

Identification Of Circular Economy Criteria and Indicators in International Standards to Support Global Sustainability: A Systematic Literature Review

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ABSTRACT

The transition to a circular economy (CE) is critical for achieving global sustainability goals. However, the identification and integration of standardized criteria and indicators to support CE remain a challenge. This study conducts a systematic literature review (SLR) to identify the criteria and indicators embedded in international standards and their implications for CE implementation. Using the PRISMA methodology, 100 relevant publications were analyzed, focusing on prominent standards such as ISO, the EU Circular Economy Action Plan, the Ellen MacArthur Foundation framework, Cradle to Cradle, and GRI. The findings reveal recurring criteria, including resource efficiency, waste reduction, sustainable product design, and compliance with environmental regulations. Indicators such as carbon footprint, recycling rates, and material reuse emerge as pivotal for assessing CE progress. These findings offer valuable insights for policymakers and organizations in developing comprehensive strategies to advance CE adoption. Recommendations include the harmonization of standards, enhanced stakeholder collaboration, and the integration of CE principles across sectors.

Keywords: Circular Economy, International Standards, Global Sustainability

Introduction

Climate change and the increasing greenhouse gas (GHG) emissions have emerged as the most pressing global issue. The impacts are becoming more evident, including rising global temperatures, extreme weather events, floods, droughts, and threats to global ecosystems [1]. The IPCC 2021 report highlighted those human activities have contributed to an average global temperature rise of approximately 1.1°C, with projections indicating it may exceed 1.5°C in the coming decades [2]. This temperature increase has intensified extreme weather phenomena, such as storms, floods, heatwaves, and droughts, disrupting ecosystems, infrastructure, and human livelihoods. Consequently, the concept of Net Zero Emissions has become a primary target for numerous countries and organizations to combat climate change and achieve environmental sustainability.

Amid the growing urgency for sustainability, the Circular Economy (CE) has emerged as a strategic solution to address global sustainability challenges. CE emphasizes the principles of reduction, reuse, and recycling of resources to minimize waste and maximize the value of products throughout their lifecycle [3], [4], [5]. The rapid growth in research and publications focused on CE reflects this trend [6]. Furthermore, CE is interdisciplinary, encompassing diverse fields such as business, environment, engineering, social sciences, design, and economics [7], [8].

However, implementing CE faces significant challenges, particularly in industrial sectors, distribution systems, and supply chain management, which remain heavily reliant on fossil-based raw materials and linear production systems. As a result, carbon emissions continue to rise significantly [9].

On the other hand, adopting CE offers numerous benefits, including reducing global material extraction by up to 10% [10] [11] and decreasing carbon footprints by 10.1%, material use by 12.5%, and freshwater consumption by 14.6% [11]. Despite these advantages, challenges such as declining economic value and job creation highlight the need for a more comprehensive approach.

Thus, CE presents a strategic approach to supporting global sustainability by optimizing resource use, reducing waste, and enhancing production efficiency. Implementing CE principles also reduces reliance on finite natural resources, strengthens economic resilience, and fosters more sustainable production systems.

To promote CE adoption across sectors, international standards have been developed by organizations such as the International Organization for Standardization (ISO), Ellen MacArthur Foundation, European Commission, and Global Reporting Initiative (GRI). These international standards play a pivotal role in providing technical guidance for effective circular practices, offering evaluation parameters to measure CE implementation success, and harmonizing cross-border policies that facilitate global trade and industrial collaboration.

Therefore, identifying CE criteria and indicators within international standards is crucial to understanding how CE principles can be implemented in a measurable and consistent manner. This effort not only supports global sustainability but also provides clear guidance for industrial, business, and governmental sectors transitioning toward a more circular and sustainable economy. This study addresses two key research questions:

RQ1. What are the criteria and indicators of circular economy outlined in various international standards?

RQ2. How can these criteria and indicators support the implementation of the circular economy?

The purpose of this study is to provide a clear framework for developing and implementing indicators that can be utilized by various stakeholders, including governments, industries, and communities, in efforts to achieve the sustainability development goals set by the United Nations. In this context, the importance of effective indicators to support the transition to a Circular Economy (CE) cannot be overstated. Indicators must be coherent, relevant, and easy to use to accelerate CE adoption [12]. Similarly, [13] emphasize that indicators relevant to assessing CE should encompass aspects of resource efficiency and waste reduction, thus significantly contributing to the development of international standards that are not only relevant but also applicable in supporting global sustainability.

Therefore, this research is expected to make a significant contribution to the improvement of international standards for measuring CE that are not limited to specific sectors. The findings of this study aim to benefit decision-makers in formulating policies and strategies that support CE at the global level.

Research Methods

A systematic literature review (SLR) was conducted to enable a reliable assessment of circular criteria and indicators in international standards, including their relevance to supporting global sustainability. This study aims to identify the key criteria and indicators of the Circular Economy (CE), develop a systematic framework for CE implementation on an international scale, and identify potential future research directions. The SLR process adheres to PRISMA guidelines. The following figure illustrates the SLR process utilized in this study.

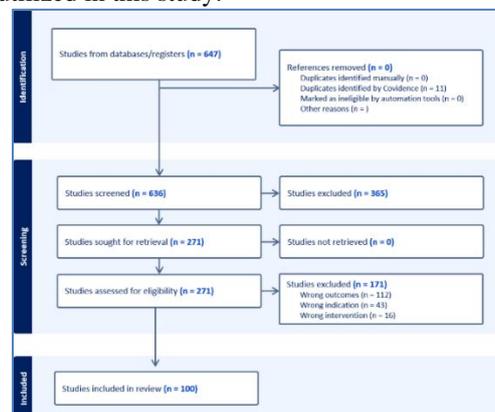


Figure 1. SLR Flow Diagram Following the PRISMA Procedure

Literature that did not meet the eligibility criteria was excluded, resulting in 100 articles selected for further analysis. Each article was further categorized based on methodology and the country of the institution. The selected articles were synthesized to address the research questions. In addition to article relevance, qualitative descriptive research was conducted to identify and analyze the criteria and indicators of the circular economy (CE) within various international standards, including the International Organization for Standardization (ISO), the European Union Circular Economy Action Plan, the Ellen MacArthur Foundation, Cradle to Cradle, and the Global Reporting Initiative (GRI). The data analysis method involved examining international standards documents to identify CE criteria and indicators. Additionally, a comparison of standards was carried out to explore similarities and differences in the criteria and indicators used.

Bibliometric analysis was also employed to identify emerging trends in the field. Articles that met the inclusion criteria were imported into R-Studio (127.0.0.1:5838) for analysis. This analysis assessed the relationships among articles based on keywords. Figure 2 illustrates the significant growth of academic literature on CE and its specific linkages to criteria and indicators in international standards, including sustainability, life cycle assessment (LCA), waste management, circular business models, circularity, and Industry 4.0 as it relates to technology and digitalization.

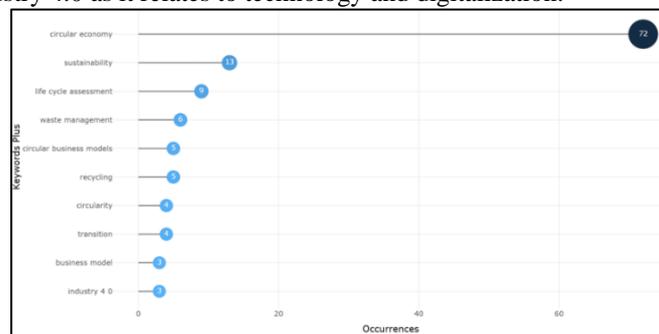


Figure 2. Keyword Relevance

Figure 3. The analysis revealed 14 distinct clusters. The blue cluster represents the Circular Economy (CE) and its supporting criteria and indicators. Other clusters include criteria and indicators from international standards. For instance, the International Organization for Standardization (ISO) focuses on environmental sustainability, while the European Union (EU) Circular Economy Action Plan emphasizes sustainable and eco-friendly product design. Additionally, the Cradle to Cradle (C2C) standard highlights the use of renewable materials, and the Global Reporting Initiative (GRI) primarily addresses organizational performance related to economic, environmental, and social aspects.

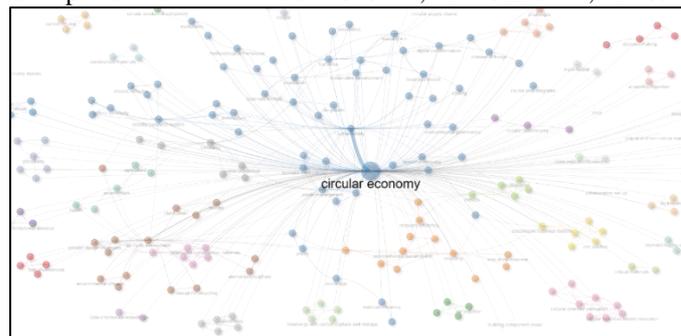


Figure 3. Network of Thematic Clusters from R-Studio

Results and Discussion

The Concept of Circular Economy (CE)

The fundamental concept of the Circular Economy (CE) represents a paradigm for managing economic resources and waste with the objective of establishing a more sustainable, efficient, and environmentally friendly system. This approach emphasizes reducing waste, maximizing resource utilization, and minimizing environmental impacts [14]. While the primary goal of CE is often perceived

as fostering economic prosperity, its implications for environmental quality, social equity, and intergenerational well-being are less frequently discussed [15].

CE can be understood as an economic model aimed at promoting economic growth by maintaining the value of products, materials, and resources for as long as possible [16]. This model seeks to minimize the negative social and environmental impacts associated with the linear economy. CE is not solely about improved waste management through recycling practices; it also encompasses a series of interventions across the entire supply chain.

Three core principles of CE have been identified by the Ellen MacArthur Foundation (2015), Preservation and enhancement of natural resources by managing finite stocks and balancing the flow of renewable resources. Optimization of resource use through the circulation of products, components, and materials at their highest utility within technical and biological cycles. System effectiveness improvement to reduce negative externalities.

The primary focus of CE lies in optimizing and enhancing the efficiency of product and material flows, including their constituent components. For instance, products can be redesigned to remain longer in the system by leveraging circular approaches such as maintenance, repair, remanufacturing, recycling, and the processing of biochemical materials through anaerobic digestion and composting [17].

The Fundamental Concepts of Circular Economy (CE)

Recycling

The principle of recycling within the circular economy framework emphasizes that all goods or materials should be recycled and reused to the maximum extent possible. This involves processes such as collection, processing, and recovery of used items to be reintegrated into production cycles. According to [18], challenges in recycling stem from low efficiency levels due to limitations in technology and infrastructure [19].

Recycling and Utilization

Beyond recycling, another key to the success of the circular economy model lies in the utilization of used goods and materials, which includes maintenance, repair, and extending the lifespan of products. Challenges related to infrastructure and technology include uncertainties in material standards and process standardization of products (Schulz-Mönninghoff, 2023).

Sustainable Design Principles

Every product generated by production processes must be designed with environmental considerations. This means designing products to facilitate recycling, extend their lifespan, and minimize waste during production. However, sustainable design faces operational and supply chain management challenges, such as underdeveloped recovery markets and low return rates for damaged products [18].

Efficient Resource Utilization

Efficient resource utilization is essential in the circular economy, encompassing the use of water, energy, and raw materials to reduce environmental impacts and production costs. [21] highlights those barriers to efficient resource utilization include high handling, transportation, and recovery costs, which are often seen as less profitable.

Waste Reduction

Minimizing waste disposal into the environment is one of the primary objectives of the circular economy. By recycling, adopting sustainable practices, and reducing inefficiencies, waste generation can be significantly reduced. Recovering value from waste streams within small and medium enterprises (SMEs) can vary depending on the processes. For instance, some industrial systems recycle waste as raw materials for insulation products [22]. These foundational principles underscore the importance of systemic changes across production, resource management, and waste reduction, forming the core of a sustainable circular economy.

The 9R Principles

According to [22], the 9R Principles provide a framework for sustainability-oriented alternatives in raw material extraction and production, without compromising the functionality of products and materials. This approach emphasizes creating products that use fewer raw materials while maintaining equivalent functionality. The 9R framework is structured hierarchically from level 0 to level 9, where

lower numbers represent more circular activities, while higher numbers of approach linear economic practices. Furthermore, the 9R Principles categorize levels of circularity based on resource usage higher levels of circularity correspond to reduced consumption of natural resources.

The distinction between circular and linear economies lies in the efficiency of product use throughout its lifecycle. In a linear economy, products are designed under a "take-make-dispose" model, where resources are continuously extracted from nature to create new products, assuming unlimited resource availability. Conversely, in a circular economy, the value of products is retained within continuous cycles to extend their lifespan [14]. Circular economies aim to minimize the consumption of resources, and the volume of waste sent to landfills by promoting reuse and resource efficiency for both renewable and non-renewable materials within product cycles [17].

International Standards in Circular Economy (CE)

Various international standards and frameworks have been established to assist organizations in adopting circular economy (CE) practices, ensuring sustainability, and fostering global collaboration. These standards provide structured guidance for implementing CE principles effectively. ISO offers a range of standards that support CE by integrating sustainability into organizational business processes. For instance, ISO 14040 and ISO 14044, focused on Life Cycle Assessment (LCA), assist organizations in evaluating the environmental impacts of a product or service throughout its lifecycle. By employing the LCA approach, organizations can identify opportunities to reduce waste and optimize resource efficiency [23]. Additionally, LCA enables the prediction of waste probability and quantity, as well as its environmental impact [24]. ISO 14067, addressing the Carbon Footprint of Products, further promotes CE by reducing environmental impacts through lifecycle-based methodologies.

Recently, ISO introduced ISO 59010, a comprehensive guideline for organizations to transition from linear models to circular value creation networks. This standard emphasizes business-oriented strategies for implementing CE practices at both organizational and inter-organizational levels. ISO 59010 is designed to facilitate effective transitions, contributing to sustainable business practices and a resilient global economy [25] [26]. Its benefits include improved resource efficiency, waste reduction, enhanced adaptability to regulatory and market changes, alignment with global sustainability goals, and increased competitiveness and stakeholder trust.

The European Union (EU) is also advancing its transition to a CE to alleviate pressure on natural resources, create sustainable job growth, achieve climate neutrality by 2050, and halt biodiversity loss. The EU's 2020 Circular Economy Action Plan outlines key criteria for monitoring CE progress, including production and consumption, waste management, secondary raw materials, competitiveness, innovation, sustainability, and resilience (2020 Circular Economy Action Plan-KH0420483ENN, n.d.). This plan explicitly supports CE transition by focusing on sustainable product design, waste management, and the transformation of priority sectors such as electronics, textiles, construction, and plastics, which hold significant potential for waste reduction and CE adoption.

The Global Reporting Initiative (GRI) provides reporting frameworks to promote transparency and accountability in CE practices. For example, GRI 306 (Waste 2020) focuses on organizational waste reporting, encouraging waste reduction through reuse, and recycling [26]. Similarly, GRI 301 (Materials) emphasizes reporting on renewable material usage and strategies for enhancing material efficiency, which are critical components of CE [27].

The Ellen MacArthur Foundation identifies three design-driven principles underlying CE, eliminating waste and pollution, circulating products and materials, and regenerating nature. Waste and pollution are minimized by designing products, materials, and infrastructures that reintegrate into the economy after use. Recycling serves as an initial step, supported by designing systems that inherently prevent waste [28], [29]. Circulating products and materials involves maintenance, reuse, and renewal, enabling non-renewable resources to be reused and recycled [30]. Finally, regenerating natural systems and biodiversity involves adopting models that mimic nature's zero-waste systems.

CE provides a pathway to achieving various United Nations Sustainable Development Goals (UNSDGs). By improving resource efficiency, reducing waste, and adopting environmentally friendly production systems, CE serves as a foundational pillar for global sustainability. Organizations, governments, and communities adopting CE principles can contribute to responsible consumption and production, reduce carbon emissions, and enhance climate action [31], [32].

The Cradle-to-Cradle Certified framework exemplifies an international certification standard designed to encourage sustainable production and design. This holistic approach evaluates entire product

lifecycles, ensuring products are safe for the environment, economically viable, and socially equitable. Key areas of focus include safe materials, renewable energy, recycling, wastewater management, and social fairness [33]. This framework provides companies with tools to design products that meet human needs while preserving the environment and supporting global sustainability [34].

International standards are essential tools for integrating CE on a global scale. By providing uniform frameworks, fostering innovation, enhancing transparency, and harmonizing policies, these standards ensure the consistent, efficient, and effective adoption of CE worldwide. This not only supports environmental sustainability but also generates long-term economic and social benefits. In this review, five international standards are identified as key criteria and indicators supporting CE implementation.

Criteria and Indicators of Circular Economy in International Standards

Table 2. Comparison of Criteria and Indicators Across Various Standards

No	International Standard	Description	Criteria	Indicators	Source	Key Distinctions
	ISO 14001	An international standard for Environmental Management Systems (EMS), issued by the International Organization for Standardization (ISO).	Emission Reduction	Greenhouse gas (GHG) emissions Air and water emissions Reduction in energy consumption	ISO 14001:2015 - Environmental Management Systems (EMS)	ISO14001: Emphasizes internal environmental management systems. EU Circular Economy Action Plan: Prioritizes product design and waste reduction. Ellen MacArthur Foundation: Highlights renewable materials and sustainable design. Cradle to Cradle (C2): Focuses on product-level sustainability and material health. GRI: Centers on sustainability reporting and transparency.
			Resource Management	Water usage Energy usage Raw material utilization	International Organization for Standardization (ISO)	
			Waste Management	Volume of waste generated Reduction of waste sent to landfills Reuse and recycling rates		
			Environmental Quality	Quality of air, water, and soil		
			Regulatory Compliance	Adherence to environmental regulations Monitoring and compliance tracking		
2.	European Union (EU) Circular Economy Action Plan	A framework emphasizing sustainable product design and waste reduction as part of the EU's transition to a circular economy.	Product Design	Recyclability and reusability in product design Recycling rates for plastics, paper, and metals	European Commission (2020). Circular Economy Action Plan. DOI: 10.2777/61549	
			Resource Efficiency	Efficient and sustainable use of natural resources	European Parliament and of the Council. (2019).	
			Waste Reduction	Proper waste management practices and waste minimization	On the reduction of the i	

			Use of Recycled Materials	Incorporation of recycled materials in products Utilization of renewable energy Product quality aligned with circular economy principles	Impact of certain plastic products on the environment.
			Regulatory Compliance	Compliance with sustainable raw material use and environmental standards	
3	Ellen MacArthur Foundation	A framework advocating for the design of products and systems that utilize renewable resources and minimize waste.	Sustainable Product Design	Design strategies for recyclability and reuse Metrics on material recycling rate	Ellen MacArthur Foundation. (2019). Completing the Picture. Ellen MacArthur Foundation. (2020). Circular Economy. McArthur, E., Zumwinkel, K., & Stuchtey, M. (2015). Growth Within. Ellen MacArthur Foundation. (2020). Upcycle. World Economic Forum. (2020). The Future of Consumption.
			Efficient Resource Use	Optimization of natural resource utilization	
			Waste Reduction	Reduction of production waste and efficient waste management	
			Use of Recycled Materials	Adoption of recycled inputs in manufacturing Renewable energy integration	
			Regulatory Compliance	Conformance with circular economy-aligned regulations	
4	Cradle to Cradle (C2C)	A holistic certification system promoting sustainable product design, developed by William McDonough and Michael Braungart.	Material nature	Use of safe, non-toxic, and environmentally friendly materials	McDonough, W., & Braungart, M. (2002). Cradle to Cradle: Remaking the Way We Make Things. Cradle to Cradle Products Innovation Institute.
			Efficient Resource Use	Effective use of resources to minimize waste	
			Waste and Pollution Reduction	Reducing production waste and emissions	

			Circular Product Design	Products designed for disassembly, recyclability, and reuse	(2020). Certification Standards.	
			Renewable Energy Adoption	Utilization of renewable energy in production		
5	Global Reporting Initiative (GRI)	A sustainability reporting framework assisting organizations in documenting their environmental, social, and governance impacts.	Economic Performance (GRI 200)	Organizational economic performance indicators (e.g., operational revenue, costs, and community investments).	Global Reporting Initiative. (2021). GRI Standards.	
			Environmental Impact (GRI 300)	GHG emissions metrics Water usage metrics Waste management practices		
			Social Impact (GRI 400)	Employee welfare indicators (e.g., health and safety) Training and human rights tracking		

Table 3. Comparison of Criteria and Indicators Across Various Standards

No	Standar Internasional	Main Criteria	Indicators	Focus Area
1	ISO14001 (Sistem Manajemen Lingkungan)	Emission Reduction Resource Management Waste Reduction Regulatory Compliance	Greenhouse gas (GHG), air, and water emissions Consumption of water, energy, and raw materials Volume of recycled waste Compliance with environmental regulations	Focuses on internal organizational management to minimize environmental impacts, enhance resource efficiency, and ensure regulatory compliance
2	EU Circular Economy Action Plan	Product Design Resource Use Waste Reduction Use of Recycled Materials Regulatory Compliance	Products designed for recycling and reuse Use of renewable raw materials Recycling rates and waste reduction metrics	Focuses on waste minimization through product design, renewable material use, and the application of circular economy principles.
3	Ellen MacArthur Foundation	Sustainable Product Design Resource Efficiency Waste Reduction Use of Renewable Energy Regulatory Compliance	Material recycling rates Efficiency in natural resource use Use of renewable energy in production Waste-minimized products	Emphasizes innovation in sustainable product design, the integration of renewable energy, and the adoption of recycled materials to support the circular economy.
4	Cradle to Cradle (C2C)	Safe and Healthy Materials Resource Efficiency	Non-hazardous materials Minimization of waste and pollution	Prioritizes product sustainability through environmentally friendly design, safe

		Waste and Pollution Reduction Circular Design Use of Renewable Energy	Use of clean energy in production Products designed for recycling	materials, and the adoption of renewable energy sources.
5	Global Reporting Initiative (GRI)	Economic Environmental Social	Revenue and community investments (economic) GHG emissions, water use, and waste management (environmental) Workplace health, human resource training (social)	Focuses on transparent sustainability reporting across economic, environmental, and social dimensions of organizational performance

Essentially, all international standards share a common goal of supporting sustainability and the Circular Economy (CE) through various distinct approaches. Similarly, their primary focus is to promote resource management, waste reduction, and sustainable design by enhancing the efficiency of raw material and energy use while minimizing negative environmental impacts. The key differences among the international standards examined are outlined in Column 7 of Table 2.

Implications and Challenges in the Implementation of the Circular Economy (CE)

The Circular Economy (CE) represents a promising paradigm in addressing global sustainability challenges, including resource management, waste reduction, and climate change mitigation. However, the implementation of CE faces several challenges at both the global and national levels.

At the global level, implementing CE requires policy alignment among nations. Differences in regulations, approaches, and national priorities present significant barriers. For instance, while some developed countries have robust policies, such as the EU Circular Economy Action Plan, many developing nations are still grappling with basic waste management issues [35], a situation often referred to as International Policy Fragmentation.

Furthermore, CE demands infrastructure that can support the implementation of circular principles, such as advanced recycling facilities, reverse logistics systems, and innovative manufacturing technologies. Such infrastructure is primarily available in developed countries and some developing nations, but it is often not evenly distributed [36]. Consumption and production patterns also play a critical role in the transition to CE. Market and consumer resistance, especially concerning the higher prices of sustainable products, pose significant challenges on a global scale [37].

On the national level, many developing countries face limitations in institutional capacity to support the transition to CE, including weaknesses in regulations, oversight, and economic incentives [38]. The implementation of CE requires substantial investments in technology, infrastructure, and workforce training. At the national level, budget constraints often become a major obstacle, particularly in supporting small and medium-sized enterprises (SMEs), which are the backbone of many developing economies. Additionally, the lack of knowledge and awareness at the societal level about the benefits of CE, along with the limitations within educational systems to incorporate sustainability and circularity principles into curricula, are significant barriers.

To address these challenges, a multidimensional approach is required, involving integrated policies, investments in technology and infrastructure, and public education. Collaboration between governments, the private sector, and the international community is crucial to promoting the global and national adoption of circular economy principles.

Implications of Circular Economy Criteria and Indicators on Company and Government Policies in Adopting Circular Economy (CE)

The implementation of Circular Economy (CE) criteria and indicators has significant implications for both company and government policies. Circular economy principles, such as waste reduction, sustainable product design, and resource efficiency, provide a strategic framework that drives the transformation of production and consumption systems.

CE criteria encourage companies to adopt more sustainable business models, such as product-as-a-service (PaaS), internal recycling, and the sharing economy. Companies are required to redesign their supply chains to be more circular, including reducing waste through the use of recycled materials and applying environmentally friendly technologies [39]. To meet indicators such as emission reduction or renewable energy use, companies must invest in innovative technologies, such as automation for remanufacturing, reverse logistics, and blockchain for supply chain transparency.

Indicators such as compliance with environmental regulations and sustainability reporting, as stipulated by frameworks like GRI and ISO 14001, drive companies to enhance transparency. This creates incentives for companies to improve their environmental reputation while mitigating legal risks.

Governments can use CE criteria and indicators as a basis to strengthen regulations related to waste management, energy efficiency, and sustainable product design. Additionally, fiscal incentives, such as tax credits or subsidies for renewable energy use, can encourage industries to transition to a circular economy [15]. Indicators such as effective waste management and the use of recycled materials require circular infrastructure, including modern recycling facilities and integrated waste management systems. Governments play a crucial role in ensuring the availability of such infrastructure, particularly in developing countries. To support indicators such as waste reduction and resource efficiency,

governments must engage the public through awareness campaigns and educational programs. This aims to increase understanding of the benefits of the circular economy and encourage behavioral changes.

Conclusion

This study shows that the criteria and indicators of the Circular Economy (CE) identified in international standards are diverse, yet they consistently focus on waste reduction, sustainable product design, and resource efficiency. These criteria and indicators serve as strategic guidelines that can be applied to support the transition to a circular economy at both global and national levels. International standards play a crucial role as catalysts for systemic transformation toward global sustainability by facilitating policy formulation, monitoring progress, and developing relevant innovations. To support the global transition to CE, international standards need to be developed in a more comprehensive and integrated manner through global collaboration, technological innovation, and cross-sectoral approaches. Therefore, CE standards will not only serve as practical guidelines for implementation but also as strategic tools for driving global sustainability.

This study relies solely on literature available in certain databases, which do not cover all relevant publications, particularly those from developing countries, thus not fully representing the global context. Furthermore, it focuses only on standards such as ISO 14001, the EU Circular Economy Action Plan, the Ellen MacArthur Foundation, Cradle to Cradle, and GRI, which may not encompass all CE-related standards. The criteria and indicators are generalized to provide a comprehensive overview and do not reflect the specific needs of sectors. These limitations reflect the complexity and dynamics of implementing CE at the global level.

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