

Review Article

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The importance of standards in advancing the circular economy in the food industry

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Abstract

The circular economy has emerged as a transformative model for addressing the environmental and resource challenges facing the global food industry. As food systems account for significant waste, greenhouse gas emissions, and resource inefficiencies, the implementation of standards is vital for operationalizing circular economy principles. This paper highlights the role of standards in promoting circularity across the food value chain, identifies key domains of standardization, and explores the challenges and opportunities associated with harmonizing such frameworks. It argues that standards provide consistency, accountability, and scalability by translating circular principles such as resource reuse, waste reduction, and ecosystem regeneration into actionable and measurable practices. It concludes by advocating for multi-stakeholder collaboration and the development of globally aligned circular economy standards specific to food systems.

The article also identifies barriers, including the fragmentation of standards, the complexity of food systems, and challenges faced by small and medium enterprises in compliance, and state some recommendations to overcome them.

Keywords Circular economy, standards, food, resource, waste reduction

Introduction

Today, greenhouse gas emissions can be traced back to five economic sectors as energy, agriculture, industrial processes, waste, land use, land-use change and forestry. The energy sector produces the most greenhouse gas emissions by far, accounting for a whopping 75.7% worldwide.

The food industry contributes approximately 8–10% of global greenhouse gas emissions, which is significant though lower than sectors like energy and transportation. However, the complexity of food supply chains and the

high levels of food waste make mitigation efforts challenging [1]. Traditional linear models of production and consumption based on extract, produce, use, and disposal are increasingly unsustainable. In contrast, the circular economy (CE) aims to minimize waste, extend product lifecycles, and regenerate natural systems [2]. The circular economy model provides a powerful alternative to the conventional linear “take, make, dispose” system. It presents a valuable chance to protect the environment while enhancing supply chain resilience, generating employment, stimulating economic growth, and ensuring a



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sustainable future for everyone.

Central to operationalizing the circular economy in the food industry is the development and adoption of robust standards that translate circular principles into actionable, measurable practices.

A circular economy seeks to eliminate waste and extend the lifecycle of materials through continuous reuse and recycling. Within the context of food security, this approach can significantly reduce food loss and waste, improve resource efficiency, and lessen environmental impacts. By embedding circular economy principles into the food system, we can address the inefficiencies of the current linear model and support the goal of providing sufficient, safe, and nutritious food for the global population. Integrating circular economy principles into food systems centers on minimizing waste, maximizing resource efficiency, and closing nutrient cycles. This can be accomplished through strategies such as waste prevention, advanced recycling technologies, and the upcycling of food waste into valuable products. Across the entire food supply chain from production and processing to distribution and consumption, there are multiple opportunities to reduce food loss and waste.

Technologies such as preservation (heat, salt, fermentation), concentration (evaporation, dehydration), blending, and packaging are applied to convert surplus raw fruits and vegetables into condiments with extended shelf life, better taste, and added value.

A key initiative in this area is the European Union's farm to fork strategy, launched in 2020, which embeds circular economy concepts into food production. The strategy prioritizes the reduction of food waste, the reuse of by-products from food processing, and the promotion of sustainable agricultural methods [3]. By 2023, EU member states collectively reduced food waste by 10%, with a target of cutting it by 50% by 2030. These efforts have led to more efficient resource use and strengthened food security across the region [4].

In Netherlands, where circular farming has been widely adopted. Farmers and agri-food businesses utilize crop residues as livestock feed and apply livestock manure as fertilizer, effectively closing the loop between plant and animal production. This approach led to an 8% reduction in the use of synthetic fertilizers while maintaining high agricultural output [5]. This demonstrates how circular practices can support food security by increasing the resilience and sustainability of farming systems. A closed-loop food system, in which resources are continuously recycled and reintegrated into the supply chain, offers significant advantages for food security. These include reducing food waste, improving resource efficiency, and minimizing the environmental footprint of food produc-

tion. By reusing and recycling organic materials, these systems help maintain soil health, boost biodiversity, and decrease reliance on limited natural resources factors that together foster more sustainable farming methods and ensure long-term food security.

An illustrative example comes from Kamikatsu, Japan, where a closed-loop model has been successfully implemented. The city composts food waste and applies it as fertilizer on local farms, achieving a recycling rate of over 80%. This approach has reduced landfill use while improving soil fertility, leading to a 30% increase in crop yields by 2023 demonstrating how regenerative practices can directly strengthen local food systems [6].

Another notable case is in the United Kingdom, where the start-up Rubies in the Rubble transforms surplus fruits and vegetables into condiments such as chutneys and ketchup [7]. The company repurposed over 200 tons of food waste, not only diverting edible produce from landfills but also creating affordable, nutritious food products in 2022. This initiative highlights how closing the loop on food waste can increase food availability, reduce pressure on natural resources, and contribute meaningfully to food security [8].

To operationalize these goals in the food sector, standards provide a foundational tool for aligning stakeholders, enabling traceability, and ensuring accountability. Standards can be applied during the product design phase to ensure these considerations are incorporated into the final product, thereby supporting the circular economy.

2. Importance of Standards in the Circular Food Economy

2.1 Defining Circular Economy Standards

Circular economy standards refer to structured guidelines and metrics that support the implementation, assessment, and verification of circular practices. These include both process-based and performance-based standards that guide the design, production, consumption, and end-of-life stages of food products [9]. A circular economy system aims to eliminate waste and maximize efficiency across materials, products, and systems. Unlike traditional methods, which involve extracting raw materials, creating products, and then discarding them after use, the circular approach focuses on minimizing material consumption from the start. To achieve this, manufacturers design products to require fewer resources and reclaim what would typically be considered waste, using it as a valuable resource to produce new products in the future. Many people often associate the circular economy solely with waste management, recycling, and reuse. However, it encompasses much more than that. At its core, a circular economy involves designing products with circularity

in mind this includes facilitating easy disassembly and ensuring that no harmful chemicals are used during production that could pose challenges at the end of a product's lifecycle. The reality is that the circular economy begins with thoughtful product design. It requires considering the environmental and social impacts across the entire product lifecycle from raw material extraction and manufacturing to end-of-life management. Recognizing the interconnections between these stages and integrating them into the design process is essential. Careful upfront planning and foresight are crucial to enable a truly circular economy.

2.2 Functions of Standards

To address uncertainty and improve clarity around the circular economy concept, various standards are being developed by standard-setting organizations. Leading this effort, the International Organization for Standardization (ISO) is creating the ISO 59000 series of standards to provide a unified language and conceptual framework for the circular economy. Standards in the CE framework perform several critical functions:

- **Harmonization:** They provide a common language for sustainability across borders and supply chains [10].
- **Verification:** Through third-party certifications, standards enhance consumer trust and market credibility [11].
- **Innovation stimulation:** Standards often spur technological innovation by creating performance benchmarks and fostering competitive advantage [12].

In recent decades, ISO has developed several standards relevant to the circular economy, such as ISO 14001, ISO 50001, ISO 14006, and ISO 14040. Many of these are meta-standards voluntary management frameworks that support self-regulation by formalizing, systematizing, and legitimizing a wide range of management activities. Additionally, sector-specific standards are addressing circular economy principles. For instance, the European Telecommunications Standards Institute (ETSI) introduced the ETSI TR 103476:2018 standard, which defines circular economy approaches, concepts, and metrics specifically for the information and communication technologies sector. Among the various standards that have been issued or are currently under development, the ISO proposal stands out. The ISO 59000 series aims to establish a common language and conceptual framework to unify the terminology, metrics, and indicators encompassed by the broad concept of the circular economy. The final versions of these standards are anticipated to be published in 2024, five years after the technical committee was launched by AFNOR. According to publicly available information, the ISO 59000 family is expected to comprise seven distinct standards [13].

- ISO 59004: Key terminology, framework, and principles of the CE.
- ISO 59010: Guidance on business models and value networks related to CE.
- ISO 59020: Measurement and assessment of circularity.
- ISO 59040: Product Circularity Data Sheet intended for certification purposes.
- ISO 59014: Secondary materials – Principles, sustainability, and traceability requirements.
- ISO 59031: Performance based approaches.
- ISO 59032: Review of business model implementation.

3. Application of Standards in Key Domains

3.1 Sustainable Agriculture and Sourcing

Standards promote regenerative farming practices, biodiversity, and soil health—critical components of circularity [14]. These schemes aim to reduce reliance on finite inputs and ensure closed nutrient loops in agroecosystems. Agriculture faces a critical challenge to its sustainability due to increasing demands for food, feed, and renewable non-food raw materials amidst the pressures of global warming. Regenerative agriculture is gaining recognition as an essential approach to addressing a wide array of ecological and social challenges. Unlike conventional sustainable methods, regenerative agriculture actively restores ecosystems by enhancing soil health, promoting biodiversity, and mitigating climate change. Governments and organizations at global, regional, and local levels are exploring ways to integrate regenerative practices into climate initiatives to maintain ecosystem resilience. Importantly, these benefits can be achieved without compromising crop yields or farmer incomes. Soil, as a living and dynamic ecosystem, hosts diverse micro- and macro-organisms that shape its physical, chemical, and biological properties. Healthy soil exhibits optimal texture and water retention, balanced pH levels, high soil organic matter, rich microbial diversity, and robust soil respiration—all crucial factors for producing nutritious, profitable crops and supporting human health. The growing interest in regenerative farming spans public, private, and nonprofit sectors focused on improving soil vitality and sustaining ecological balance. Regenerative practices can help mitigate climate change, improve soil quality, enhance biodiversity, and positively impact socioecological systems [15].

Beyond regenerative farming practices, integrating renewable energy sources such as solar and bioenergy into food production and processing is crucial to reducing the sector's carbon footprint. Green technologies, including energy-efficient machinery and waste-to-energy systems, further enhance resource efficiency and lower greenhouse gas emissions. Together, these approaches comple-

ment circular principles by addressing the food industry's energy demands and mitigating climate impacts.

3.2 Packaging and Materials Management

Packaging waste is a major environmental concern. Standards such as EN 13432 (European Committee for Standardization, 2000) for compostable packaging and ISO 18601 series on packaging and the environment set technical requirements for recyclability, reusability, and biodegradability. The EN 13432 standard defines requirements for packaging recovery via composting and biodegradation. It establishes rigorous criteria for packaging materials and products to be considered compostable, including standards for biodegradability, disintegration, and ensuring no harmful impacts on the composting process or the quality of the resulting compost.

According to this standard, the packaging material or product must be biodegradable, meaning it can decompose into carbon dioxide, water, inorganic compounds, and biomass under specified conditions. The standard establishes criteria for both the extent and speed of biodegradation within a set timeframe. Specifically, within a maximum of six months, the test sample must produce at least 90% of the carbon dioxide generated by the control or reference material. The EN 13432 standard sets criteria for packaging materials to be considered compostable, focusing on biodegradability, disintegration, chemical composition, compost quality, testing methods, and labeling [16].

- **Biodegradability:** Materials must biodegrade into carbon dioxide, water, inorganic compounds, and biomass, achieving at least 90% carbon dioxide release within six months.
- **Disintegration:** Materials must break down into fragments smaller than 2 mm within 12 weeks, with no more than 10% exceeding this size.
- **Chemical Composition:** Limits are imposed on heavy metals and other substances (e.g., lead, cadmium, mercury) to ensure environmental safety.
- **Quality of Compost:** The resulting compost must support healthy plant growth and be free of harmful effects, contributing organic matter and nutrients beneficial for microbial activity.

These standards exemplify how clear technical requirements for packaging can enable industry-wide shifts toward circular materials management, illustrating the crucial role standards play in achieving environmental targets.

3.3 Food Waste Reduction

The ISO 14001 environmental management standard provides a framework for reducing waste throughout the supply chain [17]. Organizations such as WRAP (Waste

and Resources Action Programme) have developed sector-specific roadmaps to support food businesses in tracking and minimizing waste. WRAP is a national initiative dedicated to minimizing food waste and promoting its reuse whenever possible across multiple sectors such as manufacturing, hospitality, and retail [18]. The current methods of food production and consumption are fundamentally unsustainable. Nearly one-third of all food produced globally is lost or wasted each year, even as millions face hunger. This widespread food waste contributes to over 1.3 billion tons of discarded food annually, which in turn generates approximately 3.3 billion tons of greenhouse gases through decomposition [19, 20]. Beyond its social and environmental impacts, food loss and waste also result in substantial economic costs, amounting to \$936 billion globally every year [21]. Continuing to waste food is untenable. Addressing this challenge requires exploring alternative approaches to reduce food waste. For decades, food has largely been treated as a single-use commodity produced, consumed, and discarded following a linear model of resource use. This approach is unsustainable because natural resources are finite, yet current consumption patterns ignore these limits by attempting to fulfill unlimited human demands. Consequently, adopting a circular economy model that emphasizes the efficient and sustainable use of resources throughout their entire lifecycle offers a promising path forward. Standards such as ISO 14001 and WRAP's roadmaps illustrate how formal frameworks guide food businesses to systematically reduce waste, reinforcing the importance of standards in operationalizing circular economy principles across the supply chain.

3.4 Supply Chain and Traceability

Traceability is essential for transparency in CE systems. The GS1 Global Traceability Standard enables end-to-end monitoring of food products, supporting circular practices such as reverse logistics and redistribution of surplus [22]. Traceability refers to the capability to track the history, usage, or whereabouts of an object [23]. In the context of a product or service, it encompasses tracing the origin of materials and components, the processing history, distribution, and the product or service's location after delivery.

3.5 Lifecycle Assessment (LCA)

ISO standards 14040/14044 define the principles and procedures for LCA, a key tool for evaluating the environmental performance of products over their entire life cycle [24]. LCA helps identify hotspots and guide circular redesign efforts. An LCA evaluates a product's environmental impact across its entire lifespan, from cradle to

graver, in the case of food, from farm to waste. Emissions can occur at every stage of a food product's life cycle, all of which are accounted for in an LCA. These stages include, but are not limited to:

- **Farming:** Emissions resulting from land use changes (such as burning and carbon stock loss), farming activities, animal feed production, and on-farm processing.
- **Processing:** Emissions generated during the processing and storage of ingredients.
- **Packaging:** Emissions related to sourcing raw materials, pre-processing, packaging manufacture, transportation to product systems, and disposal at end-of-life.
- **Transport:** Emissions from moving ingredients between different stages, including farm to processor, processor to retailer, and between processors. It also covers storage emissions throughout the product's journey, like household storage before and after preparation. It excludes the final delivery from the retailer to the consumption location.
- **Retail:** Emissions from retail operations, including refrigeration, lighting, and air conditioning within the retail environment.
- **End-Mile:** Emissions from transporting food from the retail location to where it is consumed, excluding consumer travel to the retailer.
- **Cooking:** Emissions produced during food preparation, such as energy use by appliances.
- **Food Waste:** Emissions from disposing of food via anaerobic digestion, composting, incineration, sewer disposal, or landfill, as well as emissions associated with food lost during the supply chain [25].

3.6 Livestock, Fisheries, and Aquaculture

Circular economy standards and practices are equally vital for livestock, fisheries, and aquaculture sectors. These sectors can benefit from regenerative grazing, sustainable feed sourcing, waste recycling (e.g., manure to biogas), and water recirculation systems. For fisheries and aquaculture, circularity includes sustainable stock management, minimizing bycatch, and repurposing processing by-products. Developing sector-specific standards will help address their unique challenges and enhance sustainability.

4. Several notable examples of economic turn-arounds in diverse food and beverage sectors

Transitioning to a circular economy means shifting towards a food system that restores natural capital and supports thriving ecosystems. Regenerative food production involves cultivating food in ways that promote positive environmental outcomes, such as healthy, stable soils, enhanced local biodiversity, and improved air and water

quality. This approach is implemented through practices adapted to local conditions, including using diverse crop varieties and cover crops, rotational grazing, and agro-forestry growing trees among crops or pasture. The result is agricultural land that more closely resembles natural ecosystems like forests and native grasslands, providing habitats for a wide variety of organisms. The following examples highlight not only circular economy initiatives but also the role standards play or could play in supporting such transformations.

While large multinational food companies like McDonald's have logistics systems that can support circular practices such as waste collection and resource reuse, the inherent challenges in the wider food system, including land use change and meat production's environmental impact, limit the extent to which these companies embody circular economy principles. It is crucial to prioritize product design and supply chain transformations that minimize ecological damage to align fully with circular economy goals.

Nestlé, for example, uses cooking oil as a feedstock to produce renewable diesel and recognizes that some suppliers may want to purchase the diesel back as a product. About 80% of Nestlé's feedstock for renewable products comes from waste and residues, including used cooking oil. This partnership is a strong example of circularity working with partners to recycle cooking oil and then selling the fuel made from that oil.

The circular economy focuses on viewing waste as a valuable resource, keeping materials in the production cycle. But the circular economy goes beyond recycling household waste. Repurposing waste from one industry can create products for another, closing loops across sectors. This circularity can operate on a global scale or, as demonstrated by the collaboration between McDonald's, Nestlé, and HAVI, be small and highly efficient. In the Netherlands, McDonald's partners with logistics provider HAVI to manage all stock and waste transport to and from its restaurants, exemplifying a compact and effective circular system [26].

5. Challenges and Barriers

Standards in the food industry face significant hurdles:

- **Lack of harmonization:** There is currently no global standard specific to circular food systems, leading to fragmentation and inconsistent adoption [27].
- **Complexity of food systems:** The perishable nature of food and the diversity of value chains complicate standardization efforts.
- **Cost and capacity barriers:** Small and medium enterprises (SMEs) often lack the resources and expertise to implement complex certification schemes [28].

It is also necessary to develop and implement standards on the following topics:

- A classification system for discarded materials from manufacturing plants and their support facilities, detailing the location, disposal methods, and treatment of manufacturing waste to assist companies in managing these outputs.
- A guide for assessing the environmental aspects of sustainability within manufacturing processes.
- A guide to support sustainability-focused decisions when selecting chemicals throughout a product's life cycle.

6. Conclusion

Based on the review, advancing circular economy standards in the food industry requires a multi-tiered framework comprising global standard harmonization, sector-specific guidelines (agriculture, livestock, fisheries), and capacity-building initiatives for SMEs. This framework should prioritize transparency, lifecycle assessment integration, and multi-stakeholder collaboration to ensure practical applicability and measurable impact.

Standards designed to operationalize the CE must critically address the paradigm's potential limitations and clearly articulate all aspects of the model for stakeholders and the public. At a minimum, this transparency would help mitigate biases and adverse effects such as the widely discussed rebound effect associated with the CE [29]. Given that the term "circular economy" has become a broad buzzword applied to diverse and sometimes conflicting concepts [30], ISO and other standards organizations should strive for more consistent, balanced, and nuanced definitions. Standards development should be grounded in principles of consensus, transparency, openness, impartiality, effectiveness, relevance, and coherence. Moreover, ISO's Code of Ethics and Conduct mandates that the organization avoids disseminating false or misleading information and does not withhold critical information necessary for a full and fair evaluation of the issues involved [31].

For countries aiming to implement circular economy standards in the food industry, it is recommended to develop a national roadmap aligned with global ISO 59000 series, tailored to local agricultural and food processing contexts. This could include establishing sector-specific guidelines for regenerative agriculture, food waste reduction, and packaging standards, alongside support programs for SMEs to enhance compliance capacity. Comparative lessons from regions like the EU and the Netherlands demonstrate the effectiveness of combining regulatory frameworks with stakeholder collaboration to foster sustainable food systems.

For countries that rely heavily on food and raw material

imports, circular economy strategies focus on optimizing supply chain transparency, reducing food waste, and promoting circular packaging standards. These countries can leverage traceability standards to monitor product origins and ensure sustainable sourcing. Policies incentivizing the import of products with verified circular attributes can also foster global circularity while supporting domestic waste reduction.

According to ISO, the ISO 59000 series aims "to harmonize the understanding of the circular economy and to support its implementation and measurement" [32]. In light of ongoing scientific debates, rigorous and credible standards must acknowledge the limitations and challenges of the CE paradigm to truly fulfill this objective. Standards play a critical enabling role in translating circular economy principles into measurable, verifiable, and scalable actions within the food industry. As the world seeks more sustainable and resilient food systems, the development and harmonization of circular economy standards will be pivotal. Multi-stakeholder collaboration and international alignment are necessary to ensure that these standards drive real progress toward environmental regeneration, economic inclusion, and food security.

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