market pricing was investigated using the differential evolution algorithm. It was found that implementing IBDR has reduced generation costs by 10–13%, reduced peak demand by 6–8% and increased load factor by 4–5%. Integrating the weighted economic emission dispatch algorithm allowed IBDR to provide suitable optimization for different load models and costs while reducing the associated emissions to prove the method's reliability in improving microgrid efficiency.

As detailed in [18], this study investigates the production of biodiesel from waste cooking oil using waste eggshells as a heterogeneous catalyst, achieving a yield of 77.687% under specific conditions: Catalyst concentration of 4 wt.%, the temperature of the reaction was 65°C, the time taken for the reaction was 180 minutes, and methanol to oil ratio of 13:1. Thus, ML models such as Boosted Huber and Boosted LASSO and the Artificial Neural Network (ANN) were built to enhance and forecast biodiesel yields; however, ANN was found superior to other models ( $R^2 = 0.998$ , RMSE = 0.2525, MSE = 0.0637). Optimized conditions us-

ing the Adam algorithm yielded a peak biodiesel production of 76.845% at 65.87°C, 182.48 minutes, 3.8 wt.% catalyst loading, and a 13:1 methanol-to-oil ratio. Reusability assessments for the catalyst revealed that the yield reduced from 77.687% to 41.560% after four catalyst cycles, which remains comparable to other heterogeneous catalysts. This research demonstrates that waste-derived catalysts are a viable option for biodiesel production and highlights the importance of using machine learning to improve biofuel production while conserving energy and managing waste.

According to the work presented in [19], sensing, communication, and power transfer, also called ISCPT, in communication networks provide a good opportunity to develop environmentally friendly next-generation wireless systems based on information transfer, sensing of the environment, and wireless power transfer. Providing the ideal beamforming in an ISCPT system poses a problematic non-convex optimization problem with additional considerations such as QoS, radar sensing precision, and power conversion efficacy. CSI is vital for channel knowledge as CSI inaccuracies adversely affect enhanced beamforming and overall system performance. In order to address these challenges, the study proposes a Deep Reinforcement Learning (DRL) based framework that also adapts sensing, communication, and energy harvesting in dynamic environments with possibly no CSI information. DRL can address the issue of resource management and coordinate resource allocation by changing system parameters and using adaptive techniques that improve dependability and productivity. The results confirm that the proposed DRL-based approach successfully balances the amount of resources and power for transmitting data, making it a valuable solution for future ISCPT systems operating in unpredictable and challenging environments.

As described in [20], WRSNs for monitoring and data collection in large-scale and dynamic environments are used frequently, where energy self-sufficiency of sensor nodes is fundamental for continuous operation. This work presents an overview of the current scientific research and technological advances in providing energy on demand for WRSNs. It classifies energy-scavenging techniques using solar, kinetic and other ambient sources and reviews enhancements in storage devices like supercapacitors and rechargeable batteries. We also discuss adaptive energy management policies, which consider energy consumption and harvesting in controlling the overall network energy efficiency. This paper provides a detailed overview of current solutions while outlining some of the weaknesses and prospects of the study of on-demand energy provisioning. Therefore, the current survey can be beneficial to researchers and policymakers. The current study aligns the various research activities to contribute effectively toward future developments of efficient and autonomous WRSNs, providing enhancements in various applications, such as environmental and climate surveillance, smart agriculture, and smart city infrastructures.

Table 1 provides an extensive list of research studies that shed light on developments in sustainable waste management, energy optimization, and related environmental technologies. Cumulatively, the reviewed studies display the constructive affordances of novel technologies and techniques applicable to global issues. These works span sustainable chemical re-

**Table 1.** Summary of Literature Review

Ref.	Study Focus	Key Findings	Applications/Implications
[7]	Sustainable water resource management using coupled qualitative–quantitative models	NSGA-II optimization achieved high supply fulfillment and reduced pollution violations in water resource systems, focusing on environmental criteria.	Enhances sustainable water management and prioritizes ecological balance.
[8]	AI-driven sustainability in the IT sector	AI improves energy efficiency in IT operations through workload optimization, predictive maintenance, and renewable energy integration.	Reduces the environmental impact of IT systems while maintaining operational efficiency.
[9]	Industrial wastewater treatment using electrocoagulation and hybrid systems	Hybrid systems enhance pollutant removal efficiency, reduce sludge formation, and optimize energy usage through real-time monitoring.	Offers sustainable wastewater treatment solutions with resource recovery potential.
[10]	Electrocoagulation as a green water treatment method	EC eliminates pollutants such as heavy metals and pathogens, integrates renewable energy, and supports nutrient recovery.	Provides scalable, sustainable water treatment aligned with global SDGs.
[11]	Habitat suitability modeling for <i>Suaeda aegyptiaca</i> cultivation	RF outperformed SVM for habitat prediction (AUC: 0.965), with elevation and slope as key factors.	Advances sustainable agriculture and supports salinity-affected agribusiness ventures.
[12]	MSW incineration optimization for sustainability	CLC offers higher CO <sub>2</sub> capture but requires greater TCI; it gives cost savings, shorter payback, and improved environmental outcomes over CC.	Guides policymakers in adopting sustainable waste incineration technologies.
[13]	CNMs from agro-industrial wastes	Produces high-performance CNMs using pyrolysis and other methods for catalysis, energy storage, and pollution treatment.	Promotes sustainable waste management and innovation in nanotechnology.
[14]	Nickel-doped MoO <sub>3</sub> for energy and water treatment applications	Optimized MoO <sub>3</sub> nanostructures showed superior capacitive and photocatalytic properties.	Enhances energy storage and wastewater purification technologies.
[15]	Predicting chemical biodegradability using 3-D molecular descriptors	SVM and tree-based models achieved high prediction accuracy; 3-D autocorrelation descriptors were critical.	Supports green chemical manufacturing and regulatory compliance.
[16]	Digital Twin framework for PV system optimization	The framework achieved 99.77% predictive accuracy for real-time monitoring and optimization of PV systems.	Provides a cost-effective, scalable solution for PV energy management.
[17]	Incentive-based demand response in microgrids	IBDR reduced generation costs by 10–13%, peak demand by 6–8%, and improved load factors by 4–5%.	Enhances microgrid efficiency and sustainable energy practices.
[18]	Biodiesel production using waste-derived catalysts	Achieved a yield of 77.687%; ANN optimized process parameters and catalyst reuse.	Promotes waste-to-energy conversion and sustainable biodiesel production.
[19]	ISCP system optimization using DRL	DRL improved resource allocation and beamforming efficiency under incomplete CSI.	Advances wireless systems integrating sensing, communication, and power transfer.
[20]	On-demand energy provisioning in WRSNs	Reviews harvesting, storage, and adaptive management strategies for autonomy in WRSNs.	Supports environmental monitoring and smart city infrastructure.

action schemes, efficient energy-enterprise frameworks, and new material designs using advanced tools such as machine learning, renewable resources, and efficient molecular designs. The significant conclusions highlight the importance of optimization and sustainability in rational and efficient energy, environmental, and industrial applications.

### 3. DISCUSSION

Appropriate waste-management strategies for clean and efficient energy generation require the integration of modern conversion technologies, renewable-energy systems, and suitable optimization algorithms. Because this issue involves environmental, economic, and social dimensions, an integrated perspective is necessary for achieving sustainable implementation. The findings reviewed in this paper create several important discussion points for future waste-to-energy development [21].

Renewable-energy technologies such as anaerobic digesters, pyrolysis systems, and gasifiers are crucial for transforming waste streams into useful energy products. These technologies recover energy from organic and inorganic waste, reduce reliance on landfills, and lower greenhouse-gas emissions. Nevertheless, technical challenges such as feedstock variability, optimal operation, and scalability remain significant, requiring further development before these technologies can be widely deployed [22].

Optimization algorithms can substantially improve the performance of waste-to-energy systems. Methods such as genetic algorithms, particle swarm optimization, and machine-learning techniques can tune key parameters related to energy-conversion efficiency, cost performance, and environmental

efficiency. However, the mixed and unstructured nature of waste, together with variation in input data, makes it difficult to design algorithms that conform to specific system models. Future research should therefore consider hybrid optimization techniques that combine multiple methods to obtain more robust solutions [23].

Economic profitability remains a major barrier to the adoption of waste-to-energy facilities. High capital costs and operational expenses can discourage stakeholders from financing these technologies. Optimization algorithms can help address this barrier by identifying economically and practically viable resource configurations. In addition, supportive policies, grants, and fiscal incentives are important for attracting investment in sustainable waste-management practices [24].

Public acceptance is another essential factor in the success of waste-to-energy projects. Negative attitudes toward waste-processing facilities and concerns about environmental or health impacts can limit project construction. Acceptance can be improved by educating communities and involving them transparently in decision-making processes. Public input may also improve optimization feasibility when incorporated into planning and decision-support models [25].

Environmental impacts must also be carefully considered when designing waste-management systems for energy production. Although waste-to-energy systems can minimize waste and generate energy, they may also produce emissions and byproducts. Life cycle assessment (LCA) can quantify these impacts and guide the design of environmentally balanced systems. Integrating LCA with optimization algorithms can therefore help minimize environmental harm while supporting electric-power generation [26].

The current shift toward the circular economy further strengthens the importance of sustainable waste-management strategies. Waste-to-energy systems treat waste as a resource, thereby conserving resource-rich materials and reducing consumption. Adapting these systems to circular-economy principles requires knowledge from engineering, policy, and environmental science, as well as coordination among technical and institutional stakeholders [27].

Emerging technologies such as artificial intelligence and the Internet of Things (IoT) provide additional opportunities to improve waste-to-energy systems. Real-time monitoring, predictive maintenance, and decision-support tools can enhance resource optimization and operational reliability. These technologies can improve the effectiveness, dependability, and sustainability of waste-to-energy initiatives [28].

Overall, the coordinated application of waste management, renewable energy, and optimization algorithms provides a plausible pathway toward sustainable energy generation. However, existing challenges require continuous innovation, supportive policy, and public engagement. Subsequent studies should focus on designing low-cost, environmentally friendly waste-to-energy technologies that are aligned with sustainable-development goals.

#### 4. CONCLUSION

A feasible approach for the integration of waste management techniques with renewable energy systems and optimization algorithms for efficient energy generation has been discussed. Some of the key messages of this review include the fact that waste-to-energy technologies offer a unique opportunity to meet current global energy needs and offer solutions to existing environmental problems.

In this way, such systems play a significant role in waste management, resource recovery, and climate-change mitigation, supporting the principles of circular economy and sustainable development.

Renewable energy treatments, including anaerobic digestion, pyrolysis, and gasification, can convert waste streams into high-value bioenergy products such as biogas, syngas, and bio-oils.

These technologies reduce reliance on landfills and fossil fuels while supporting greener energy pathways.

However, their scalability and efficiency remain constrained by several technical factors, including feedstock variability and operation complications.

The review identifies limitations in the effectiveness and usability of these waste-to-energy systems; however, more research and development effort is required to overcome these drawbacks and enhance the performance of these systems.

Hence, optimization algorithms are crucial for improving waste-to-energy system efficiency, affordability, and viability. Genetic algorithms, particle swarm optimization, and artificial neural networks support modeling and simulation for improved decisions on waste processing, energy recovery, and resource allocation.

Nonetheless, challenges related to data quality, feedstock variability, and computational burden must be managed to obtain the best performance from these optimization techniques.

Technological, economic, and social factors significantly influence the incorporation of waste into energy systems.

Barriers related to the large-scale deployment of waste-to-energy systems include high capital costs, difficulties in access to financing, and potential social concerns about the environment.

Possible solutions to these challenges include using optimization tools to reduce costs, enhancing supportive policies and incentives, creating awareness, and involving the community in the process.

Efficient utilization of waste-to-energy technologies requires integration of technology advancement with policy framework and societal support.

In conclusion, safe and eco-friendly approaches to sustainable waste management and energy generation offer effective solutions to global energy and ecological crises.

By implementing renewable energy technologies, efficient optimization algorithms and supportive policy systems, these systems can enhance efficiency, energy economics and sustainability.

Further studies should improve conversion techniques, construct better optimization models, and address unresolved implementation issues.

These actions will help make waste-to-energy systems a cornerstone in the move to the new sustainable energy paradigm.

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