International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 21, Issue 1 (January, 2025), PP 56-67

Industrial Waste Management in the Era of Climate Change: Challenges, Strategies, and Opportunities

OkpalaCharles Chikwendu and Udu Chukwudi Emeka
Industrial/Production Engineering Department,
Nnamdi Azikiwe University, P.M.B. 5025 Awka,
Anambra State – Nigeria

Abstract

Industrial waste management is crucial for combating climate change by addressing the environmental impacts of waste generation. Industrial processes produce hazardous and non-hazardous waste, contributing to resource depletion, pollution, and greenhouse gas emissions. This paper examined the current landscape of industrial waste management, focusing on the challenges of waste generation and disposal, alongside strategies to mitigate environmental impacts. Key obstacles include weak regulatory frameworks, financial and technological constraints, and resistance to adopting sustainable practices within industries. Innovative approaches, such as waste reduction at the source, recycling, resource recovery, and Waste-to-Energy technologies, were explored as solutions. Digitalization, including the Internet of Things (IoT) and data analytics, was highlighted for their potential to enhance waste tracking, sorting, and efficiency. Emphasizing circular economy principles, industrial symbiosis, and integrated waste management systems is essential for sustainable outcomes. The paper underscores the importance of robust policy frameworks aligned with climate goals to curb industrial waste's contribution to global warming. It recommended that industries, policymakers, and communities should collaborate to adopt sustainable practices, invest in innovative technologies, and develop infrastructure. These efforts aim to achieve long-term environmental and economic sustainability, fostering a balance between industrial activity and climate change mitigation.

Keywords: *industrial waste management, climate change, environmental health, waste-to-energy, recycling, waste treatment*

Date of Submission: 02-01-2025 Date of acceptance: 13-01-2025

I. Introduction

Defined as the method of collection, treatment, and discarding of various waste produced by diversemanufacturing companies for the attainment of environmental threats minimization and resource recovery maximization, Industrial Waste Management (IWM) is essential for global sustainability and climate change mitigation due to its impacts on environmental health, resource efficiency, and GreenHouse Gas (GHG) emissions. Industrial activities produce hazardous and non-hazardous waste, contributing significantly to environmental degradation and global warming (Karan and Anusha, 2024). Natural materials for waste treatment are cost-effective and environmentally friendly (Karan and Anusha, 2024). For example, a Chinese eco-industrial park study revealed low recycling rates (5.6%) for mini-scale hazardous waste, but implementing a circular economy framework increased recycling by 26.5% (Shu et al., 2024). Integration of technologies like Extreme Learning Machine (ELM) algorithms improves real-time waste management and predictive monitoring (Ponni et al., 2024). Innovative approaches, including carbon capture and sustainable technologies reduce emissions and the industrial carbon footprint (Xie et al., 2023; Nunes, 2023).

Improper disposal of industrial waste, such as chemical byproducts, exacerbates GHG emissions, notably methane, with a warming potential 28 times greater than CO2 (Wilson et al., 2024). Circular waste management strategies like the 3Rs (reduce, reuse, and recycle) mitigate emissions and support low-carbon economy transitions (Chiang et al., 2024). Technologies such as IoT, AI, and Waste-to-Energy (WTE) solutions enhance efficiency, promote material recovery, and generate energy while reducing landfill dependency (Afshari et al., 2024; Najar et al., 2024).Stakeholder engagement, including policymakers and industries, is vital for effective waste management. Aligned with the Paris Agreement, these strategies ensure waste reduction, energy recovery, and resource efficiency while achieving climate mitigation goals. Future directions should prioritize research in innovative technologies, policy alignment, and cross-sector collaboration to achieve sustainable waste management. This comprehensive approach balances environmental protection with economic and social development, aiding the transition to a resilient and sustainable future.

II. The Impact of Climate Change on Industrial Waste Management

Climate change has introduced remarkable challenges to industrial waste management, affecting waste generation patterns, exposing vulnerabilities in existing systems, and complicating disposal and treatment processes. Some of the impacts of climate change on IWM are discussed here.

2.1 Climate Change and its Influence on Waste Generation Patterns

Climate change significantly impacts waste generation, particularly through extreme weather events like floods, hurricanes, and wildfires, which increase hazardous and mixed waste, complicating management systems (Aggarwal and Gupta, 2024; Habib et al., 2022). For example, floods not only damage infrastructure but also lead to the contamination of materials, increasing public health and environmental risks. Improper disaster waste management exacerbates these challenges, emphasizing the need for robust strategies (Ponti et al., 2022).Climate change also reshapes production and consumption, resulting in emerging waste streams like e-waste and renewable energy waste. Wind Turbine Blade (WTB) waste, anticipated to reach 43 million tons by 2050, highlights the need for innovative management approaches (Hasheminezhad et al., 2024). Current methods like mechanical recycling are viable for mixed WTB waste, but advanced techniques such as carbon fiber recycling are crucial to minimize environmental impacts (Pender et al., 2024). Sustainable reuse of WTB materials in civil engineering applications, such as concrete and asphalt, addresses resource depletion while meeting performance standards (Revilla-Cuesta et al., 2023; Zhang et al., 2023). Efficient recycling supply chains and regulatory frameworks are critical to implementing these strategies effectively, supporting sustainability and reducing the environmental footprint of emerging waste types (Zhang et al., 2023).

The transition to renewable energy technologies has led to an increase in specialized waste streams, particularly e-waste and renewable energy waste, such as decommissioned WTBs and solar panels. E-waste generation is influenced by factors like population growth, urbanization, and increased renewable energy adoption, with notable growth in categories such as small IT devices and screens (Boubellouta and Kusch-Brandt, 2022). The diverse chemical composition of e-waste demands specialized recycling methods to reduce environmental harm (Simion et al., 2023; De Oliveira Neto et al., 2022).

Disposing of WTBs presents unique environmental challenges, including risks of microplastic pollution and contamination of natural resources (Tayebi et al., 2024). Advanced recycling technologies can transform these materials into valuable products, aligning with circular economy principles, but require significant investment and innovation (Tayebi et al., 2024; De Oliveira Neto et al., 2022). However, the current emphasis on recycling and recovery has raised concerns about the insufficient focus on waste prevention, which is essential for long-term sustainability (De Oliveira Neto et al., 2022). Addressing these challenges requires proactive waste management strategies that integrate prevention, recycling, and repurposing to handle these emerging waste streams sustainably. This approach will ensure alignment with environmental and economic goals.

2.2 Vulnerabilities in Current Waste Management Systems

Industrial waste management systems face significant challenges in adapting to climate-related stressors, as they were designed for stable climatic conditions. Rising temperatures and increased precipitation intensify leachate production, a hazardous byproduct requiring advanced treatment (Al-Hazmi et al., 2024). Technologies like nutrient recovery and energy generation from waste improve landfill sustainability, but extreme weather conditions complicate gas and leachate management (Fathinezhad, 2022; Al-Hazmi et al., 2024). Communities near contaminated sites, often economically disadvantaged, face heightened risks, emphasizing the need for resilience planning and stakeholder engagement (Sinha et al., 2024; Kodandapani, 2021).

Global crises, including the COVID-19 pandemic and geopolitical conflicts, have further exposed the inefficiencies in waste management systems (Hossain et al., 2023). Climate events such as floods disrupt logistics, overwhelming infrastructure and leading to illegal dumping or hazardous waste storage (Jena et al., 2023). In Europe, flood-prone industrial zones have experienced severe contamination due to inadequate waste systems (European Environment Agency, 2021). Illegal disposal often results from logistical failures influenced by resource dependency (Troisi et al., 2023). Furthermore, hazardous waste transportation risks accidents and pollution, highlighting the need for sustainable logistics (Batarliene, 2019). These issues underscore the urgency of improved waste management, resilient infrastructure, and sustainable practices to protect human health and environmental resources.

2.3 Case Studies Illustrating Climate-Induced Challenges in Industrial Waste Management

Case Study 1: Hurricane Harvey (2017)

Hurricane Harvey exposed the vulnerabilities of industrial waste systems during extreme weather, leading to significant environmental contamination. Flooding overwhelmed storage facilities, causing hazardous chemical releases, with petrochemical facilities contributing two to three times more contaminant releases than under normal conditions (Berberian et al., 2024). Failures in storage tanks led to severe soil and groundwater contamination, underscoring the importance of enhanced risk assessment models for industrial sites in flood-prone regions (Giusti et al., 2023).

Research revealed that low-income and Hispanic communities disproportionately bore the brunt of these hazardous releases, highlighting persistent environmental injustices (Berberian et al., 2024; Giusti et al., 2023). Projections suggest that rising sea levels and increased flooding will further exacerbate these risks, disproportionately affecting already vulnerable populations (Liu and Mostafavi, 2023). These findings stress the urgent need to integrate environmental justice into industrial risk management and develop strategies to address critical disparities in pollution exposure.

Case Study 2: Flooding in Jakarta, Indonesia (2020)

The 2020 Jakarta floods revealed critical deficiencies in hazardous waste management and infrastructure. The floods caused hazardous industrial and municipal wastes to mix, exacerbating environmental contamination and health risks (Haas and Vamos, 1994; Wang et al., 2008). Hazardous waste often includes toxic substances requiring specialized treatment, such as biological and thermal processes, to mitigate environmental harm (Haas and Vamos, 1994; Wang et al., 2008).

The overwhelmed infrastructure and lack of proper waste segregation during the floods underscored the need for improved waste management systems. Applying industrial ecology principles, such as recycling and waste reduction, enhanced management strategies (Wang et al., 2008). Additionally, engaging civil society organizations and adopting participatory approaches tailored to local conditions helped address these challenges effectively and raise public awareness (Ali et al., 2023). This situation highlights the importance of strategic investments in infrastructure and community engagement to handle hazardous waste during extreme events.

Case Study 3: Wildfires in Australia (2019-2020)

The 2019-2020 Australian bushfires created significant industrial waste, straining waste management systems. The fires caused extensive damage to waste treatment facilities and generated large quantities of Construction and Demolition Waste (CandDW), such as bricks and concrete, posing public health and environmental risks (Shooshtarian, 2019). Additionally, Australia's annual waste includes 2.54 million tonnes of plastics and 1.16 million tonnes of glass, much of which ends up in landfills (Ferdous et al., 2022).

The fires worsened landfill dependency by disrupting recovery efforts, compounded by a 2021 export ban on mixed plastics and glass, adding 500,000 tonnes of waste to domestic landfills annually (Ferdous et al., 2022). Current waste management practices are unsustainable, and there is an urgent need for stronger intergovernmental cooperation to improve waste management policies (Jones, 2020). These challenges emphasize the necessity of resilient infrastructure and coordinated policies to address increasing waste burdens effectively.

III. The Link between Industrial Waste and Climate Change

Industrial waste management and climate change are intricately linked, with waste management practices contributing to GHGemissions and resource depletion. Addressing these interconnections is critical for reducing the environmental impact of industrial activities and achieving sustainability goals.

3.1 Greenhouse Gas Emissions from Waste Management

Industrial waste management practices, such as landfilling and incineration, significantly contribute to GHG emissions. Landfills alone account for approximately 64 million tons of methane emissions annually, generated through the anaerobic decomposition of organic waste (Kopecká et al., 2024). Methane's global warming potential, 25 times greater than carbon dioxide over a century, highlights the critical need to reduce landfill emissions (Vaiškūnaitė and Zagorskis, 2024). Innovative methods like aeration and probiotics have demonstrated promise in reducing methane by improving biodegradation processes (Vaiškūnaitė and Zagorskis, 2024).

A notable shift from landfilling to incineration is evident, with incineration’s share of GHG emissions in China rising from 16.5% to 60.1% between 2010 and 2020 (T. Zhang et al., 2023). This trend underscores the necessity of optimizing waste classification and enhancing landfill gas collection systems to mitigate emissions effectively (T. Zhang et al., 2023). Additionally, waste transportation is a major contributor to GHG emissions, accounting for 76.8% of the carbon footprint in waste management facilities (Demirbas and Ateş, 2021). In Tehran, transportation alone emits 8.47 k tons of CO2 annually, further illustrating the environmental toll (Rouhi et al., 2023).

While incineration reduces waste volume, it emits GHGs and toxic byproducts like dioxins and furans, posing significant health and environmental risks (Nath et al., 2024; Satin and Kutsyi, 2024). These challenges emphasize the urgency of adopting sustainable waste management solutions to minimize environmental impacts.

3.2 Resource Depletion and Circular Economy

Industrial waste contains valuable materials that can be reintegrated into production processes, reducing the need for raw material extraction. However, current practices deplete resources like fossil fuels, minerals, and metals, worsening climate change through energy-intensive extraction processes. Adopting a circular economy model offers a sustainable solution by emphasizing waste minimization, resource recovery, and material reintegration. This approach decreases resource consumption, lowers carbon emissions, and improves efficiency. For instance, recycling aluminum saves up to 95% of the energy required for primary production, significantly cutting the carbon footprint (Wilson et al., 2024). Although the waste sector contributes only 3% of global GHG emissions, it holds immense potential for climate mitigation through enhanced recycling and waste reduction (Wilson et al., 2024). Furthermore, circular economy strategies drive innovation in technologies such as advanced sorting systems and bio-based recycling, reducing environmental impacts while creating economic opportunities by transforming waste into valuable resources.

3.3 Integrated Perspectives

The connection between industrial waste and climate change highlights the necessity for a comprehensive waste management strategy. Transitioning to a resource-efficient circular economy and reducing greenhouse gas (GHG) emissions are essential for mitigating climate change. Sustainable practices like Waste-to-Energy conversion (Wilson et al., 2024), enhanced recycling systems (Aiguobarueghian et al., 2024), and material substitution (Suresh et al., 2024) play a key role in minimizing environmental impacts while also fostering economic resilience.

IV. Challenges in Industrial Waste Management

4.1 Regulatory and Policy Limitations

Industrial waste management regulations often lack the strength needed to effectively promote sustainable practices. Enforcement disparities across countries, including advanced economies, reveal the global need for stronger regulatory frameworks (Wilson et al., 2024). Limited financial incentives and government support deter industries from adopting sustainable methods, such as in the apparel sector, where better incentives and sustainable design could address waste recovery challenges (Randhawa, 2024). Poor coordination between sectors also impedes comprehensive waste strategies, highlighting the importance of multi-stakeholder cooperation to improve recycling rates and minimize waste (Shu et al., 2024). Inconsistent policy enforcement and inadequate incentives further compound these challenges, emphasizing the need for robust and uniform approaches to waste management.

4.2 Technological and Financial Barriers

The limited adoption of modern waste management technologies, such as Waste-to-Energy systems and advanced recycling methods, is mainly due to high costs and technical complexities (Pant et al., 2023). Small and medium-sized enterprises (SMEs) often find these investments prohibitive (Anamika and Malhotra, 2024), and rapid technological advancements can outpace the capabilities of industries, particularly in regions lacking technological expertise (Afshari et al., 2024). Regions with limited access to technological expertise face additional barriers, struggling to keep up with advancements in waste management technologies (Afolalu et al., 2024). Integrating new technologies with existing systems are complex, requiring specialized knowledge and training (Czekała et al., 2023). The absence of supportive government policies further exacerbates these challenges, hindering the development of sustainable waste management practices (Afshari et al., 2024).

4.3 Social and Organizational Resistance to Change

Organizational inertia and societal attitudes significantly impede the adoption of sustainable practices in industries. A primary obstacle is the prioritization of short-term financial gains over long-term sustainability benefits, fostering resistance to new practices (Aliu et al., 2024). Limited funding and the high costs of implementing sustainable measures further deter necessary investments (Reynolds, 2024; Durrani et al., 2024). Resistance is often rooted in entrenched routines and a reluctance to embrace new systems, exacerbated by insufficient awareness of environmental impacts and the advantages of sustainability. This lack of knowledge diminishes stakeholder engagement (Filho et al., 2024; Durrani et al., 2024). However, growing consumer and stakeholder demand for sustainable practices encourages organizations to adapt (Reynolds, 2024).

4.4 Risks Associated with Hazardous Waste and Extreme Weather Events

Industrial hazardous waste poses significant environmental and health challenges, particularly in the context of climate change. Improper disposal contaminates soil, water, and air, with extreme weather events like floods and hurricanes amplifying the spread of toxic substances (Fuller, 2024). Hazardous waste leaching introduces toxins into drinking water sources and agricultural land (Nath et al., 2024). Heavy metals from industrial processes, such as electroplating, present serious risks to ecosystems and biodiversity (Ghodke et al., 2023). Industrial emissions contribute to air pollution, exacerbating health issues and climate change (Ditia, 2024). Contaminated sites become increasingly vulnerable during extreme weather events, intensifying ecological and public health crises (Fuller, 2024). While developed nations have initiated remediation efforts, many developing countries lack adequate resources and regulations to manage hazardous waste, heightening risks to human and ecological health (Fuller, 2024). Urgent action is required to address these challenges effectively.

4.5 Lack of Infrastructure and Investment

Inadequate infrastructure severely limits effective waste management in developing regions, where unplanned settlements and a lack of facilities like recycling plants and waste treatment systems are common (Dissanayake et al., 2022). The absence of these facilities contributes to increased waste generation and environmental pollution (Ahmed, 2024). Insufficient investment in innovative technologies further hampers waste reduction and resource recovery efforts (Xu, 2024). Addressing these challenges requires integrated strategies involving policy reforms, technological advancements, public awareness, and global collaboration to improve industrial waste management, especially in the context of climate change.

4.6 **Complex Waste Streams in Industrial Waste Management**

Industrial waste presents significant challenges due to its diverse composition, complexity, and environmental impacts. Waste streams include general waste, often recyclable; hazardous waste, which requires specialized handling to prevent contamination (Karan and Anusha, 2024); and waste from emerging technologies, for which disposal protocols are still evolving (Nath et al., 2024). Effective management requires tailored treatment and disposal solutions to ensure sustainability, particularly in the context of climate change (Rao et al., 2024).

The chemical complexity of industrial waste necessitates advanced treatment technologies. Methods such as chemical precipitation, coagulation, and ion exchange are effective for removing heavy metals from industrial effluents (Bulgariu, 2024). Advanced Oxidation Processes (AOPs) degrade organic pollutants, while membrane technologies treat diverse wastewater compositions and enable water reuse (Suresh et al., 2023). Renewable energy waste, including materials from solar panels and batteries, poses unique challenges due to composite materials that require innovative recycling approaches (Nath et al., 2024).

E-waste management is vital to prevent environmental degradation and health risks. The global production of e-waste, projected to reach 74.7 million tons by 2030, includes toxic substances like lead, cadmium, and mercury that contaminate soil and water (Sonawane et al., 2023; Singh, 2024). Regulations such as India’s E-Waste Management Rules (2022) emphasize specialized disposal methods, while advanced recycling technologies recover valuable materials, reducing environmental impacts (Singh, 2024; Kumar et al., 2024). Public education campaigns are essential for improving e-waste disposal and recycling rates (Oyebode, 2024). Addressing these challenges sustainably requires integrating policy frameworks, technological advancements, and public awareness initiatives.

End-of-life waste from renewable energy infrastructure, such as PhotoVoltaic (PV) cells, wind turbines, and energy storage systems, demands innovative circular economy strategies. By 2050, global PV waste is projected to reach 60.2 million tons, requiring advanced recycling methods like mechanical, thermal, and chemical processes, each with cost and environmental challenges (Bošnjaković et al., 2023; Chen et al., 2023). Extended Producer Responsibility (EPR) policies, adopted by the EU, promote sustainable practices, while regions like China face regulatory gaps (J. Wang et al., 2024). Decommissioned wind turbine blades, made from hard-to-recycle composite materials, risk environmental contamination and microplastic formation, necessitating effective recycling technologies (Tayebi et al., 2024).

Advanced waste management technologies are crucial for addressing climate change. Automation and AI improve sorting precision, enhancing recycling efficiency (Arsakhanova et al., 2024). Plasma-assisted recycling transforms waste polymers into high-value products, tackling polymer waste accumulation (Shuvo et al., 2023). The circular economy model, advocating for closed-loop systems, minimizes resource extraction and waste generation while promoting sustainable design for product longevity and recyclability (Muljaningsih et al., 2023). Proper waste separation also reduces landfill-bound materials, cutting methane emissions (Wilson et al., 2024). Addressing industrial waste challenges requires systemic approaches combining technological innovation, regulatory frameworks, and industry collaboration. Lifecycle product management, robust recycling infrastructure, and international cooperation can reduce the environmental impact of complex waste streams (Aiguobarueghian et al., 2024; Shuvo et al., 2023). These measures align with global sustainability goals, mitigating environmental degradation, combating climate change, and minimizing industrial environmental footprints.

V. Strategies for Sustainable Industrial Waste Management

Sustainable industrial waste management requires innovative approaches and coordinated efforts to minimize waste generation and enhance resource efficiency.

5.1 Waste reduction at the source

Waste reduction at the source is the most effective strategy, focusing on prevention rather than post-production management. This approach reduces environmental impact, improves operational efficiency, and aligns with sustainability goals. Lean manufacturing techniques help in the elimination of wasteful practices by streamlining operations and removing non-value-adding processes (Okpala, 2014, Ihueze and Okpala, 2014). Efficient production processes, cleaner technologies, and green chemistry principles further optimize resource use, lowering waste outputs. Additionally, designing products for recyclability and reduced resource consumption throughout their lifecycle is critical for minimizing waste (Hussain et al., 2021).Despite these benefits, industries often encounter challenges like technological limitations and cultural resistance. Regulatory support and financial incentives can play a key role in overcoming these barriers, thereby facilitating the adoption of effective waste reduction strategies.

5.2 Recycling and Resource Recovery

Recycling and resource recovery are pivotal in transforming waste into valuable resources, advancing sustainability and environmental conservation. AI-driven systems and chemical recycling play critical roles in enhancing material recovery and promoting a circular economy. Advanced sorting techniques powered by AI improve recycling efficiency through precise material separation (Arsakhanova et al., 2024). Machine learning enhances production processes, reduces defects, and optimizes resource recycling rates, leading to cost savings and environmental benefits (Lin and Wei, 2023).

Sustainable chemical processes reclaim waste materials, transforming them into valuable resources and mitigating environmental impacts (Yu et al., 2024). Green chemistry initiatives further minimize waste generation and resource depletion, supporting sustainable practices within a circular economy (Wattanakit et al., 2024). Industrial collaborations exemplify material loop closure, where one sector's waste serves as raw material for another. The textile industry demonstrates this approach by recovering materials to extend textile life cycles and reduce the need for virgin materials (Papamichael et al., 2023). These strategies foster material reuse, reduce landfill reliance, and lower greenhouse gas emissions linked to raw material extraction, significantly contributing to environmental sustainability.

5.3 Waste-to-Energy Technologies

WTE technologies offer a sustainable alternative to traditional waste disposal by converting waste into energy, addressing waste management and energy production challenges. Anaerobic digestion decomposes organic waste to produce biogas, a renewable energy source that reduces carbon footprints and supports sustainable development goals (Archana et al., 2023). Incineration is particularly effective in regions like Egypt and Indonesia, where it generates significant electricity with lower greenhouse gas emissions and the lowest Levelized Cost of Energy (LCOE) in many areas, making it economically attractive (Ahmed et al., 2024).

WTE technologies not only reduce greenhouse gas emissions and reliance on fossil fuels, but also create employment opportunities, especially in developing countries. However, the full potential of anaerobic digestion is limited by operational challenges and public acceptance issues. Innovative methods such as hydrothermal carbonization and microbial fuel cells are being explored to enhance the efficiency and sustainability of WTE systems (Potdar et al., 2024; Archana et al., 2023).

5.4 Digitalization and Data-Driven Waste Management

Digital tools are transforming waste management by improving efficiency, compliance, and sustainability through real-time insights. IoT devices enable continuous monitoring of waste generation and movement, allowing for timely adjustments to management strategies (Ameh, 2024). AI-powered smart waste bins with computer vision enhance waste sorting, increase recycling rates, and minimize environmental impact (Raut, 2024). AI-driven predictive models analyze historical data to anticipate waste inflows, optimizing landfill operations and resource allocation (Faiz et al., 2024). Blockchain technology ensures transparent waste tracking from generation to disposal, fostering accountability and regulatory compliance (Faiz et al., 2024). Additionally, digital reporting tools improve tracking and reporting systems, supporting adherence to environmental regulations and encouraging stakeholder engagement (Audu et al., 2024; Faiz et al., 2024). These innovations leverage IoT, AI, and blockchain to enhance waste management, boost resource recovery, and enable data-driven policy decisions.

5.5 Industrial Policy and Collaboration

Achieving effective waste management necessitates collaboration between industries, governments, and communities, supported by measures such as subsidies for recycling technologies and tax incentive to reduce waste. Financial incentives play a key role in encouraging the adoption of innovative waste management solutions, including advanced recycling methods and Waste-to-Energy systems (Zakhilwal et al., 2024; Ansari and Savale, 2024). Developing communal waste management facilities facilitates industry-wide waste reduction goals and fosters cooperation among businesses (Rani and Yendluri, 2024; Dada et al., 2024). Actively involving communities in waste management initiatives enhances participation and compliance, leading to better outcomes (Rani and Yendluri, 2024; Ansari and Savale, 2024). Educational programs empower communities to embrace sustainable practices, thereby lowering waste generation (Ansari and Savale, 2024). Embracing circular economy principles helps cut costs by improving resource efficiency and reducing waste disposal expenditures (Aiguobarueghian et al., 2024). Furthermore, adopting sustainable waste management practices stimulates innovation and generates employment opportunities in the green economy (Aiguobarueghian et al., 2024). These comprehensive approaches are essential for progressing toward a sustainable and circular economy.

VI. Discussion

6.1 Evaluation of Proposed Strategies

Sustainable industrial waste management strategies, including waste reduction at source, recycling, WTE technologies, digitalization, and industrial collaboration, offer effective methods for reducing the environmental impact of industrial activities. While promising, these approaches must be assessed in relation to both immediate and long-term climate objectives.Waste Reduction at Source is the most sustainable and cost-efficient method, focusing on process optimization, lean manufacturing, and resource efficiency to cut waste generation. Design-for-Environment (DFE) principles further enhance sustainability and profitability by saving resources (Jamal, 2024; Ali et al., 2024). However, the approach requires industries to invest in training, technology, and process redesign, posing challenges for smaller enterprises.Recycling and Resource Recovery leverage technologies like AI-driven waste sorting and industrial symbiosis, where one industry's waste becomes raw material for another, to boost material recovery and promote circular economies (Moorthy et al., 2024; Saeed et al., 2023). Nonetheless, the complexity of waste streams and uneven recycling infrastructure hinder effectiveness. Advancements in chemical recycling and material purity are key to scalability.WTE Technologies provide a practical solution for non-recyclable waste, despite concerns about emissions. Integrating WTE systems with Carbon Capture and Storage (CCS) minimizes environmental impact while generating energy, aligning with circular economy goals (Mukherjee, 2024). Effective oversight is necessary to prevent air pollution and greenhouse gas emissions.Digitalization and Data-Driven Waste Management incorporate IoT, AI, and data analytics to monitor waste in real time, improving operational efficiency and recovery rates. However, adopting these technologies demands significant investments in infrastructure and skilled personnel. Industry-wide standardization of digital platforms is essential to maximize their potential.

Industrial Policy and Collaboration are fundamental for achieving sustainable outcomes. Policies that incentivize waste reduction and resource recovery, supported by subsidies for green technologies, encourage industries to adopt sustainable practices. Partnerships among industries, governments, and communities enhance these policies' effectiveness, promoting shared waste reduction goals and better infrastructure (Saeed et al., 2023). Each strategy plays a vital role in achieving sustainable waste management by balancing environmental and economic priorities.

6.2 Potential for Scalability and Replicability in Various Industrial Sectors

The effectiveness and adaptability of sustainable waste management strategies are influenced by industrial context, financial capacity, regulatory policies, and technological infrastructure. Process optimization and lean manufacturing have yielded notable advantages across various sectors. In the automotive industry, for example, lean manufacturing has significantly decreased cycle times while enhancing product quality (Okpala, 2013). Similarly, in the textile industry, lean methodologies such as Just-In-Time production and value stream mapping have improved efficiency and reduced waste, though challenges like raw material variability persist (Okpalaet al., 2020).

Waste-to-Energy technologies show particular promise in energy-intensive sectors with substantial non-recyclable waste. These technologies are also highly applicable in the agricultural and food processing industries, where organic waste can be transformed into biogas or compost, advancing sustainability efforts (Sasso et al., 2024). Nevertheless, broader implementation is constrained by obstacles such as inefficient waste segregation and inadequate infrastructure.

Industrial symbiosis offers another valuable approach, particularly in petrochemical industries, where by-products from one plant are utilized as raw materials for another (Sasso et al., 2024). However, managing hazardous waste in these settings remains a significant challenge, necessitating advanced treatment technologies and stringent safety measures. While these strategies hold substantial promise, their adoption depends on industry-specific circumstances.

6.3 Balancing Economic, Environmental, and Social Considerations

Balancing economic, environmental, and social considerations is central to sustainable industrial waste management. Implementing strategies like waste reduction at the source and recycling can lower long-term operational costs but often requires substantial initial investments in infrastructure and technology, posing barriers, especially in developing economies. Despite this, the economic benefits of reduced disposal costs, resource recovery, and improved process efficiency frequently outweigh these initial expenses (Dutta, 2024). Environmentally, these strategies aim to minimize damage by reducing waste generation and enhancing resource recovery, leading to lower carbon emissions, decreased resource extraction, and reduced air, soil, and water contamination. However, technologies such as WtE must be carefully managed to mitigate potential environmental risks, including air pollution and harmful gas emissions (Gil, 2021).

Socially, these strategies can generate employment in sectors like recycling, waste management, and green technology development. Nevertheless, challenges such as societal resistance to WtE and recycling initiatives remain. Overcoming these issues requires public awareness campaigns and community engagement to foster acceptance (Okere et al., 2019; Rao et al., 2024). Ultimately, the success of sustainable industrial waste management strategies depends on addressing financial, technological, and societal barriers (Zakhilwal et al., 2024) and continuously improving waste management technologies to enhance efficiency and reduce environmental impacts (Somya et al., 2024). Collaborative efforts among governments, industries, and communities are essential to ensure economically viable and environmentally beneficial waste management practices.

VII. Conclusion

7.1 Summary of Findings

This research emphasized on the crucial role of industrial waste management in addressing climate change impacts. Key findings highlight the challenges of managing complex industrial waste streams due to limited infrastructure and uneven adoption of advanced technologies like Waste-to-Energy processes and AI-driven sorting systems. Prioritizing waste reduction at the source through production optimization, resource efficiency, and lean manufacturing is identified as a highly effective strategy for minimizing environmental harm.

The study underscores gaps in regulatory frameworks, including inadequate policy enforcement and insufficient incentives for sustainable practices. Collaborative efforts among industries, governments, and communities are deemed essential for scaling waste reduction and recycling initiatives. Additionally, the paper calls for significant investment in innovative technologies and infrastructure to overcome barriers, particularly in developing regions.

7.2 Recommendations for Policymakers, Industries, and Communities

Policymakers should enhance regulations to promote sustainable industrial waste management, enforce stricter waste reduction laws, and support circular economy initiatives, especially in developing nations. International collaboration is essential for harmonizing waste management policies globally. Industries must prioritize waste reduction through lean manufacturing, resource efficiency, and environmentally conscious design, while investing in advanced technologies like chemical recycling and AI-driven sorting systems. Encouraging industrial symbiosis fosters circular economies by repurposing waste between industries. Communities impacted by industrial waste should actively participate in decision-making and push for improved waste management infrastructure. Public education on waste reduction and recycling is vital, alongside collaboration between governments, industries, and citizens to ensure sustainable and community-centered waste strategies.

7.3 Future Research Directions

Future research should focus on the scalability of emerging waste management technologies, such as AI-driven sorting, chemical recycling, and WtE processes, across various industries. Economic feasibility in low-resource settings and the long-term environmental impact of these technologies should be further investigated. Additionally, the social aspects of waste management, including community roles and barriers to policy implementation, need exploration. Research should also examine the potential of digitalization, including IoT and big data, for real-time waste monitoring and optimization. The use of blockchain for improving transparency and traceability in waste management should be studied as well. In conclusion, while progress has been made, more research and collaboration between industries, governments, and communities are needed to fully leverage sustainable waste management practices in tackling climate change.

References

[1]. Afifa, N., Arshad, K., Hussain, N., Ashraf, M. H., and Saleem, M. Z. (2024). Air pollution and climate change as grand challenges to sustainability. *The Science of the Total Environment*, *928*, 172370. https://doi.org/10.1016/j.scitotenv.2024.172370

[2]. Afolalu, S. A., Ogedengbe, T. S., Ikumapayi, O. M., and Adediran, A. A. (2024). Waste Management Technology: The Engineering Approach for Achieving Sustainable Development Goal– A review. *2024 International Conference on Science, Engineering and Business for Driving Sustainable Development Goals (SEB4SDG)*, 1–7. https://doi.org/10.1109/seb4sdg60871.2024.10629879

[3]. Afshari, H., Gurtu, A., and Jaber, M. Y. (2024). Unlocking the potential of solid waste management with circular economy and Industry 4.0. *Computers and Industrial Engineering*, *195*, 110457. https://doi.org/10.1016/j.cie.2024.110457

[4]. Aggarwal, B., and Gupta, A. K. (2024). Managing disaster waste in the Aftermath of Emergencies: Addressing Future Climate Risk-Integrating Adaptation. In *Disaster Resilience and Green Growth* (pp. 263–280). https://doi.org/10.1007/978-981-99-4105-6_12

[5]. Ahmed, M. M., Hossan, M. N., and Masud, M. H. (2024). Prospect of Waste-to-Energy technologies in selected regions of lower and lower-middle-income countries of the world. *Journal of Cleaner Production*, *450*, 142006. https://doi.org/10.1016/j.jclepro.2024.142006

[6]. Ahmed, R. (2024). Innovative Waste Management Solutions: A Global perspective Challenges and opportunities and the Bangladesh context. *Environmental and Earth Sciences - Waste Management and Disposal*. https://doi.org/10.20944/preprints202407.2617.v1

[7]. Aiguobarueghian, N. I., Adanma, N. U. M., Ogunbiyi, N. E. O., and Solomon, N. N. O. (2024). Waste management and circular economy: A review of sustainable practices and economic benefits. *World Journal of Advanced Research and Reviews*, *22*(2), 1708–1719. https://doi.org/10.30574/wjarr.2024.22.2.1517

[8]. Alazaiza, M., Albahnasawi, A., Eyvaz, M., AlMaskari, T., Abuamr, S., Nassani, D. E., Abu Jazar, M., and Al Abod, S. (2024). An overview of Circular Economy Management approach for sustainable construction and Demolish Waste management. *Global NEST Journal*. https://doi.org/10.30955/gnj.05824

[9]. Al-Hazmi, H. E., Hassan, G. K., Kurniawan, T. A., Śniatała, B., Joseph, T. M., Majtacz, J., Piechota, G., Li, X., El-Gohary, F. A., Saeb, M. R., and Mąkinia, J. (2024). Technological solutions to landfill management: Towards recovery of biomethane and carbon neutrality. *Journal of Environmental Management*, *354*, 120414. https://doi.org/10.1016/j.jenvman.2024.120414

[10]. Ali, A. A., Golbert, Y., Reksa, A. F. A., Kretzer, M. M., and Schweiger, S. (2023). Transformative Solutions in the Global South: Addressing solid waste management challenges in Jakarta through participation by civil society organizations? In *Environment and policy* (pp. 329–351). https://doi.org/10.1007/978-3-031-15904-6_18

[11]. Ali, R. F., Harel, S., Shaikh, T., and Chakraborty, P. (2024). "Impact of Design Principles on End-of-Life and Recycling." *SAE Technical Papers on CD-ROM/SAE Technical Paper Series*. https://doi.org/10.4271/2024-26-0163

[12]. Aliu, J., Oke, A. E., Odia, O. A., Akanni, P. O., Leo-Olagbaye, F., and Aigbavboa, C. (2024). Exploring the barriers to the adoption of environmental economic practices in the construction industry. *Management of Environmental Quality an International Journal*. https://doi.org/10.1108/meq-01-2024-0053

[13]. Ameh, N. B. (2024). Digital tools and AI: Using technology to monitor carbon emissions and waste at each stage of the supply chain, enabling real-time adjustments for sustainability improvements. *International Journal of Science and Research Archive*, *13*(1), 2741–2757. https://doi.org/10.30574/ijsra.2024.13.1.1995

[14]. Anamika, and Malhotra, H. (2024). Waste-to-Energy Initiatives: entrepreneurial Opportunities and Challenges. *International Journal of Scientific Research in Engineering and Management*, *08*(06), 1–5. https://doi.org/10.55041/ijsrem36035

[15]. Ansari, T. M. K. D. J. J. D. S., and Savale, A. M. V. D. T. (2024). Solid waste management for environmental sustainability and human health. *Journal of Informatics Education and Research*, *4*(1). https://doi.org/10.52783/jier.v4i1.599

[16]. Archana, K., Visckram, A., Kumar, P. S., Manikandan, S., Saravanan, A., and Natrayan, L. (2023). A review on recent technological breakthroughs in anaerobic digestion of organic biowaste for biogas generation: Challenges towards sustainable development goals. *Fuel*, *358*, 130298. https://doi.org/10.1016/j.fuel.2023.130298

[17]. Arsakhanova, Z., Ravil, S., and Statsenko, E. (2024). Effective use of secondary resources: Technologies and recycling methods. *E3S Web of Conferences*, *537*, 03007. https://doi.org/10.1051/e3sconf/202453703007

[18]. Audu, N. A. J., Umana, N. A. U., and Garba, N. B. M. P. (2024). The role of digital tools in enhancing environmental monitoring and business efficiency. *International Journal of Multidisciplinary Research Updates*, *8*(2), 039–048. https://doi.org/10.53430/ijmru.2024.8.2.0052

[19]. Batarliene, N. (2019). Research on transportation of health-hazardous waste. *European Journal of Sustainable Development Research*, *4*(1). https://doi.org/10.29333/ejosdr/6342

[20]. Berberian, A. G., Morello-Frosch, R., Karasaki, S., and Cushing, L. J. (2024). Climate Justice Implications of Natech Disasters: Excess Contaminant Releases during Hurricanes on the Texas Gulf Coast. *Environmental Science and Technology*, *58*(32), 14180–14192. https://doi.org/10.1021/acs.est.3c10797

[21]. Bošnjaković, M., Galović, M., Kuprešak, J., and Bošnjaković, T. (2023). The end of life of PV systems: Is Europe ready for it? *Sustainability*. https://doi.org/10.20944/preprints202309.1420.v1

[22]. Boubellouta, B., and Kusch-Brandt, S. (2022). Determinants of e-waste composition in the EU28 + 2 countries: a panel quantile regression evidence of the STIRPAT model. *International Journal of Environmental Science and Technology*, *19*(11), 10493–10510. https://doi.org/10.1007/s13762-021-03892-0

[23]. Bulgariu, L. (2024). Physico-chemical methods for the removal of heavy metals and their use in remediation technologies. In *Elsevier eBooks* (pp. 217–232). https://doi.org/10.1016/b978-0-443-13659-7.00017-5

[24]. Chen, P., Chen, W., Lee, C., and Wu, J. (2023). Comprehensive review of Crystalline Silicon Solar panel recycling: From historical context to Advanced Techniques. *Sustainability*, *16*(1), 60. https://doi.org/10.3390/su16010060

[25]. Chiang, P. F., Zhang, T., Claire, M. J., Maurice, N. J., Ahmed, J., and Giwa, A. S. (2024). Assessment of solid waste management and decarbonization strategies. *Processes*, *12*(7), 1473. https://doi.org/10.3390/pr12071473

[26]. Czekała, W., Drozdowski, J., and Łabiak, P. (2023). Modern Technologies for Waste Management: a review. *Applied Sciences*, *13*(15), 8847. https://doi.org/10.3390/app13158847

[27]. Dada, N. M. A., Obaigbena, N. A., Majemite, N. M. T., Oliha, N. J. S., and Biu, N. P. W. (2024). Innovative Approaches To Waste Resource Management: Implications For Environmental Sustainability And Policy. *Engineering Science and Technology Journal*, *5*(1), 115–127. https://doi.org/10.51594/estj.v5i1.731

[28]. De Oliveira Neto, J. F., Candido, L. A., De Freitas Dourado, A. B., Santos, S. M., and Florencio, L. (2022). Waste of electrical and electronic equipment management from the perspective of a circular economy: A Review. *Waste Management and Research the Journal for a Sustainable Circular Economy*, *41*(4), 760–780. https://doi.org/10.1177/0734242x221135341

[29]. Demirbas, F., and Ateş, N. (2021). Evaluation of carbon footprint in a Waste Recovery/Recycle Facility. *Energy Environment and Storage*,*1*(1). https://doi.org/10.52924/yana8929

[30]. Dissanayake, P. A. K. N., Dissanayaka, D. M. S. B., Rankoth, L. M., and Abeysinghe, G. (2022). Waste management challenges in developing countries. In *CRC Press eBooks* (pp. 5–28). https://doi.org/10.1201/9781003132349-2

[31]. Ditia, S. (2024). The effect of industrial waste on air pollution and water pollution causes climate change. *Journal of Waste and Sustainable Consumption*, *1*(1), 18–26. https://doi.org/10.61511/jwsc.v1i1.2024.668

[32]. Dumble, P. (2022). Demonstrating Regional Climate and Meteorological Sensitivity in Landfill Methane Inventories from Historical Californian Databases. *Advances in Environmental and Engineering Research*, *03*(04), 1. https://doi.org/10.21926/aeer.2204054

[33]. Durrani, N., Raziq, A., Mahmood, T., and Khan, M. R. (2024). Barriers to adaptation of environmental sustainability in SMEs: A qualitative study. *PLoS ONE*, *19*(5), e0298580. https://doi.org/10.1371/journal.pone.0298580

[34]. Dutta, N. S. S. (2024). Lean manufacturing and process Optimization : enhancing efficiency in modern production. *International Journal of Scientific Research in Computer Science Engineering and Information Technology*, *10*(5), 265–273. https://doi.org/10.32628/cseit241051024

[35]. Faiz, N. F., Ninduwezuor-Ehiobu, N. N., Adanma, N. U. M., and Solomon, N. N. O. (2024). AI-Powered waste management: Predictive modeling for sustainable landfill operations. *Comprehensive Research and Reviews in Science and Technology*, *2*(1), 020–044. https://doi.org/10.57219/crrst.2024.2.1.0031

[36]. Fathinezhad, A. (2022). *Numerical investigation of heat generation and accumulation contributing to elevated temperature in MSW landfills*. https://doi.org/10.31390/gradschool_dissertations.6013

[37]. Ferdous, W., Manalo, A., Burey, P., Elks, G., Zhuge, Y., Abousnina, R., and Vimonsatit, S. (2022). Landfill waste: Challengesand Opportunities. *Proceedings of International Structural Engineering and Construction*, *9*(2). https://doi.org/10.14455/isec.2022.9(2).sus-05

[38]. Filho, M. G., Gonella, J. D. S. L., Latan, H., and Ganga, G. M. D. (2024). Awareness as a catalyst for sustainable behaviors: A theoretical exploration of planned behavior and value-belief-norms in the circular economy. *Journal of Environmental Management*, *368*, 122181. https://doi.org/10.1016/j.jenvman.2024.122181

[39]. Filonchyk, M., Peterson, M. P., Zhang, L., Hurynovich, V., and He, Y. (2024). Greenhouse gases emissions and global climate change: Examining the influence of CO2, CH4, and N2O. *The Science of the Total Environment*, *935*, 173359. https://doi.org/10.1016/j.scitotenv.2024.173359

[40]. Fuller, R. (2024). Hazardous waste and toxic hotspots. In *Oxford University Press eBooks* (pp. 398–408). https://doi.org/10.1093/oso/9780197662526.003.0030

[41]. Ghodke, S. A., Maheshwari, U., Gupta, S., and Bhanvase, B. A. (2023). Treatment of hazardous industrial solid wastes from electroplating industry: a comprehensive review. *Elsevier eBooks*, 141–167. https://doi.org/10.1016/b978-0-323-90909-9.00002-2

[42]. Gil, A. (2021). Challenges on Waste-to-Energy for the valorization of industrial wastes: Electricity, heat and cold, bioliquids and biofuels. *Environmental Nanotechnology Monitoring and Management*, *17*, 100615. https://doi.org/10.1016/j.enmm.2021.100615

[43]. Giusti, R., Arosio, M., Nascimbene, R., and Martina, M. (2023). Evaluating Environmental Impacts of Flood-Induced Tank Failures: A Risk chain model for soil and Groundwater Contamination in NATech context. *EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023*. https://doi.org/10.5194/egusphere-egu23-11291

[44]. Haas, C. N., and Vamos, R. J. (1994). Hazardous and industrial waste treatment. *SciSpace - Paper*. https://typeset.io/papers/hazardous-and-industrial-waste-treatment-1jabkk50vl

[45]. Habib, M. S., Maqsood, M. H., Ahmed, N., Tayyab, M., and Omair, M. (2022). A multi-objective robust possibilistic programming approach for sustainable disaster waste management under disruptions and uncertainties. *International Journal of Disaster Risk Reduction*, *75*, 102967. https://doi.org/10.1016/j.ijdrr.2022.102967

[46]. Hasheminezhad, A., Nazari, Z., Yang, B., Ceylan, H., and Kim, S. (2024). A comprehensive review of sustainable solutions for reusing wind turbine blade waste materials. *Journal of Environmental Management*, *366*, 121735. https://doi.org/10.1016/j.jenvman.2024.121735

[47]. Hossain, M. A., Ferdous, N., and Ferdous, E. (2023). Crisis-driven disruptions in global waste management: Impacts, challenges and policy responses amid COVID-19, Russia-Ukraine war, climate change, and colossal food waste. *Environmental Challenges*, *14*, 100807. https://doi.org/10.1016/j.envc.2023.100807

[48]. Hussain, C. M., Paulraj, M. S., and Nuzhat, S. (2021). Source reduction and waste minimization—concept, context, and its benefits. In *Elsevier eBooks* (pp. 1–22). https://doi.org/10.1016/b978-0-12-824320-6.00001-0

[49]. Ihueze C. C. and Okpala C. C. (2014). The Tools and Techniques of Lean Production System of Manufacturing. International Journal of Advanced Engineering Technology, 5(4)

[50]. Illiash, O., and Smoliar, N. (2022). Risk assessment of impact on the environment and public health when planning and implementing the Regional Waste Management Plan. *Labour Protection Problems in Ukraine*, *38*(3–4), 41–46. https://doi.org/10.36804/nndipbop.38-3-4.2022.41-46

[51]. Jamal, A. (2024). The role of circular economy principles in revolutionising sustainable manufacturing practices. *International Journal for Multidisciplinary Research*, *6*(5). https://doi.org/10.36948/ijfmr.2024.v06i05.27955

[52]. Jena, M. C., Mishra, S. K., and Moharana, H. S. (2023). Challenges and the way forward for management and handling of hazardous waste. *The Global Environmental Engineers*, *10*, 13–17. https://doi.org/10.15377/2410-3624.2023.10.2

[53]. Jones, S. (2020). Waste management in Australia is an environmental crisis: what needs to change so adaptive governance can help? *Sustainability*, *12*(21), 9212. https://doi.org/10.3390/su12219212

[54]. Joshi, R. (2024). A true green cover for industrial waste landfills. *TAPPI Journal*, *23*(4), 187–199. https://doi.org/10.32964/tj23.4.187

[55]. Karan, S., and Anusha, B. (2024). Low cost and economical alternatives for remediation of industrial waste. In *CRC Press eBooks* (pp. 187–206). https://doi.org/10.1201/9781003359326-10

[56]. Kodandapani, N. (2021). Adapting to Climatic Extremes through Climate Resilient Industrial Landscapes: Building Capacities in the Southern Indian States of Telangana and Andhra Pradesh. In *IntechOpen eBooks*. https://doi.org/10.5772/intechopen.98732

[57]. Kopecká, R., Hrad, M., and Huber-Humer, M. (2024). Die Rolle der Abfallwirtschaft im Rahmen der Nachhaltigkeitsziele und der IPCC-Klimaberichte. *Österreichische Wasser- Und Abfallwirtschaft*, *76*(5–6), 300–307. https://doi.org/10.1007/s00506-024-01034-7

[58]. Kumar, C. S., Sathya, A., Deb, R., and Rahman, M. M. (2024). Managing Electronic Waste: A Comprehensive Review of current state and challenges. *Transactions on Sustainable Environmental Sciences*, *1*(1), 10–18. https://doi.org/10.69888/ftsess.2024.000144

[59]. Lamani, H. D., Kumar, R. V., Devi, H. L., and Parveen, S. (2024). Climate Crisis Chronicles: Understanding global warming’s impact and solutions. *Journal of Diversity Studies*, *3*(1), 37–41. https://doi.org/10.51470/jod.2024.03.01.37

[60]. Lin, K., and Wei, S. (2023). Advancing the industrial Circular Economy: The Integrative role of Machine learning in resource optimization. *Journal of Green Economy and Low-Carbon Development*, *2*(3), 122–136. https://doi.org/10.56578/jgelcd020302

[61]. Liu, Z., and Mostafavi, A. (2023). Collision of Environmental Injustice and Sea Level Rise: Assessment of Risk Inequality in Flood-induced Pollutant Dispersion from Toxic Sites in Texas. *arXiv (Cornell University)*. https://doi.org/10.48550/arxiv.2301.00312

[62]. Moorthy, K. S., Balakrishnan, G., Kumar, S. S., Raja, L., and Vijayalakshmi, A. (2024). Embracing circular economy principles for sustainable green supply chain management in manufacturing industries. In *Advances in human resources management and organizational development book series* (pp. 85–110). https://doi.org/10.4018/979-8-3693-1343-5.ch005

[63]. Mukherjee, A. (2024). The Circular Supply Chain: Closing the Loop through Green Design, Reverse Logistics, and Sustainable Waste Management. *International Journal of Research Publication and Reviews*, *5*(2), 3189–3193. https://doi.org/10.55248/gengpi.5.0224.0602

[64]. Muljaningsih, S., Andayani, W., Ekawaty, M., and Asrofi, D. a. N. (2023). Scenario for mitigating climate change in indonesia: circular economy-based waste management (9r). *IOP Conference Series Earth and Environmental Science*, *1268*(1), 012001. https://doi.org/10.1088/1755-1315/1268/1/012001

[65]. Najar, I. N., Sharma, P., Das, R., Tamang, S., Mondal, K., Thakur, N., Gandhi, S. G., and Kumar, V. (2024). From waste management to circular economy: Leveraging thermophiles for sustainable growth and global resource optimization. *Journal of Environmental Management*, *360*, 121136. https://doi.org/10.1016/j.jenvman.2024.121136

[66]. Nath, S., Singh, K. K., Tangjang, S., and Das, S. (2024). Industrial Solid Wastes and Environment: An Overview on global generation, implications, and available management options. In *Springer water* (pp. 221–246). https://doi.org/10.1007/978-3-031-52633-6_9

[67]. Nunes, L. J. R. (2023). The rising threat of Atmospheric CO2: A review on the causes, impacts, and mitigation strategies. *Environments*, *10*(4), 66. https://doi.org/10.3390/environments10040066

[68]. Okere, J. K., Ofodum, C. M., Azorji, J. N., and Nwosu, O. J. (2019). Waste-to-Energy: A Circular Economy Tool towards Climate Change Mitigation in Imo State, South-Eastern, Nigeria. *Asian Journal of Advanced Research and Reports*, 1–17. https://doi.org/10.9734/ajarr/2019/v7i130164

[69]. Okpala C. C. (2013). The World's Best Practice in Manufacturing. International Journal of Engineering Research and Technology, 2(10), http://www.ijert.org/view-pdf/5760/the-worlds-best-practice-in-manufacturing

[70]. Okpala C. C. (2014). Tackling Muda – The Inherent Wastes in Manufacturing Processes. International Journal of Advanced Engineering Technology, 5(4)

[71]. Okpala C. C., Nwankwo C. O., and Onu C. E. (2020). Lean Production System Implementation in an Original Equipment Manufacturing Company: Benefits, Challenges, and Critical Success Factors. International Journal of Engineering Research and Technology, 9(7) https://www.ijert.org/volume-09-issue-07-july-2020

[72]. Onuoha, D. C., Ogbo, O. G., and Amaechi, M. (2022). The need for resilient infrastructure as an adaptive measure for climate change. *British Journal of Environmental Sciences*, *10*(4), 17–27. https://doi.org/10.37745/bjes.2013/vol10n4pp1727

[73]. Oyebode, O. J. (2024). Management of computer and electronic waste through the Fifth Industrial Revolution for the cleaner environment. *2024 International Conference on Science, Engineering and Business for Driving Sustainable Development Goals (SEB4SDG)*, 1–14. https://doi.org/10.1109/seb4sdg60871.2024.10629821

[74]. Pant, G., Rawat, P., Kathuria, S., Gehlot, A., and Rathor, N. (2023). Waste Management System with Technological intervention: Advantages and challenges. *2023 4th International Conference on Electronics and Sustainable Communication Systems (ICESC)*, *11*, 1461–1466. https://doi.org/10.1109/icesc57686.2023.10193334

[75]. Papamichael, I., Voukkali, I., Economou, F., Loizia, P., Demetriou, G., Esposito, M., Naddeo, V., Liscio, M. C., Sospiro, P., and Zorpas, A. A. (2023). Mobilisation of textile waste to recover high added value products and energy for the transition to circular economy. *Environmental Research*, *242*, 117716. https://doi.org/10.1016/j.envres.2023.117716

[76]. Pender, K., Romoli, F., and Fuller, J. (2024). Lifecycle Assessment of Strategies for Decarbonising Wind Blade Recycling toward Net Zero 2050. *Energies*, *17*(12), 3008. https://doi.org/10.3390/en17123008

[77]. Ponni, N. R., Sharmila, N. R., Jayasankar, N. T., and Perumal, N. C. (2024). Enhancing Environmental Sustainability: Extreme Learning Machine approach to industrial waste management. *Journal of Environmental Nanotechnology*, *13*(2), 220–228. https://doi.org/10.13074/jent.2024.06.242595

[78]. Ponti, M. G., Allen, D., White, C. J., Bertram, D., and Switzer, C. (2022). A framework to assess the impact of flooding on the release of microplastics from waste management facilities. *Journal of Hazardous Materials Advances*, *7*, 100105. https://doi.org/10.1016/j.hazadv.2022.100105

[79]. Potdar, S., Teja, M. S., and Sonawane, S. H. (2024). The recent development of waste to energy system for municipal solid management system in developing countries. In *CRC Press eBooks* (pp. 147–160). https://doi.org/10.1201/9781003229919-9

[80]. Randhawa, R. K. (2024). Waste management and recovery practices in the apparel sector through a sustainable approach. In *Practice, progress, and proficiency in sustainability* (pp. 37–52). https://doi.org/10.4018/979-8-3693-4264-0.ch003

[81]. Rani, T. S., and Yendluri, J. M. (2024). Sustainable Waste Management: Innovations and best practices. *International Journal of Innovative Science and Research Technology (IJISRT)*, 2686–2689. https://doi.org/10.38124/ijisrt/ijisrt24aug1613

[82]. Rao, K. M., Kumar, U. A., and Swamy, A. (2024). Effective technical approaches to industrial solid waste management. In *Futuristic Trends in Agriculture Engineering and Food Sciences* (pp. 175–184). https://doi.org/10.58532/v3bcagp1ch13

[83]. Raut, S. (2024). Waste Segregator: Waste Management Prototype. *International Journal for Research in Applied Science and Engineering Technology*, *12*(10), 457–459. https://doi.org/10.22214/ijraset.2024.64545

[84]. Revilla-Cuesta, V., Manso-Morato, J., Hurtado-Alonso, N., Skaf, M., and Ortega-López, V. (2023). Mechanical and environmental advantages of the revaluation of raw-crushed wind-turbine blades as a concrete component. *Journal of Building Engineering*, *82*, 108383. https://doi.org/10.1016/j.jobe.2023.108383

[85]. Reynolds, S. (2024). Uncovering the motivations and barriers for suppliers in adopting sustainable practices. *Research Square (Research Square)*. https://doi.org/10.21203/rs.3.rs-4289738/v1

[86]. Rouhi, K., Motlagh, M. S., and Dalir, F. (2023). Developing a carbon footprint model and environmental impact analysis of municipal solid waste transportation: A case study of Tehran, Iran. *Journal of the Air and Waste Management Association*, *73*(12), 890–901. https://doi.org/10.1080/10962247.2023.2271424

[87]. Saeed, S., Arshad, M. Y., and Ahmed, A. S. (2023). Advancing circular economy in industrial chemistry and environmental engineering: Principles, alignment with United Nations sustainable development goals, and pathways to implementation. *European Journal of Chemistry*, *14*(3), 414–428. https://doi.org/10.5155/eurjchem.14.3.414-428.2452

[88]. Sasso, R. A., Filho, M. G., and Ganga, G. M. D. (2024). Synergizing lean management and circular economy: Pathways to sustainable manufacturing. *Corporate Social Responsibility and Environmental Management*. https://doi.org/10.1002/csr.2962

[89]. Satin, I. V., and Kutsyi, D. V. (2024). Greenhouse gas emissions from municipal waste disposal sites and measures for its reduction. *Naukovì Dopovìdì Nacìonal'nogo Unìversitetu Bìoresursiv Ì Prirodokoristuvannâ Ukraïni*, *109*(3). https://doi.org/10.31548/dopovidi.3(109).2024.003

[90]. Shooshtarian, S. (2019). Construction waste management in natural disasters in Australia. *Global Journal of Engineering Sciences*, *3*(5). https://doi.org/10.33552/gjes.2019.03.000573

[91]. Shu, C., Feng, Z., Liang, C., Guo, J., Xu, F., Tian, J., and Chen, L. (2024). Whole- process and multi- stakeholder- based solid waste management framework construction for industrial parks: Toward circular economy development. *Journal of Industrial Ecology*, *28*(4), 928–941. https://doi.org/10.1111/jiec.13508

[92]. Shuvo, Z. H., Rahman, M. Z., Saha, B., and Ador, M. S. H. (2023). Progress in recovery, recycling and reuse of polymers, biopolymers and their composites. In *Elsevier eBooks* (pp. 555–578). https://doi.org/10.1016/b978-0-323-96020-5.00185-0

[93]. Simion, I. M., Gavrilescu, M., Ghiga, S. C., Filote, C., Rosca, M., Hlihor, R., and Cozma, P. (2023). Sources, Composition and Management Strategies Of Waste Electrical And Electronic Equipment: A Review. *Environmental Engineering and Management Journal*, *22*(3), 509–526. https://doi.org/10.30638/eemj.2023.040

[94]. Singh, N. G. (2024). E-Waste: A judicious management for the protection of human health and environment. *International Journal of Science and Research Archive*, *12*(2), 435–437. https://doi.org/10.30574/ijsra.2024.12.2.1253

[95]. Sinha, P., Fry, M., Julius, S., Truesdale, R., Cajka, J., Eddy, M., Doraiswamy, P., Albright, R., Riemenschneider, J., Potzler, M., Lim, B., Richkus, J., and O'Neal, M. (2024). Building resilience to extreme weather events in Phoenix: Considering contaminated sites and disadvantaged communities. *Climate Risk Management*, *43*, 100586. https://doi.org/10.1016/j.crm.2024.100586

[96]. Somya, A., Peter, A., Varshney, A. P., and Thakur, A. (2024). Recent technologies used in waste management. In *Practice, progress, and proficiency in sustainability* (pp. 177–202). https://doi.org/10.4018/979-8-3693-4054-7.ch007

[97]. Sonawane, B., Kadry, A. M., and Kancherla, J. (2023). Electronic waste: human health and environmental risk. *Patty's Toxicology*, 1–18. https://doi.org/10.1002/0471125474.tox163

[98]. Suresh, N. R., Subramaniyan, R., K, N. S. K., Kumar, N. N., and Chenniappan, M. (2023). Sustainable technologies for treatment of industrial wastewater and its potential for reuse. In *Futuristic Trends in Chemical, Material Sciences and Nano Technology* (pp. 143–168). https://doi.org/10.1007/978-981-99-2435-6_9

[99]. Suresh, P., Paul, A., Kumar, B. A., Ramalakshmi, D., Dillibabu, S. P., and Boopathi, S. (2024). Strategies for carbon footprint reduction in advancing sustainability in manufacturing. In *Advances in chemical and materials engineering book series* (pp. 317–350). https://doi.org/10.4018/979-8-3693-3625-0.ch012

[100]. Tayebi, S. T., Sambucci, M., and Valente, M. (2024). Waste Management of Wind Turbine Blades: A Comprehensive Review on Available Recycling Technologies with A Focus on Overcoming Potential Environmental Hazards Caused by Microplastic Production. *Sustainability*, *16*(11), 4517. https://doi.org/10.3390/su16114517

[101]. Troisi, R., De Simone, S., and Franco, M. (2023). Illegal firm behaviour and environmental hazard: The case of waste disposal. *European Management Review*, *21*(3), 605–617. https://doi.org/10.1111/emre.12600

[102]. Vaiškūnaitė, R., and Zagorskis, A. (2024). Influence of aeration and introducing of probiotics and supplying of water on landfill gas production − Models study. *Processes*. https://doi.org/10.20944/preprints202408.0210.v1

[103]. Wang, J., Feng, Y., and He, Y. (2024). Insights for China from EU management of recycling end-of-life photovoltaic modules. *Solar Energy*, *273*, 112532. https://doi.org/10.1016/j.solener.2024.112532

[104]. Wang, L. K., Shammas, N. K., and Hung, Y. (2008). Advances in hazardous industrial waste treatment. In *CRC Press eBooks*. https://doi.org/10.1201/9781420072310

[105]. Wattanakit, C., Fan, X., Mukti, R. R., and Yip, A. C. K. (2024). Green chemistry, catalysis, and waste valorization for a circular economy. *ChemPlusChem*. https://doi.org/10.1002/cplu.202400389

[106]. Wilson, D. C., Paul, J., Ramola, A., and Filho, C. S. (2024). Unlocking the significant worldwide potential of better waste and resource management for climate mitigation: with particular focus on the Global South. *Waste Management and Research the Journal for a Sustainable Circular Economy*, *42*(10), 860–872. https://doi.org/10.1177/0734242x241262717

[107]. Xie, Y., Zhou, B., Wang, Z., Yang, B., Ning, L., and Zhang, Y. (2023). Industrial Carbon Footprint (ICF) calculation approach based on Bayesian Cross-Validation improved cyclic stacking. *Sustainability*, *15*(19), 14357. https://doi.org/10.3390/su151914357

[108]. Xu, J. (2024). Research on innovative models of waste recycling in urban infrastructure. *Academic Journal of Science and Technology*, *9*(2), 245–248. https://doi.org/10.54097/4b1cqh43

[109]. Yu, H., Zahidi, I., Fai, C. M., Liang, D., and Madsen, D. Ø. (2024). Mineral waste recycling, sustainable chemical engineering, and circular economy. *Results in Engineering*, *21*, 101865. https://doi.org/10.1016/j.rineng.2024.101865

[110]. Zakhilwal, S. A., Shirzad, W., and Behsoodi, M. M. (2024). A Comprehensive review of engineering Strategies for environmental sustainability in sustainable waste management. *International Journal of Current Science Research and Review*, *07*(10). https://doi.org/10.47191/ijcsrr/v7-i10-02

[111]. Zandieh, Z., Thornley, P., and Chong, K. (2024). Progress of waste management in achieving UK's net-zero goal. *Journal of Material Cycles and Waste Management*. https://doi.org/10.1007/s10163-024-02003-8

[112]. Zhang, T., Gao, S., Teng, X., Jiang, X., Chen, J., Gao, C., Bian, R., Sun, Y., Li, W., Wang, Y., and Wang, H. (2023). Spatio-temporal change in city-level greenhouse gas emissions from municipal solid waste sector in China during the last decade and its potential mitigation. *PubMed*, *44*(11), 5946–5953. https://doi.org/10.13227/j.hjkx.202211184

[113]. Zhang, W., Yu, H., Yin, B., Akbar, A., and Liew, K. (2023). Sustainable transformation of end-of-life wind turbine blades: Advancing clean energy solutions in civil engineering through recycling and upcycling. *Journal of Cleaner Production*, *426*, 139184. https://doi.org/10.1016/j.jclepro.2023.139184