Transition to a Circular Economy in Waste Management: A Review of International Experiences and Approaches

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Abstract

The circular economy, as a novel and systematic approach, is considered a response to the environmental and structural inefficiencies of the linear economy. The primary objective of this model is to preserve the value of resources, materials, and products at the highest possible level and for the longest possible duration. Unlike the linear model of "extraction, production, consumption, and disposal," the circular economy, through the design of closed loops, regulates the flow of materials and energy in a way that minimizes waste generation. The various definitions proposed by the Ellen MacArthur Foundation, Kirchherr, and Geissdoerfer all emphasize the characteristics of regenerativity, restorability, and the elimination of the concept of end-of-life consumption. In this article, the conceptual and operational dimensions of the circular economy and the waste management hierarchy are examined. The key stages of this hierarchy include prevention, reduction, reuse, recycling, energy recovery, and final disposal. Furthermore, policy frameworks, evaluation indicators, and global implementation challenges—particularly in the Global North and Global South—are analyzed. Ultimately, achieving a circular economy requires the synergy of public policies, technological innovation, cultural education, and cross-sector collaboration. This model outlines a sustainable horizon for the future of the global economy that simultaneously addresses economic growth, social justice, and environmental preservation.

Keywords: *Circular economy, waste management, sustainable development*

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1. Introduction

Over the past decades, the world has witnessed a significant increase in the consumption of natural resources, the production of goods, and, consequently, a substantial rise in the volume of municipal, industrial, and agricultural solid waste. The dominant production and consumption pattern in many countries is known as the linear economy, which is based on three main stages: resource extraction, production and consumption, and waste disposal. This model has not only led to the excessive exploitation of limited natural resources but has also resulted in the generation of massive amounts of waste and environmental pollution. In such a system, products often turn into waste after use and rarely re-enter the production cycle. This situation threatens environmental sustainability, reduces resource efficiency, and increases the economic and social costs of waste management [1].

In contrast, the circular economy (CE) has, in recent years, attracted increasing attention from researchers, policymakers, and industry stakeholders as an innovative and sustainable approach. The circular economy is based on the idea of closing product life cycles, avoiding waste generation, and effectively recycling and reusing resources at all stages of the value chain. In such a system, waste is minimized, and what was once considered “waste” is now regarded as a “new resource” for production. This model not only contributes to the conservation of natural resources and the reduction of greenhouse gas emissions but also creates

new opportunities for innovation, job creation, and sustainable economic growth [2].

One of the most important areas for implementing and realizing the circular economy is waste management. Traditionally focused on disposal and landfilling, waste management is now moving toward strategies such as source reduction, product redesign, separation and recycling, remanufacturing, and energy recovery from waste. Transitioning from traditional waste management to circular models requires rethinking existing policies, technologies, consumer behavior, and economic systems [3].

Historically, the concept of the circular economy has evolved from theories such as industrial ecology, cradle-to-cradle design, and life cycle analysis. Today, in light of global environmental crises and resource challenges, it has emerged as a macro-level strategy at both national and international scales. International organizations such as the European Commission, the United Nations Environment Programme (UNEP), and the Ellen MacArthur Foundation have played key roles in promoting and developing policies related to the circular economy [4].

International experiences demonstrate that the successful implementation of the circular economy in waste management requires a coordinated set of environmental policies, economic mechanisms, technological innovations, and social participation. For example, European Union member states, through adopting the Circular Economy Action Plan as part of the European Green Deal, have taken significant steps in this direction. These policies include sustainable design requirements, the development of recycling markets, economic incentives for green industries, and public education programs. Similarly, countries such as China, Japan, and the Netherlands have designed and implemented localized circular economy models in waste management, taking into account their specific economic, environmental, and technological contexts [5].

In Iran, given the serious challenges arising from population growth, urban expansion, consumerism, and limited natural resources, the necessity of transitioning to circular waste management is more urgent than ever. Although sporadic initiatives have been undertaken in recycling, source separation, and waste-to-energy conversion, the absence of a comprehensive policy and operational framework based on circular economy principles has resulted in a considerable portion of potential resources still being landfilled or incinerated. Meanwhile, with its human, scientific, and technological capacities, Iran can benefit from international experiences and develop a suitable localized model for circular waste management [6].

Considering the extensive scientific and practical literature on the circular economy and its application in waste management, the main aim of this article is to review international experiences and approaches in implementing the circular economy in the field of waste management. In doing so, it seeks to provide a comparative analysis of successful global policies, tools, and models, creating a basis for scientific and practical benchmarking in developing countries, including Iran. Furthermore, this article seeks to answer the key question: what factors contribute to the success or failure of countries in achieving circular waste management, and how can these experiences be adapted to local contexts?

2. Circular Economy in Waste Management

The circular economy is a modern concept developed in response to the structural inefficiencies of the linear economy, aiming to maintain the value of resources, materials, and products at the highest possible level for the longest possible time within the economic cycle. The traditional “extraction, production, consumption, and disposal” model prevalent in the linear economy is replaced in the circular economy by interconnected material loops, preventing waste generation and ensuring that the output of one process serves as the input for another. One of the earliest and most influential definitions in this field was introduced by the Ellen MacArthur Foundation. In its 2013 report, the Foundation described the circular economy as a regenerative and restorative industrial system, intentionally designed to keep materials, energy, and products in circulation in such a way that no “waste” exists at the end of a product’s life cycle. This design-oriented perspective provides a fundamental framework for rethinking global production and consumption models [7].

3. Review of International Studies for Conceptual Clarification

In a more comprehensive analysis, Kirchherr, Reike, and Hekkert examined 114 different definitions and concluded that the circular economy is an economic system that, by eliminating the traditional concept of “end-of-life” consumption, incorporates strategies such as reduction, reuse, recovery, and material reclamation across all stages of production and consumption. According to these researchers, the circular economy is not merely a new

production model but a holistic paradigm for redefining the relationship between the economy, the environment, and society [8].

Similarly, Geissdoerfer et al., in a widely cited review article, defined the circular economy as a regenerative system in which resource inputs, waste, emissions, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. They argued that the circular economy, aimed at long-term sustainability and value creation from resources, plays a significant role in sustainable development [9].

Taken together, these definitions indicate that the circular economy is not merely an advanced recycling model but an integrated economic framework for redesigning economic and industrial structures, seeking to create a sustainable system through innovation, cross-sector collaboration, and environmental considerations. The waste management hierarchy in the circular economy plays a fundamental role in providing a structured and coherent approach to prioritizing responses to the challenges of waste generation and disposal. As the first priority, prevention is emphasized, as it avoids waste generation at the source, thereby reducing environmental and economic damage. This stage involves designing sustainable products, improving processes, and promoting sustainable consumption behaviors, all aimed at reducing resource use and, consequently, waste generation. Since any product not produced generates no waste, prevention serves as the most fundamental and root-level strategy [10].

The second stage, reduction, aims to optimize the use of materials and replace them with lower-cost and more environmentally friendly alternatives. This can include using more durable, lighter, or recyclable materials, thereby reducing the consumption of natural resources and the amount of waste generated. Following reduction, reuse involves returning products or components to the consumption cycle without complex processing or significant alteration. This not only reduces resource use but also decreases the need for manufacturing new products, thereby preventing the generation of new waste. Reuse can also include repair, repurposing, or even exchanging second-hand goods, which in many societies has evolved into a consumption culture. The next stage, recycling, is recognized as the process of converting waste into secondary raw materials. In the circular economy, recycling is essential for preserving material value, reducing the need for virgin resources, and lowering energy consumption in the production of new products. This stage requires advanced technologies and proper collection and sorting systems to ensure quality in the remanufacturing process. Recycling of materials such as paper, plastics, metals, and glass plays a major role in reducing environmental pressure. Energy recovery follows, offering a solution for waste streams that cannot be directly recycled. This involves converting waste into energy—through technologies such as controlled incineration—which can be used for electricity generation, heating, or industrial processes. While this method reduces waste volume, it also produces pollutant emissions, making its environmental impacts a point of concern [11].

Finally, landfilling or incineration without energy recovery is considered the last resort in waste management, used only when none of the previous options are viable. These methods often have harmful environmental impacts, including soil and water contamination. For this reason, the circular economy aims to prevent waste from reaching this stage by successfully implementing the higher levels of the hierarchy. Environmental policymakers and managers worldwide seek to minimize landfilling through strict regulations and financial incentives.

Given the increasing volume of waste and the depletion of natural resources globally, adhering to the waste management hierarchy within the circular economy is vital to moving toward a more sustainable society. Implementation at both micro and macro levels requires cross-sector collaboration, specialized education, investment in modern technologies, and cultural mindset shifts, all of which collectively play a crucial role in its success.

The study by Abu-Bakar and Charnley presents a comprehensive theoretical framework for improving strategic planning in circular economy initiatives, helping to chart its trajectory through more structured and systematic approaches. Recognizing the fragmented nature of current CE strategies, the authors integrate principles of strategic management, systems thinking, and sustainability science to offer a unified methodology that aligns long-term CE objectives with practical, measurable outcomes. Developed through an extensive literature review that identified key theoretical gaps, this framework was validated by examining various CE roadmaps at sectoral, urban, national, and regional levels. This cross-context analysis highlights existing inconsistencies in current CE methods and underscores the need for a standardized yet flexible roadmap structure, providing a valuable tool for policymakers, business leaders, and sustainability practitioners to navigate the complexities of CE planning [12].

Awino and Apitz, in their comprehensive international review, examine the challenges and potential strategies for solid waste management (SWM) by integrating the waste hierarchy (WH) and circular economy (CE) frameworks. The authors explore how rising global consumption, population growth, and waste trade complicate waste management across nations. Updating a conceptual framework used by international organizations, they assess SWM practices worldwide, identifying key stakeholders, critical factors, and effective strategies. Their analysis shows that only a few countries achieve near-zero waste generation, while most still rely heavily on incineration, open dumping, and landfilling. The study contrasts the reliance of Global North countries on technological, economic, and policy tools with the dependence of Global South countries on informal recycling economies, identifying barriers such as weak governance, poor data, limited public engagement, and policy misalignment. The authors advocate for interregional cooperation and knowledge exchange to enhance compliance with environmental regulations, promote inclusive stakeholder participation, and support the United Nations Sustainable Development Goals through fairer and more effective waste management systems [13].

Pires and Martinho introduce the Waste Hierarchy Index (WHI) as a novel metric for assessing the implementation of the waste hierarchy within the circular economy framework. They argue that current European Union directives lack a unified index to measure the success of countries in applying waste management strategies—namely, prevention, preparation for reuse, recycling, other recovery (e.g., incineration), and disposal (e.g., landfilling). The proposed WHI integrates these processes by assigning positive values to recycling and preparation for reuse and negative values to incineration and landfilling. Designed to prioritize conservation-oriented operations, the WHI offers a comprehensive view of waste management performance. Tested at both local and national levels, it has shown its potential as a practical and straightforward tool that simplifies data requirements while fostering deeper discussions on aligning waste policies with CE goals. The research also highlights the ambiguous role of incineration and calls for clearer integration of this method into CE assessment criteria [14].

In a 2022 study, D'Adamo and colleagues analyzed the relationship between waste management policies and circular economy goals, emphasizing the critical role of social and regulatory mechanisms. Focusing on major waste streams—municipal solid waste (MSW), waste electrical and electronic equipment (WEEE), and end-of-life vehicles (ELV)—they combined an expert-supported literature review with targeted surveys to assess policy effectiveness. The results indicate that "end-of-waste" strategies are particularly effective in WEEE and ELV management, while social behavioral change is essential for improving MSW management. The study stresses that behavioral and regulatory interventions act as significant accelerators in the CE transition, noting that technological readiness is largely achieved. To enhance reuse and recycling and achieve broader CE objectives, the authors call for urgent policy measures integrating both technical and social dimensions, aligned with the European Union's vision for a sustainable, digitized industry under the Horizon Europe program [10].

Another study examines the role of green supply chains in eco-industrial parks (EIPs) as a pathway toward a green economy. Effective strategies and evaluation methods for developing a green economy are proposed through identifying barriers in institutional, legal, technological, and financial contexts. Three case studies from Taiwan's iron and steel, paper and pulp, and petrochemical industries illustrate success in establishing green supply chains. For example, by 2012, the Lin-Hai Industrial Park had created 15 efficient green supply chains using waste-to-resource conversion technologies, generating an annual economic benefit of USD 100 million. These results demonstrate that establishing green supply chains can simultaneously foster economic growth and environmental protection, and the approach should be widely promoted in industrial parks to achieve sustainable industry and social equity [15].

Table 1. Analysis of Concepts and Frameworks of the Circular Economy

Source/Study	Description/Definition	Component
[8]	Elimination of the end-of-life concept and creation of loops for reduction, reuse, and recycling	Broader concept of the circular economy
[9]	Slowing, closing, and narrowing resource flows to reduce inputs and pollutant emissions	Systemic dimensions
[10]	(1) Prevention, (2) Reduction, (3) Reuse, (4) Recycling, (5) Energy recovery, (6) Final disposal/incineration	Waste management hierarchy in the circular economy
[12]	Integrating strategic management, systems thinking, and sustainability for CE roadmap design	Integrated strategic framework

[13]	Policy misalignment, reliance on informal economy, and differing approaches between Global South and Global North	Global challenges of waste management
[14]	Quantitative integration of the waste hierarchy to assess national performance within the CE framework	WHI evaluation index
[10]	Emphasis on social and regulatory interventions to improve MSW, WEEE, and ELV management	Behavioral and policy approaches
[15]	Use of green supply chains in various industries to achieve a green economy	Eco-industrial parks (EIPs)

4. The Future of the Circular Economy

The circular economy, as an innovative model, offers a clear response to the inefficiencies, unsustainability, and resource wastage inherent in the traditional linear economy. As shown by the literature review, this conceptual model is not limited to reconfiguring recycling and reuse patterns but encompasses a structural rethinking of the relationships among production, consumption, natural resources, and the environment.

From a conceptual perspective, the circular economy is defined as a systematic and regenerative framework based on purposeful design and a systemic approach, in which the flow of materials, energy, and information is managed to maximize resource life cycles and minimize waste generation. This approach, grounded in the principle of "zero waste" and the synergy among supply chain components, requires fundamental revisions in many areas, including policymaking, industrial planning, and consumption culture.

Recent research analyses further indicate that realizing the circular economy requires convergence among advanced technologies, coherent policy frameworks, effective institutions, and active social participation. In particular, studies such as [14], through the introduction of quantitative indices, and [12], through the development of strategic frameworks, have created the foundation for more effective evaluation and structured planning. Furthermore, successful industrial-level experiences, such as the establishment of green supply chains in Taiwan's eco-industrial parks, demonstrate the feasibility of implementing these concepts at both enterprise and regional levels [15].

5. Discussion

The findings and analysis presented throughout this study highlight the transformative potential of the circular economy in the realm of waste management. The review of international experiences shows that the circular economy is more than a technical or operational model; it is a comprehensive paradigm shift that requires systemic rethinking of how societies produce, consume, and manage resources. Unlike the traditional linear model, which inevitably leads to the depletion of finite resources and the accumulation of waste, the circular economy provides a regenerative framework designed to keep resources in use for as long as possible, thereby extracting maximum value before recovery and regeneration.

One of the central points emerging from this study is the importance of integrating the waste hierarchy into circular economy strategies. The waste hierarchy, which prioritizes prevention, reduction, reuse, recycling, energy recovery, and finally disposal, serves as a practical roadmap for transitioning from waste-intensive systems to more sustainable cycles. The analysis suggests that prevention and reduction at the source remain the most impactful measures for reducing environmental burdens and economic costs. These upstream interventions, such as product redesign, material substitution, and sustainable consumption patterns, not only address waste issues but also influence the entire production-consumption chain, leading to systemic efficiency gains.

Reuse and recycling, while essential, depend heavily on the existence of supportive infrastructure, advanced technology, and conducive policy environments. Countries that have achieved high levels of reuse and recycling have invested heavily in collection systems, sorting technologies, and market development for secondary materials. Additionally, cultural factors, including public awareness and participation, play a critical role in the success of these measures. In regions where waste separation and reuse are embedded in social norms, recycling rates tend to be significantly higher, and the quality of recovered materials is superior.

Energy recovery from non-recyclable waste presents an interesting point of debate. While it offers a means to reduce landfill dependency and generate useful energy, it also carries environmental trade-offs, including greenhouse gas emissions and air pollutants. This highlights the need for a nuanced approach, ensuring that energy recovery is employed only where higher-priority waste management options are not feasible. Moreover, the role of landfilling as a last resort must be further minimized through strict regulations, economic disincentives, and continuous investment in alternatives.

The study also underlines the critical role of integrated policy frameworks in enabling circular economy transitions. Countries with coherent, cross-sectoral policies that link waste management to broader sustainability and economic strategies tend to demonstrate more significant progress. Such integration requires coordination among multiple governmental levels, alignment of environmental regulations with economic incentives, and the incorporation of circular economy principles into industrial and urban planning. The case studies reviewed indicate that isolated or fragmented policy initiatives often fail to achieve systemic change, whereas coordinated efforts yield more substantial and sustainable outcomes.

Technological innovation emerges as another central pillar in the transition to a circular economy. Advances in materials science, digital technologies, and industrial processes are essential to closing resource loops and improving the efficiency of resource use. For instance, smart waste tracking systems, AI-based sorting technologies, and bio-based material alternatives are reshaping the possibilities for waste management. However, technology alone cannot deliver the desired transformation without the institutional capacity, skilled workforce, and financing mechanisms necessary for widespread adoption.

Social and behavioral dimensions also play a decisive role. Even the most advanced policies and technologies can fall short without active participation from citizens, businesses, and communities. Public engagement campaigns, education programs, and participatory governance models have been shown to increase buy-in and compliance. Equally important is the role of the private sector, whose innovations, investments, and business models can either accelerate or hinder the circular transition. Businesses that integrate circular principles into their operations not only contribute to environmental objectives but also gain competitive advantages through resource efficiency, brand differentiation, and resilience to supply chain disruptions.

One particularly notable insight from the comparative analysis is that the circular economy is not a one-size-fits-all model. Contextual factors such as economic structure, governance capacity, cultural norms, and available resources shape the feasibility and design of circular strategies. High-income countries often leverage advanced technologies and regulatory frameworks, while low- and middle-income countries may rely more on informal recycling sectors and community-based initiatives. This variation underscores the importance of tailoring circular economy approaches to local realities while maintaining alignment with overarching sustainability goals.

Furthermore, the circular economy offers broader benefits beyond waste management. By promoting resource efficiency and product longevity, it contributes to economic diversification, job creation, and innovation. It also strengthens resilience against resource price volatility and supply disruptions. From a social perspective, circular initiatives can foster inclusion by creating opportunities in repair, refurbishment, and remanufacturing sectors. Environmentally, the reduction of resource extraction and waste generation leads to lower emissions, reduced pollution, and conservation of ecosystems.

Nonetheless, the transition is not without its challenges. Institutional inertia, entrenched linear business models, and resistance from stakeholders benefiting from the status quo can slow progress. Financial barriers, particularly in developing economies, limit the capacity to invest in the necessary infrastructure and technologies. Data gaps, especially regarding waste flows and material composition, hinder evidence-based policymaking and performance monitoring. Moreover, the need for coordination across multiple policy domains—such as energy, industry, trade, and environment—adds complexity to implementation.

The review also reveals that successful circular economy adoption is iterative, involving continuous learning, adaptation, and improvement. Pilots and demonstration projects can serve as valuable testing grounds for new technologies, policies, and business models before scaling up. Monitoring and evaluation frameworks are critical for tracking progress, identifying bottlenecks, and ensuring that interventions are delivering the intended environmental, economic, and social benefits.

In the case of Iran, the discussion suggests significant potential for circular economy integration within waste management systems, particularly given the country's growing waste generation, resource constraints, and existing technological and human capital. However, this potential remains largely untapped due to the absence of a comprehensive, coherent policy framework and the fragmentation of initiatives. Leveraging international experiences while adapting them to local conditions could accelerate progress. This would involve establishing clear targets, creating economic incentives for circular practices, and fostering partnerships between government, industry, academia, and civil society.

Ultimately, the discussion points to the circular economy as both a necessity and an opportunity. As environmental

pressures intensify and the global demand for resources grows, traditional linear models become increasingly untenable. The circular economy offers a pathway that aligns environmental stewardship with economic prosperity and social well-being, but its realization demands systemic change, sustained commitment, and multi-stakeholder collaboration.

6. Conclusion

The evidence and analysis presented in this study affirm that the circular economy provides a robust and forward-looking framework for addressing the multifaceted challenges of waste management. By shifting focus from end-of-pipe solutions to preventive and regenerative strategies, it enables societies to decouple economic growth from resource depletion and environmental degradation.

A key takeaway is that the effectiveness of circular economy implementation depends on the integration of technical, policy, economic, and social dimensions. Technical innovations are necessary to improve material recovery and resource efficiency, but they must be supported by coherent policy frameworks, financial mechanisms, and institutional capacities. Similarly, behavioral change at the societal level—driven by awareness, education, and cultural transformation—is essential to ensure the adoption and persistence of circular practices.

The study's review of international experiences underscores that while there is no universal blueprint, certain common success factors emerge: strong political commitment, cross-sectoral coordination, alignment of regulations with incentives, investment in infrastructure and innovation, and inclusive stakeholder participation. Countries that combine these elements within a coherent strategy are better positioned to realize the full benefits of the circular economy.

For developing countries, the transition offers an opportunity to leapfrog directly to more sustainable systems, avoiding the resource- and waste-intensive pathways of the past. This requires adaptive approaches that respect local contexts while drawing on global knowledge and best practices. Collaboration between the Global North and Global South—through technology transfer, capacity building, and equitable partnerships—can accelerate the global transition while addressing disparities in resources and capabilities.

From an environmental standpoint, the adoption of circular economy principles in waste management has the potential to significantly reduce greenhouse gas emissions, pollution, and pressure on ecosystems. Economically, it can open new markets, stimulate innovation, and create employment in emerging sectors. Socially, it can promote inclusivity and resilience, empowering communities through participation in resource recovery and reuse initiatives.

In moving forward, the priority should be to translate the conceptual and strategic advances of the circular economy into tangible, measurable outcomes. This requires not only setting ambitious targets but also ensuring that progress is tracked through reliable data and transparent reporting. Pilot projects, incremental improvements, and continuous learning should be embraced as part of an adaptive, long-term strategy.

In conclusion, the circular economy in waste management is not merely an environmental or technical agenda—it is a comprehensive socio-economic transformation. By reimagining the life cycle of materials and redefining the relationship between human activity and the natural environment, it offers a viable and sustainable pathway for the future. The challenge lies in mobilizing the collective will, resources, and ingenuity to make this vision a reality.

Authors' Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

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