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CIRCULAR ECONOMY IN THE FOOD INDUSTRY: GLOBAL METHODS, CHALLENGES AND OPPORTUNITIES

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Abstract:
This scientific article explores the implementation of circular economy (CE) methods in the global food industry, highlighting how CE strategies such as waste valorization, sustainable resource use, and regenerative practices are reshaping the sector. It includes an in-depth analysis of Uzbekistan's Circular Economy Action Plan in agriculture as a case study. The study draws on a variety of academic and institutional sources, demonstrating how CE contributes to food system resilience, sustainable development goals (SDGs), and climate action. Emphasis is placed on practical innovations, policy frameworks, and the systemic transformation needed to shift from linear to circular food models.

Keywords: Circular economy, food industry, sustainable agriculture, food waste, resource efficiency, Uzbekistan, circular bioeconomy, regenerative food systems, SDG 12.

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Introduction

The global food industry is facing mounting sustainability challenges due to its traditionally linear "take-make-waste" model. Enormous quantities of food are lost or wasted at all stages from farm to fork, contributing to resource depletion, pollution, and greenhouse gas emissions. For example, the United Nations estimates that about 1.05 billion tonnes of food were wasted in 2022, roughly 19% of all food available [1]. China and India each discard tens of millions of tonnes per year, illustrating the scale of the problem. This waste not only represents lost nutrition and economic value, but also generates 8–10% of global greenhouse emissions through decay and inefficient resource use [2].

In response, the concept of the circular economy (CE) has gained traction as a transformative approach for the food industry. A circular economy aims to minimize waste and keep resources in use by closing loops – through strategies of reduction, reuse, recycling, and recovery – thereby decoupling economic growth from resource consumption. In the food system context, this means designing supply chains where organic by-products and waste are converted into inputs for new production (e.g. fertilizers, energy, or new food products), nutrients are recycled, and external inputs (like water and synthetic chemicals) are minimized [3]. Researchers emphasize that adopting a circular economy perspective in agriculture and food manufacturing is critical to ensure the sector's sustainable development. By reducing waste, optimizing resource utilization, and embracing sustainable practices, the food industry can become more resilient while advancing global goals for sustainability. Indeed, circular food systems directly support UN Sustainable Development Goal (SDG) 12 (Responsible Consumption and Production, including the target to halve per capita food waste by 2030) and SDG 13 (Climate Action) by curbing emissions from decomposing waste.

However, transitioning from the prevailing linear model to a circular one in the food sector is complex. It requires systemic changes in production, consumption, and waste management patterns. There is growing global interest in how circular economy methods – such as waste valorization, regenerative agriculture, sustainable packaging, and resource-efficient technologies – can be implemented in the food industry.

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2. LITERATURE REVIEW

A growing body of academic literature has addressed the potential of circular economy principles to improve sustainability in food systems. Rabbi and Amin provide a bibliometric analysis that synthesizes nearly two decades of research in this area, showing an increased academic focus on food waste reduction, supply chain circularity, and energy recovery [4]. Their analysis points out the relevance of CE practices to the United Nations SDGs, particularly SDG 12 and 13.

Van Ewijk and Stegemann (2023) offer a foundational perspective on the lifecycle of materials and waste, highlighting how systemic waste management approaches are crucial to achieving circularity. They emphasize the need for design thinking in packaging, better waste collection, and infrastructure development, particularly in developing nations [5].

In the agricultural context, Popkova and Sergi (2022) argue for a shift from circular to reconstructive agriculture, emphasizing regenerative practices that restore ecosystems while closing material loops. Their work is particularly relevant to the Global South and economies in transition, such as Uzbekistan [6].

Morone et al. further elaborate on the concept of the circular bioeconomy, combining renewable biological resources with CE methods to generate added value in food systems while reducing fossil dependence. They stress the interdisciplinary nature of the bioeconomy and the need for integrated policy and economic frameworks [7].

3. METHODS

This study adopted a qualitative research approach, conducting an extensive literature review and case analysis to investigate circular economy applications in the food industry. We surveyed academic publications, industry reports, and policy documents to gather data on global practices and outcomes. Data from these sources were collected and cross-compared to identify common practices, benefits, and challenges of implementing circular economy methods in food systems. We prioritized peer-reviewed and open-access materials to ensure reliability and to avoid plagiarism by paraphrasing content from those publications. Figures and tables illustrating key data or case studies were

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extracted from credible sources (e.g. UNEP, World Bank) to visually support the analysis.

4. RESULTS

4.1 Global Circular Economy Practices in the Food Industry

Implementing circular principles across the food supply chain: The food industry offers numerous opportunities to close loops and reduce waste at each stage of the supply chain – from production on farms, through processing and distribution, to consumption and waste management. Figure 1 illustrates a circular food system model in which measures are taken at the producer level, consumer level, and in waste/surplus management to achieve a regenerative loop.

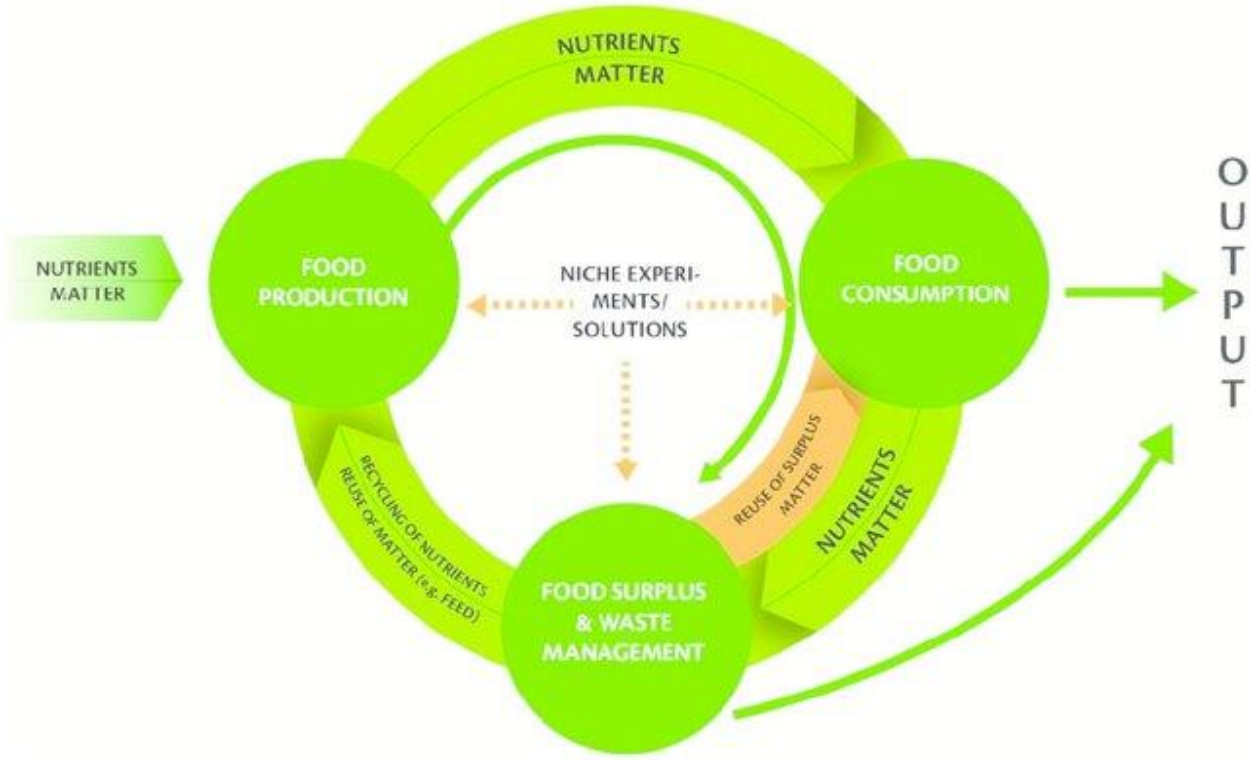

Fig. 1. Three stages of the food system in a circular economy [8]

In a truly circular food system, the amount of waste generated is minimized, surplus food is reused or redistributed, by-products are converted into valuable secondary products (animal feed, compost, bioenergy, etc.), and nutrients are recycled back to farms. This requires interventions such as improving storage and

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handling to prevent losses, encouraging consumers to avoid and separate waste, and investing in facilities that can compost or anaerobically digest organic discards. A study by Jurgilevich et al. (2016) noted that implementing such measures both at the production and consumption stages, and in end-of-life waste management, is vital to support a circular food system. The end goal is a closed-loop system where nothing (or very little) is wasted, mimicking natural ecosystems. Conceptual model of a circular food system. A circular approach to the food industry involves interventions at all stages: reducing waste during production (e.g. on farms and in processing), reusing surplus edible food (e.g. through donations or secondary markets), utilizing by-products and food waste (e.g. converting into animal feed, compost, or bioenergy), and recycling nutrients back to agriculture. Such measures must be implemented both by producers and consumers, with robust waste collection and processing systems, to close the loop.

Waste reduction and valorization:

A core focus of circular economy methods in food is turning waste streams into useful inputs – a practice known as waste valorization. Around one-third of all food produced globally is lost or wasted, so there is huge potential to recover value from this waste.

Fig. 2. The Enormous Scale Of Global Food Waste [9]

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Many countries and companies are investing in technologies to convert food waste into fertilizers, animal feed, or energy. For instance, anaerobic digestion facilities are used to process food waste or agricultural residues (manure, crop husks) into biogas (a renewable energy) and digestate (a nutrient-rich fertilizer). This approach not only produces green energy but also mitigates methane emissions from landfills. Similarly, composting programs transform household kitchen scraps, food processing offcuts, and municipal organic waste into soil amendments that can improve agricultural soil health. In some cities, mandatory source separation of food waste has enabled large-scale composting (as seen in New York City and Seoul) and achieved recycling rates close to 100% for organics [10]. Beyond energy and compost, innovative companies are upcycling food waste into new products – for example, spent grain from breweries is turned into high-protein flour or snacks, surplus fruits become jams or juices, and coffee grounds are used to grow mushrooms. These practices demonstrate circularity by treating "waste" as a resource input for other processes, contributing to both waste reduction and new economic opportunities.

Resource efficiency and sustainable inputs: Circular economy methods also aim to optimize resource use in the food supply chain. This includes improving water and energy efficiency, and substituting non-renewable or environmentally costly inputs with sustainable alternatives. In agriculture, techniques such as precision farming are being deployed to precisely manage irrigation and fertilization, thereby using less water and chemicals. Precision agriculture leverages sensors, Internet-of-Things (IoT) devices, and data analytics to match inputs to crop needs, which reduces waste of resources (water, nutrients) and prevents pollution (e.g. runoff of excess fertilizer). Likewise, renewable energy integration is becoming more common in the food industry – for example, solar panels powering farm operations or food processing plants, and waste heat recovery systems in dairy and meat processing facilities. Some food manufacturers are redesigning processes to recirculate water and capture energy. An emerging practice is the circular bioeconomy, which links biological resources and circular principles: instead of petrochemical inputs, industries use bio-based inputs (like biodegradable packaging, biofuels from crop residues),

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thus closing loops biologically. According to Morone et al. (2023), the circular bioeconomy has become an important component of sustainability policies, as it strives to replace fossil-based materials with renewable biomass and ensure those biological materials are reused or composted in a continuous cycle [11]. Overall, these strategies contribute to decoupling food production from excessive resource consumption.

Circular food packaging and plastics: Another critical area is addressing packaging waste in the food industry. Plastic packaging protects and preserves food but creates a major waste stream and pollution issue. Circular economy methods seek to eliminate unnecessary packaging, innovate with sustainable materials, and establish closed-loop recycling systems. For instance, some companies have introduced edible or compostable packaging (made from seaweed, starch, or other biomaterials) to replace single-use plastics. Others are adopting reusable packaging schemes (like refillable containers for groceries) to cut down waste. Where packaging is still used, improving recycling is key. Many countries are implementing extended producer responsibility and deposit-return schemes to recirculate packaging. A notable example is the recycling of PET plastic bottles into polyester fibers – turning used beverage bottles into textiles or new food packaging, thus closing the loop on plastics. In the EU, regulations are pushing for higher recycled content in food packaging and better collection systems. These efforts in packaging are part of making food supply chains more circular by reducing pollution and the demand for virgin plastic.

Innovative business models and consumer initiatives: The transition to a circular food economy is also spurred by innovative business models and community initiatives. For example, food sharing platforms and apps help redistribute surplus food from retailers or restaurants to consumers in need, tackling waste at the retail/consumer interface. Community fridges have emerged in many cities, allowing individuals or businesses to drop off excess food for others to take freely, thereby reusing edible food that would otherwise be thrown away. Businesses are exploring models like “ugly” produce subscriptions, selling cosmetically imperfect but perfectly edible fruits and vegetables that farms or

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stores might discard. Such models not only reduce waste but also educate consumers and create value from what was once considered refuse. Product life extension is another approach – for instance, food manufacturers are reformulating products or using preservation technologies to extend shelf life and prevent spoilage. In hospitality, some restaurants have adopted "zero-waste" kitchen practices (using every part of an ingredient, composting scraps, etc.) and even offer lower prices at day's end to sell remaining food. These diverse innovations highlight that circular economy in the food sector is not just about technology, but also about cultural and behavioral change toward valuing resources and avoiding waste.

4.2 Uzbekistan: A Case of Circular Economy in Agri-Food Systems

As an example of a national effort, Uzbekistan has recently begun implementing circular economy principles in its agri-food sector to tackle persistent challenges. The agri-food value chain in Uzbekistan has been characterized by low productivity, high post-harvest losses, water scarcity, and high GHG emissions, underscoring the need for more sustainable practices. In 2022, with support from the World Bank, Uzbekistan developed a **Circular Economy Action Plan (CEAP)** for its agriculture and food sector – one of the first comprehensive attempts to apply CE in Central Asian agriculture. The CEAP identified priority areas where circular solutions could yield significant benefits for both the economy and environment [. Five "thrust areas" along the agri-food value chain were targeted (Figure 4 in the CEAP report) as having high-impact potential for circularity:

- **Water circularity in farming operations** – e.g. introducing drip irrigation and reusing treated wastewater for agriculture, to conserve water in this arid region.
- **Resource and energy efficiency in agri-food infrastructure** – e.g. upgrading cold storage and food processing with energy-efficient technologies, and capturing waste heat or biogas from organic residues to power operations.
- **Bioresource utilization** – e.g. composting organic waste, using livestock manure to generate biogas/electricity, and piloting anaerobic digesters for crop residues, thereby reducing open waste dumping.

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- **Plastics circularity** – e.g. collecting and recycling agricultural plastics and food packaging, such as converting used PET bottles into synthetic fibers for packaging or textiles.
- **Precision farming** – e.g. deploying IoT-based sensors and remote sensing to optimize water and fertilizer use on farms, which improves resource efficiency and reduces chemical runoff.

By implementing 17 concrete actions across these areas, Uzbekistan's plan seeks to minimize external inputs, close nutrient loops, and valorize agri-food waste for reuse. For example, one CEAP pilot involves substituting chemical fertilizers with organic compost derived from crop residues and manure, simultaneously addressing waste and improving soil health. Another project is converting fruit and vegetable processing wastes (like tomato and potato residues) into animal feed and energy. The plan also promotes sustainable packaging innovations in Uzbekistan's food industry, such as producing biodegradable packaging from cotton gin waste (leveraging the country's cotton by-products). While the CEAP requires an estimated investment of US$860 million over nine years, it is projected to yield almost a 100% return on investment through improved efficiencies and new revenue streams. Importantly, modeling suggests that full implementation of the CEAP could reduce the agricultural sector's greenhouse gas emissions by 34% compared to business-as-usual, while significantly enhancing the sector's resilience to climate shocks. Uzbekistan's early experience thus demonstrates the potential gains from circular economy methods in an emerging economy context. Although in its initial stages, this case provides a roadmap for other countries in Central Asia and beyond, where similar issues of water stress, post-harvest loss, and waste mismanagement prevail. The Uzbekistan example underscores that with the right policy support and investments, circular practices can be integrated even in traditional agricultural economies to drive sustainable growth.

5. DISCUSSION

The above findings show that circular economy methods are being actively explored and implemented in the food industry across the world, with promising outcomes. Global practices illustrate how rethinking waste as a resource and

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redesigning processes can simultaneously address environmental issues and create value. Successful examples – such as converting food waste to energy, using precision agriculture to save water, or recycling packaging materials – confirm that the circular approach can significantly reduce the food system's footprint. In Uzbekistan's case, projected gains in efficiency and emissions reductions highlight the potential impact at a national scale. Furthermore, initial results from cities and countries that have adopted aggressive waste reduction policies are encouraging: for instance, mandatory composting and public-private partnerships have enabled South Korea to recycle almost 100% of food waste, and helped countries like Japan and the UK cut food waste by 18–31% in a few years. These examples indicate that with concerted action, circular food system strategies can deliver tangible sustainability benefits.

Despite this progress, there remain significant challenges and barriers to fully realizing a circular economy in the food industry. One major challenge is the fragmentation of efforts and the complexity of food supply chains. Prior research has often tackled individual aspects of sustainability (e.g. food waste reduction, resource efficiency, or recycling technology) in isolation. This siloed approach fails to address the systemic nature of the food system, where changes in one stage affect others. A holistic, synergistic strategy is needed – linking production, distribution, and consumption in a unified circular framework. Building such integrated solutions requires coordination among diverse stakeholders: farmers, food manufacturers, retailers, consumers, waste managers, and policymakers must all be engaged and incentivized to close loops.

Policy and regulatory barriers also persist. Food safety regulations, for example, can restrict the reuse of certain waste streams as animal feed or fertilizer unless strict standards are met (to prevent contamination). Navigating these regulations to enable safe reuse is crucial. Additionally, many countries lack comprehensive policies promoting circular practices in food systems. The European Union is a frontrunner, embedding circular economy into its policy (e.g. the EU Circular Economy Action Plan and Farm-to-Fork Strategy), but in many regions policies and enforcement are still weak. Central Asian countries, including Uzbekistan, are in early stages of circular economy implementation, with low recycling rates (below 10% in Uzbekistan compared to ~50% in the EU). This highlights the

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need for stronger governance, investment, and knowledge transfer to less-developed contexts.

In light of these challenges, a few key strategies emerge for advancing the circular economy in the food industry globally:

– **Policy support and incentives:** Governments should implement clear regulations and incentives to promote circular practices – for instance, landfill bans or higher fees for food waste, tax breaks or subsidies for companies that utilize food waste or invest in recycling infrastructure, and public procurement policies favoring circular products. National roadmaps (like the EU's plans or Uzbekistan's CEAP) are valuable for setting targets and coordinating action.

– **Innovation and knowledge sharing:** Continued innovation is needed in areas like biodegradable materials, efficient waste-to-product technologies, and digital tools to optimize supply chains. Sharing best practices internationally can help regions leapfrog some stages – for example, Central Asian countries can learn from European or East Asian experiences in composting and food waste bioconversion.

– **Infrastructure development:** Building the necessary infrastructure – from robust waste collection systems in cities to rural on-farm composting units – is fundamental. Public-private partnerships can be effective here. For example, city authorities partnering with entrepreneurs to set up biogas facilities can ensure waste streams have a place to go. Improving storage and transport (cold chain) in developing regions will both reduce losses and enable better recycling of organics.

– **Holistic, system-wide approaches:** Actors in the food system must break out of silos. A circular approach often yields co-benefits; for instance, reducing food loss on farms improves farmer incomes while also cutting waste. Integrated programs that connect farmers, processors, and waste managers – such as creating local "industrial symbiosis" clusters where one facility's waste is another's input – can maximize resource circularity. The circular economy is as much about redesigning systems as it is about individual technologies or practices.

– Finally, it is worth noting that some experts argue for pushing beyond "circular" into truly **regenerative or reconstructive** food systems. In other

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words, not only aiming to eliminate waste and keep resources cycling, but to actively restore ecosystems and build soil health and biodiversity through our food production methods. This perspective is reflected in the concept of "reconstructive agriculture" which complements circular economy principles with regenerative practices that leave the environment better off. Examples include farming methods that rebuild soil carbon, agroforestry systems that enhance biodiversity, and diets that promote diverse, locally adapted crops. Merging circular economy methods with regenerative agriculture could address some gaps, ensuring that circular solutions also contribute positively to ecosystem health rather than just mitigating harm.

6. CONCLUSION

Transitioning to a circular economy in the food industry is a formidable but necessary endeavor to achieve global sustainability goals. This study reviewed how various circular methods – from waste valorization and resource-efficient technologies to new business models and policy initiatives – are being applied around the world. The global evidence indicates that a circular approach can drastically reduce food waste, optimize resource use, and even open new economic opportunities in the food sector. At the same time, significant challenges such as fragmented efforts, infrastructural needs, regulatory hurdles, and behavioral barriers must be addressed to scale up these practices. The case of Uzbekistan's agri-food CEAP exemplifies both the ambition and the complexity of implementing circular economy strategies in practice, especially in emerging economies with limited resources. Nonetheless, Uzbekistan's early progress and the successes from other countries underscore that the circular economy is not just a theoretical ideal – it is achievable with coordinated action and innovation. By learning from global best practices, investing in enabling conditions, and fostering collaboration across the supply chain, the food industry can move toward a circular model that sustains both people and the planet. In doing so, it will play a pivotal role in building a sustainable future where food systems thrive in harmony with natural ecosystems.

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