



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, industrialization, and technological development. Conventional Energy is responsible for most environmental pollution through greenhouse emissions and other pollutants. These challenges demonstrate the rapid need to tap into sustainable and renewable energy sources to meet energy requirements without worsening environmental impact [1].

Thus, increasing interest has been in switching from fossil-based to renewable energy resources like solar, wind, hydro and biomass. One of them is biomass, which acts as a feed in waste-to-energy (WTE) systems where organic and inorganic waste is converted into useful energy products. Efficient waste management solves challenging issues related to accumulating waste stocks and contributes to efficient resource utilization, including energy production [2].

Renewable Energy refers to the availability of sufficient Energy in the present demand without exhausting the energy resources that the succeeding generations could use. The principle related to waste management for energy recovery is maintaining the circularity of waste that will not end up in landfills, hence decreasing

emissions. However, to fully harness the capabilities of WtE systems, additional methods and approaches must be incorporated to attain adequate results [3].

Optimization algorithms have, therefore, been established to be indispensable in promoting the efficiency of waste management and energy systems. These algorithms are meant to solve various issues: manufacturing process optimization, reduction of expenses, or environmental effects. This means that with the help of outlined optimization methods, stakeholders can make effective decisions on waste processing technologies and logistic and energy recovery pathways [4].

Based on the analysis, different optimization techniques like linear programming, genetic algorithms, particle swarm optimization, and artificial neural networks have been employed under waste-to-energy systems. Such methods allow for the construction of a model and subsequent simulation of various situations to find the best usage of resources and efficient ways to treat wastes and convert Energy. The integration of these algorithms ensures that waste management practices are consistent with economic, environmental and social objectives [5].

The complementary renewable energy technologies used in waste management systems have produced solutions like anaerobic digestion, pyrolysis, and gasification. These processes transform waste material into energy-bearing products such as biogas, bio-oil and syngas that can be applied in electricity production, heating and automotive use. Optimization algorithms complement these technologies by optimizing the process parameters, minimizing costs and increasing energy generation.

Again, there are key issues, including high capital costs, public acceptance, and technical constraints. Solutions to these points need effort from engineering, policy support, and efforts to engage the community. Closer consideration of resource use can also help with these challenges, as optimization algorithms help determine the most efficient solution [6].

This review aims to present a synthesis of the works related to waste management for sustainable energy production, focusing on optimization techniques. It is designed to indicate the field today, the personnel technologies utilized, and the thrusts for further study. This review highlighted how waste management, RE, and optimization can be used together to point the way toward 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. Because of the works in question, the following ideas on influencing sustainable development underpinning paradigms are outlined: 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.

Based on Gosling [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 simulation the current affairs with the coupled model, which has an active connection between them and defines the 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 lesser quality standard 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. Given these results, the applicability of qualitative quantitative dynamics and sophisticated solutions such as NSGA-II is revealed for the development of sustainable water resource management, considering clients' requirements and impacts on the environment.

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 targeting 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 emission 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 author describes *Suaeda aegyptiaca* as a halophytic plant that has excellent prospects in industrial use, such as the use of bioremediation of saline land, pharmaceuticals, bioactive compounds, and biofuel production. The assessment of habitat suitability for large-scale cultivation of *S. Egyptian* is assessed in saline areas using the Species Distribution Models (SDMs) together with other machine learning algorithms such as Random Forest (RF) and Support Vector Machine (SVM), among others. 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 data for training and 30% for validation, the RF model demonstrated superior predictive accuracy (AUC: 0.965) while the SVM model has adopted 0.886 of AUC. 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 environmentally 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], MoO₃ 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 MoO₃ 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 MoO₃ demonstrated that the MoO₃ electrode had a very high specific capacitance of 1677.3 Fg⁻¹ at 1 Ag⁻¹, 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 MoO₃. 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 3D 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, 3D autocorrelation, and 3D-MoRSE were the most effective. For the SVM model trained with 3D 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 3D autocorrelation descriptors. Overall, the results demonstrate the importance of 3D molecular descriptors, especially 3D 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, low-optimal energy management PV system for optimal energy management.

As pointed out in [17], more current trends in microgrid energy management tend to concentrate on optimizing the dispatch of DERs based on the cost function while polluting emissions consideration. 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. A trade-off mission Management of economic and environmental sustainability encompasses 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 using 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% down to 41,560% in the catalyst. Four cycles are comparable to other heterogeneous catalysts. This research demonstrates that waste-derived catalysts are a viable option for biodiesel production and the importance of using machine learning to improve bio-fuel 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 the means end by changing system parameters and utilizing adaptation 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 existing 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 today's solution 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 the features of development in sustainable ways, energy saving, and novel technologies. The studies include a broad range of issues, such

as managing water supply, applying Artificial Intelligence in the sustainability of the IT industry, treating industrial wastewater, and biodiesel synthesis by utilizing biodiesel-originated catalysts from wastes. Prominent observations focus on applying improved optimization algorithms like NSGA-II and employing machine-learning models to increase efficiency and develop sustainability in multifarious use. The studies also explore the possibilities of using new materials and frameworks, carbon nanomaterials and Digital Twin systems, especially in addressing today's energy, pollution and resource issues. These researched studies strongly support the need for incorporating technology and cross-sectoral strategies to realize sustainable development and global environmental objectives.

Table 1: Summary of Literature Review

<i>Reference</i>	<i>Study Focus</i>	<i>Key Findings</i>	<i>Applications/Implications</i>
[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 (EC) 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 efficiently eliminates pollutants like heavy metals and pathogens, integrates renewable Energy, and supports nutrient recovery in circular water economies.	Provides scalable, sustainable water treatment aligned with global SDGs.
[11]	Habitat suitability modeling for Suaeda aegyptiaca cultivation	RF model outperformed SVM for habitat prediction (AUC: 0.965), with elevation and slope as key factors; it promotes salt-tolerant crop cultivation in saline regions.	Advances sustainable agriculture and supports salinity-affected agribusiness ventures.

[12]	MSW incineration optimization for sustainability	The CLC method offers higher CO ₂ capture but requires greater TCI; it achieves cost savings, shorter payback, and improved environmental outcomes over the CC method.	Guides policymakers in adopting sustainable waste incineration technologies.
[13]	CNMs from agro-industrial wastes	Produces high-performance CNMs using pyrolysis and other methods; supports diverse applications like catalysis, energy storage, and pollution treatment.	Promotes sustainable waste management and fosters innovation in nanotechnology.
[14]	Nickel-doped MoO ₃ for energy and water treatment applications	Optimized MoO ₃ nanostructures demonstrated superior capacitive and photocatalytic properties with high specific capacitance and efficient pollutant degradation.	Enhances energy storage and wastewater purification technologies.
[15]	Predicting chemical biodegradability using 3D molecular descriptors	SVM and tree-based models achieved high prediction accuracy; 3D autocorrelation descriptors proved critical for robust biodegradability modeling.	Supports green chemical manufacturing and regulatory compliance.
[16]	Digital Twin framework for PV system optimization	Framework achieved 99.77% predictive accuracy for real-time monitoring and optimization of PV systems under varying environmental conditions.	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%, balancing economic and environmental sustainability.	Enhances microgrid efficiency and supports sustainable energy practices.

[18]	Biodiesel production using waste-derived catalysts	Achieved a yield of 77.687%; machine learning (ANN) optimized process parameters; catalyst showed reusability over multiple cycles.	Promotes waste-to-energy conversion and sustainable biodiesel production.
[19]	ISCPT system optimization using DRL	DRL improved resource allocation and beamforming efficiency in dynamic ISCPT systems, overcoming the challenges of incomplete CSI.	Advances next-generation wireless systems with integrated sensing, communication, and power transfer.
[20]	On-demand energy provisioning in WRSNs	Reviews energy harvesting, storage, and adaptive management strategies; highlights innovations for enhancing energy efficiency and autonomy in WRSNs.	Supports sustainable WRSN applications in environmental monitoring and smart city infrastructures.

Cumulatively, the reviewed studies display the constructive affordances of novice technologies and techniques applicable to global issues. These works span from sustainable chemical reaction schemes for producing chemicals to enhanced frameworks for efficient enterprises for energy applications and the design of new materials 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. These innovations fill technological and practice gaps that support environmentally friendly systems' sustainability in response to global goals. This review underscores the need to practice interdisciplinary research and advancement further to cope with emerging societal and environmental challenges.

3. Discussion

Appropriate waste management strategies for efficient, clean energy generation entail applying modern technologies, enhanced forms of renewable Energy and suitable algorithms. Solving this complex issue requires an integrated analysis of the environmental, economic and social factors for sustainability. The ideas and findings suggested in this review create several discursive topics worth considering [21].

Renewable energy technologies such as biodigesters, pyrolizers, and gasifiers are crucial in transforming waste workout into energy products. These technologies help harvest Energy from wastes, be they organic or inorganic, decreasing landfill reliability and emissions of greenhouse gases. Nevertheless, technical issues like feedstock variability, optimal operations, and general scalability remain thorny. More development is required to make these technologies more exploitable across the board [22].

As discussed in this paper, optimization algorithms can enhance waste-to-energy systems. Such optimization methods as genetic algorithms, particle swarm optimization, and machine learning techniques adjust some of the most important parameters, namely photoelectric conversion efficiency, cost performance and eco-efficiencies. However, the mixture and unstructured nature of waste and the variation of input data represent some of the issues that make it difficult to design algorithms that conform to specific structural models. Further research should then look at combining two or more optimization techniques to arrive at more optimized solutions [23].

Economic profitability continues to act as a limitation to adopting waste-to-energy facilities. High capital costs and operational expenses that may discourage stakeholders from financing the technologies characterize

these technologies. He mentioned optimization algorithms of software requirements to address these issues by identifying economic and practical resource configurations. In addition, friendly policies, grants and fiscal incentives are important for attracting capital investments in sustainable waste management practices [24].

Community support and information on using waste for Energy is therefore deemed significant. Stakeholders' negative attitudes toward waste processing facilities and concerns over environmental and health effects limit project construction. The alternative of raising the acceptance is to educate the communities and involve them in the decision-making process of their leaders in an open manner. Another way that public input might increase optimization feasibility is through the incorporation of such data with optimization models [25].

Hence, there is a need to consider the environmental impact of waste management for energy production. Although waste-to-energy systems have the strength of providing a mechanism to minimize waste and generate Energy, they have the weakness of generating emissions and byproducts. These life cycle impacts can be quantified using life cycle assessment (LCA) to inform the design of environmentally harmonized systems. Therefore, the integration of LCA with optimization algorithms can guarantee the avoidance of harm to the environment and the generation of electric power [26].

The current shift towards the circular economy puts more emphasis on sustainable ways in which waste can be managed. Since waste-to-energy systems consider waste a resource, resource-rich material is conserved and reduced in consumption. Adapting these systems to fit a circular economy entails integration with knowledge from various fields of engineering, policy, and environmental science [27].

There are new possibilities to improve waste-to-energy systems using, for example, artificial intelligence and IoT. Opportunities for innovative waste management include resource optimization through real-time monitoring, predictive maintenance, and decision support. The following technologies can improve the effectiveness, dependability, and sustainability of waste-to-energy undertaking [28].

The coordinated application of the WM, RE, and optimization algorithms provides a plausible route to sustainable energy generation. However, existing challenges cannot be fully solved without constant innovation, policy, or public promotion. Subsequent studies should seek to design waste-to-energy technologies that have low costs and are environmentally friendly, as espoused by sustainable development.

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. This way, such systems play a significant role in waste management, resource recovery and climate change, on which the principles of circular economy and sustainable development hinge.

Renewable energy treatments, including anaerobic digestion, pyrolysis, and gasification, could convert waste streams into high-value bio-energy sources such as biogas, syngas, and bio-oils. These technologies include offerings that do not rely on landfills and fossil fuels and go green. However, their scalability and efficiency remain constrained by several technical factors, including feedstock variability and operation complications. The current study identified some limitations in the effectiveness of these social systems and their usability; 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 energy systems' waste efficiency, affordability and viability. Genetic algorithms, particle swarm optimization and artificial neural networks are model and simulation methods that try to make good decisions on waste processing, energy recovery and resource allocation. Nonetheless, question marks arise regarding data of manageable quality, variability of feedstock, and computational burdens, which are to be managed to get the best of these techniques optimization techniques.

Technology, economic and social factors significantly influence the incorporation of waste into energy systems. Barriers related to the large-scale deployment of wave energy 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 ways for sustainable waste management to generate Energy open the most effective solution to the global Energy and ecological crisis. By implementing renewable energy technologies, efficient optimization algorithms and supportive policy systems, these systems can enhance efficiency, energy economics and sustainability. More studies should be conducted on improving techniques, constructing a better model optimization, and solving 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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