

Waste Valorisation Through Circular Economy: Pathways Toward Sustainable Food Systems

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ABSTRACT: Food waste is becoming one of the topmost sustainability challenges around the world, leading to significant environmental damage, financial losses, and social inequities, besides food insecurity and inefficient resource use (FAO, 2011; UNEP, 2024). Even with intensified efforts toward food loss reduction throughout the supply chains, fragmentary management practices continue to act as barriers to sustainability and circularity within the food systems. The current study offers a detailed review of the approaches used within the circular economy concept to reduce food waste and introduces a waste-to-wealth strategy framework incorporating technology innovations, circular business models, and policies for resource management. Through analysis of the latest literature, the review considers food waste drivers and impacts, waste valorization technologies such as composting, anaerobic digestion, energy production from food waste, bioconversion, upcycling, and digital platforms, besides other emerging circular industries and case studies worldwide. The findings from the review highlight that utilizing food waste in generating renewable energy and bio-based fertilizers, among other value-added products, increases resource efficiency, encourages green entrepreneurship, and fosters climate change mitigation and resilience in the food system (Kirchherr et al., 2017; UNEP, 2024). Additionally, the review outlines some of the barriers hindering the adoption of circular food systems at a large scale and suggests some strategic measures for promoting their adoption. By considering environmental, economic, and social aspects in an integrated conceptual framework, the present study not only adds to the literature on circular economy but also makes a meaningful contribution to the literature on sustainable food systems, thus helping to meet the SDGs.

KEYWORDS: Food waste; Circular economy; Waste valorization; Sustainable food systems; Green entrepreneurship; Resource recovery; Sustainable Development Goals.

1. INTRODUCTION

Food waste has proven itself to be one of the biggest sustainability problems of the modern age. Even though agriculture has seen impressive achievements concerning food production, about one-third of all the food prepared for human consumption is being wasted and lost at various stages of the food value chain (FAO, 2011). It has been reported that, according to the data by the United Nations Environment Programme (UNEP, 2024), around 1.05 billion tons of food have been wasted worldwide in 2022, which constitutes 19% of the amount of food available for the consumers' use; however, about 783 million people still suffer from hunger (FAO et al., 2023). In addition to the moral aspect of the problem related to the problem of hunger, food waste results in greenhouse gas emissions, inefficient use of water and land resources, biodiversity loss, and economic losses which surpass the sum of more than 1 trillion US dollars per year (UNEP, 2024). Therefore, reducing food waste has become one of the priorities for achieving the goals of sustainable development, including SDG 2, 12, and 13.

The increasing awareness of these problems has led to a change of academic and political focus from traditional waste management methods to more sustainable options, which are based on the principles of the circular economy. As opposed to the classical "take-make-dispose" approach of a linear economic model, the circular economy encourages reduction, reuse, recycling, recovery, and regeneration of resources in order to avoid waste production and improve resource efficiency (Kirchherr et al., 2017; Geissdoerfer et al., 2017). In case of food systems, circular economy approaches imply transformation of food waste into resources with the help of such technologies as composting, anaerobic digestion, bioenergy production, biochar production, insect bioconversion, food upcycling, and nutrients recovery. Such actions do not only help to preserve environment but also encourage

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green entrepreneurship, innovation, production of renewable energy, and resource management (Mia et al., 2025; Pan et al., 2025).

In the last ten years, there has been a significant increase in research on food waste and circular economy in different fields such as environmental science, waste management, agriculture, business, engineering, and policy-making. The existing research has explored many aspects such as food waste generation drivers, waste prevention methods, waste valorization technologies, consumer behavior, digital platforms for food redistribution, circular business models, and policy interventions (Michelini et al., 2018; Johnson et al., 2023). Even though much has been learned from the increased research conducted in the field, it is still very fragmented. There are numerous studies that explore individual technologies or phases in the food chain process but not many that consider all these factors in the context of a circular food system framework.

Moreover, prior review researches have mainly focused on waste management technologies, sectors, and regions, disregarding the interrelatedness between resource recovery, value generation, policies, and sustainable transformation of food systems. Likewise, while circular economy is more frequently being considered in relation to food waste management, little effort has been put into analyzing how all the valorization strategies are combined to create sustainable impacts both environmentally, economically, and socially and thus lead to multiple SDG achievements. In other words, there is still no sufficient knowledge on the integration of circular strategies into a coherent waste-to-value chain that would promote sustainable transformation.

In light of this discussion, this review seeks to consolidate the increasing amount of scholarly work on the topic of food waste valorization within the context of circular economy. In contrast to previous research that usually focused on one technology or sector, this study aims to incorporate insights drawn from different technological advancements, circular business models, resource recovery techniques, governance policies, interventionist measures, and case studies to offer an integrated understanding of sustainable food waste management. This review further develops a framework of the Waste-to-Wealth Circular Food System using existing literature, which depicts the interlinkages between food waste production, circular economy approach, valorization technologies, sustainability impacts, and Sustainable Development Goals.

The rest of the paper will be divided into sections, as follows. Section 2 covers the notion of sustainable food systems and explores the reasons and consequences of food wastage. Section 3 provides information on circular economy concepts and food waste valorisation technologies. Section 4 presents the emerging circular industries and cases from around the world. Section 5 discusses the advantages of circular food systems in terms of the environment, economics and society. Lastly, Section 6 deals with current limitations and policy implications.

Objectives

In this chapter, we will try to analyze the potential of circular economy in creating sustainable food systems. First, we define the notion of sustainable food systems and explain the reasons and consequences of food waste. Next, we cover the concepts of circular economy in the food industry. In particular, we review some of the innovative waste management technologies and emerging circular industries. Using the cases, we will also show the practical application of “waste-to-wealth” approach. In all of this, we bring together current findings and studies to deliver a consistent analysis, as per the guidelines set out by Bentham (originality, clarity, and broader thematic connections). Upon completion of this chapter, readers will be able to understand how circular approaches in food systems help with sustainable development and green entrepreneurship.

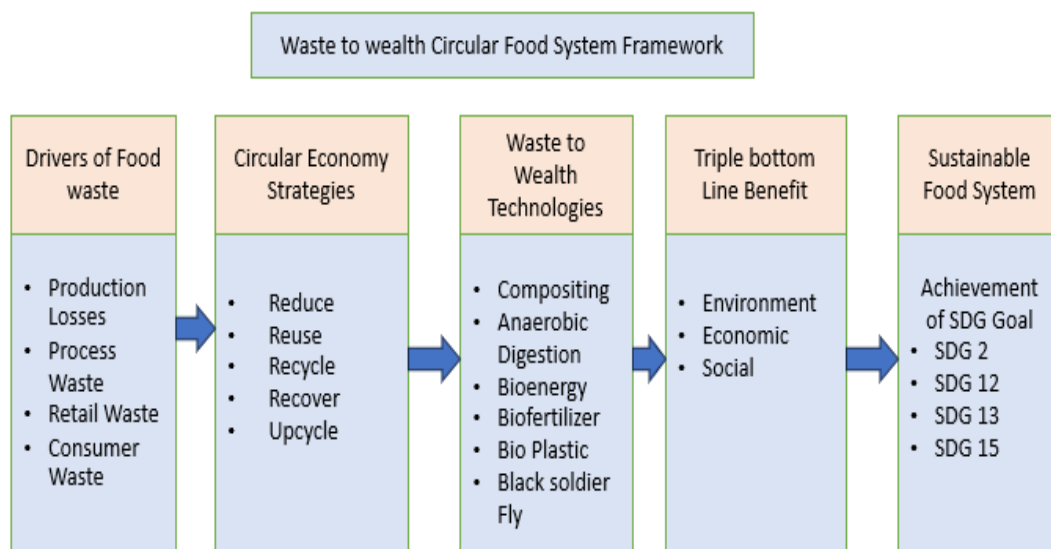


Figure 1: Waste-to-Wealth Circular Food System Framework

The conceptual framework of this chapter is provided in Figure 1 below. It demonstrates how food waste produced within the entire food chain can be turned into resources by using circular economy interventions. Interventions help recover resources, encourage green entrepreneurship, and ensure sustainable development results which altogether will create resilience in the food systems and the achievement of SDGs.

Sustainable Food Systems

Sustainable food systems (SFS) provide all people with adequate amounts of food and sustain natural resources for future use (High Level Panel of Experts [HLPE], 2014). This means that SFS has to provide food security and nutrition to everyone without harming the economic, social and environmental base for future food production (HLPE, 2014). The Food and Agriculture Organization of the United Nations states that sustainable food systems combine productivity with conservation (climate smart agriculture, agroecology, etc.), promote local food chains, and provide equitable access to healthy diets.

The components of the food system such as production, distribution, consumption, and waste disposal are interconnected with sustainability. In agriculture, which accounts for over 90% of food production, the consumption is around 70% of global water and a significant proportion of GHGs emissions (World Bank, 2017). Industrialized agriculture and fishing caused degradation of biodiversity and soils. Supply chain and retail operations are resource-intensive and inefficient. As regards consumption, dietary trends (for instance, large consumption of meat in wealthy regions) determine the increase in resource consumption. Crucially, about half of the food loss happens during the post-harvest phases in developing nations, and around half at the retail or consumer phase in developed nations (FAO, 2011). Failure to address this problem negatively impacts food security and resource waste.

Hence, a sustainable food system should decrease waste and increase resource efficiency through adopting agroecology and climate-smart agriculture (that decreases water and fertilizer use), shortening the supply chain (locally and seasonally produced products), and shifting to plant-based diets, that do not require as much resources. It involves viewing the organic waste not as a waste material but a resource input into value chains. Through nutrient looping, such as using organic waste as compost rather than sending it to the landfill, communities can become less dependent on artificial fertilizers, saving energy (in fertilizer production and methane gas emissions in landfills). Such system-wide improvements promote several SDGs; for instance, SDG 2 (Zero Hunger) through losses reduction and availability of more food, SDG 6 (Clean Water) and SDG 15 (Life on Land) through efficiency in land/water use, SDG 13 (Climate Action) through emission reduction, and SDG 12 (Responsible Consumption).

In conclusion, sustainable food systems comprise all stages in the life of food and consist of economic sustainability (food farmers' income, business profitability) and social and ecological sustainability. These require collaboration between government (implementation of sustainable agricultural practices), businesses (investment into cold chain and waste treatment), and people (reduction of waste, sustainable consumption). This chapter is devoted to the waste stage of food systems and ways to enhance the sustainability of food systems through food waste management innovations.

Food Waste: Causes and Impacts

Floridas defines FLW as edible material meant for consumption that gets discarded or goes bad. In the same context, the Food and Agriculture Organization (FAO) differentiates between food loss, which occurs during production, harvesting and processing and food waste that occurs during the retail and consumption stages (FAO, 2011). The reasons for food waste are numerous and include the lack of infrastructure and proper storage facilities in under-developed areas and inefficient supply chain in developed countries as well as consumer habits and cosmetic issues (FAO, 2011).

There are many ways in which food can be wasted. Food is wasted in supermarkets or restaurants because there is too much or because of certain labelling rules. Consumers throw food away because of over-purchasing, poor planning or misunderstanding of dates. Also, even so-called "inedible" parts such as peels or bones can be used elsewhere. The most important thing is that a lot of food is wasted unnecessarily.

The impacts of FLW are enormous

Impacts on Nutrition and Food Security: Food waste defeats attempts to feed the hungry. As many as 783 million people are still undernourished worldwide (FAO et al., 2023), despite tremendous amounts of food wasted. According to FAO (2011), the amount of food wasted each year could sustain approximately four times more undernourished people. Therefore, minimizing FLW has a social benefit of food availability and reduced need for production to satisfy the demands.

Economic Impacts: The hidden economic cost of FLW is estimated at about USD 1 trillion a year (UNEP, 2024). This estimate accounts for the value of wasted inputs (seed, fertilizer, labor, energy), as well as the costs associated with disposal of food waste. UNEP (2024) stresses that "food loss and waste costs the global economy USD 1 trillion annually." Besides, investments into prevention of food waste are extremely profitable, as stated by Champions 12.3: every dollar invested in reducing food waste may save up to \$92 (Champions 12.3, n.d.). Green entrepreneurship related to FLW involves very attractive financial opportunities, from

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the sales of extra food ("sharing economy") to development of businesses around by-products (e.g., selling peel leftovers to feed producers).

Environmental and Climate Impacts: Food waste causes environmental problems at all levels. The production of food that goes to waste contributes to the depletion of water resources and the soil and causes the emission of GHGs with no nutritional output. FLW is estimated to be responsible for about 8–10% of human-induced GHG emissions globally (UNEP, 2024). This is because wasted food decomposing in landfills emits methane, which is a powerful GHG, and the activities prior to wasting the food cause emissions of CO₂ and N₂O. According to UNEP (2024), if food waste was a country, it would be among the top three GHG emitters globally. Moreover, food waste affects biodiversity and water: FAO (2011) estimates that about 28% of the global cropland is utilized for growing foods that are never consumed, and about 25% of the agricultural freshwater is being used on the wasted food.

Social Ramifications: Apart from quantitative impacts, food waste has qualitative social ramifications as well. It is an ethical lapse and a social injustice since while some people suffer hunger, others waste edible food. Decreasing food waste will improve community resilience (by donating food) and social awareness of sustainable consumption. Initiatives such as the International Day of Awareness of Food Loss and Waste (celebrated on Sept 29 by UN) seek to transform social attitudes through focusing on personal and collective responsibility (UNEP, 2024).

To conclude, food waste contributes to food insecurity, inefficiency, and environmental degradation. On the other hand, preventing waste ensures co-benefits. Elimination of FLW is important for achieving food system resilience and sustainability.

Circular Economy in Food Systems

Circular economy (CE) provides a promising way for solving the problem of food waste. At the broadest level, circular economy is "an industrial system that is restorative or regenerative by intention and design" (Geissdoerfer et al., 2017; Kirchherr, Reike, & Hekkert, 2017). Central to the circular economy are such concepts as replacement of the "end-of-life" concept with reduce, reuse, recycle and recover materials, and the product design for the minimization of waste. CE is an economy without waste where waste products are recycled in the production process.

As applied to food system, circularity presupposes a reconsideration of such processes as food production, consumption, and its disposal. It includes both upstream and downstream activities like, for example, application of regenerative agricultural practices, precision farming to avoid overproduction and redesign of the food products, so that their residues can be used as raw materials for other products. Farmers may use crop rotation and permaculture to regenerate soils and restore nutrients, and food industry will have to redesign their products so that their residues become raw materials. The Ellen MacArthur Foundation (2012) emphasizes "*the elimination of waste through the superior design of materials, products, systems, and ... business models.*" In practical terms, this means designing meals and supply chains so that outputs (food scraps, pulp, leftovers) become inputs for new uses (feeding livestock or generating energy).

The CE framework is naturally resource-efficient since it involves following the "3Rs" tradition (Reduce, Reuse, Recycle) along with the more complex hierarchy that includes other "Rs," including Refuse, Rethink, Repair, Recover, and so forth. In the case of food systems, they can involve:

Refuse/Rethink: Stop unnecessary overproduction and packaging. Retailers can refuse excessive single-use packaging, and individuals can plan meals and avoid buying extra products.

Reduce: Optimize production and transportation to minimize the amount of wasted food. For instance, more efficient demand forecasting by supermarkets or shortening of supply chains can minimize losses during transportation.

Reuse: Direct reuse of excess food for another purpose. For example, restaurants could donate excess meals to food banks; individuals could reuse meal remnants (such as using vegetable peels to prepare broth).

Recycle/Recover: Transform inedible or excessive organic materials to another resource (compost, fertilizer, animal feed, fuel, and so on). That is the point where businesses such as composting and anaerobic digestion become useful.

Circular business models also exist. For example, "food-as-service" business models such as buffets (where people pay for their food consumption) or reusable containers are designed to foster reuse. The development of digital technologies that help share meals (such as Too Good To Go and OLIO) reflects the sharing economy aspect of CE and helps match excess food with demand instead of throwing it away. Such approaches correspond to the "sharing-for-profit" models suggested by Michelini, Principato, and Iasevoli (2018) as they involve using technologies to reduce waste and earn money on it.

It should be noted that CE not only implies the environmental benefit but also promises economic advantages as well. According to Kirchherr et al. (2017), most definitions include economic prosperity and profitability along with reducing waste. Innovative solutions allowing businesses to use waste streams as inputs generate new business opportunities. For example, a company that manufactures juice can sell peels from fruit to distilleries or producers of pectin.

Summary

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The use of CE in food systems essentially involves treating food waste as a resource and not a garbage. In essence, food supply chains become cyclic where nutrients and energy reenter the cycle rather than a linear approach where there is movement from “farm to landfill.” These systems are more environmentally sustainable, equitable, and resilient, which are what SDGs seek for holistic sustainability.

Innovations in Food Waste Management

Application of circular economy in food systems is based on innovations in both technology and businesses. In the recent past, quite a number of innovations have been seen within the waste hierarchy.

Food waste Source	Circular Strategy	Technology	Output	Sustainability Benefit
House hold waste	Composting	Anaerobic Composting	Organic Fertilizer	Soil Health
Restaurant waste	Anaerobic Digestion	Bio gas Plant	Renewable Energy	Lower GHG emission
Fruit waste	Upcycling	Extraction	Nutraceuticals	High value Products
Agricultural waste	Pyrolysis	Biochar	Carbon Sequestration	Climate mitigation
Mixed organic waste	Black Soldier fly	Bio conversion	Animal Feed	Circular Protein Output

Composting and Anaerobic Digestion (AD): The established technologies continue to be critical in resource recovery. Composting is an aerobic process in which organic materials are broken down to form soils. AD involves processing of wet materials such as food wastes and manure in closed reactors to produce biogas (fuel gas made primarily of methane) and digestate (liquid fertilizer). Both of the technologies are being scaled up in projects around the world. South Korea and Japan, for instance, have large-scale composting operations turning huge volumes of market and kitchen waste into standard organic fertilizers (Xu et al., 2023). Food scraps are collected in several cities of Europe and North America and used for AD to generate energy locally. Technical developments include co-digestion of food waste (increased production of biogas) and more efficient aeration in composting.

Bioenergy via Waste Conversion: Direct conversion of food waste to energy is yet another revolutionary technique. Besides anaerobic digestion, waste-to-energy facilities convert organic waste through burning or gasification for the production of electricity. Bio2Watt, a startup in South Africa, has established a 4.8 MW biogas plant on a dairy farm using anaerobic digestion of cow manure and local organic waste (Afrik21, 2021). The produced electricity is sold under power purchase agreements to a brewery company. In India and other countries, new startups develop low-cost biogas digesters converting food waste to methane that powers households' cooking and/or fuels vehicles. Such an approach not only solves the issue of waste disposal but also replaces the traditional carbon energy.

Biofertilizers and Soils Improving Agents: Interest is growing to transform food waste into value-added soil additives. For instance, vermicomposting has become popular in developing countries; composting of vegetable market waste with the help of earthworms has substantially enhanced soil fertility and agricultural productivity. Another technology involves the production of biochar: the firm Takachar (India) utilizes portable reactors for conversion of crop residues (straw rice, corn cobs) to biochar and bio-oil (Afrik21, 2021). It prevents open-field burning by almost 98%, stores carbon in soil as biochar, and offers farmers a new source of income (sale of biochar or electricity), while decreasing air pollution.

Nutrients and Wastewater Management: Urban and agricultural runoff, which results from organic waste, holds valuable nutrients (nitrogen, phosphorus). Technologies for struvite precipitation reactors extract nutrients from digestate and sewage and manufacture slow-release fertilizer granules. Some advanced wastewater treatment facilities extract nutrients from wastewater, which would otherwise pollute water bodies, closing nutrient cycle of waste to fertilizer.

Digital Technologies and Monitoring: “Smart” solutions become more popular in the field of waste management. Smart technologies allow tracking waste production through sensors and software equipped with artificial intelligence. For example, camera recognition system in industrial kitchens allows identifying and weighing discarded food, and thus helps managers find waste sources. Digital technologies also allow connecting surplus food with consumers. Restaurants offer extra food at reduced price using such applications as Too Good To Go, supermarkets donate food close to expiration dates using applications, and people can exchange food among each other using OLIO. Michelini et al. (2018) stress that such digital platforms have greatly developed and facilitate food redistribution and waste prevention.

Bioconversion (Insects and Microbes): Waste biocorversion through biological means is an increasingly popular method. The insect industry is a good example; black soldier fly larvae (BSFL) consume many types of organic waste (food scraps, manure) and convert them to insect biomass. According to Johnson, Domínguez, and Zhou (2023), BSFL have 40-60% of protein content and are capable of processing more than 80% of the consumed waste, creating high-quality feedstuff for animals. BSFL production consumes much less space, water, and food compared to traditional livestock or aquaculture and is therefore sustainable. Another

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biocorversion technology uses fungi and bacteria to ferment waste to edible biomass and biochemicals (fermenting yeast on lactose waste to obtain food or fertilizer).

Product Redesign and Bioproducts: Besides directly recycling the products, the scientists extract valuable substances from waste. Beer brewing grains, fruit residues and vegetable peelings are full of valuable nutrients and biologically active substances. Modern researches (Pan et al., 2025) found out that extraction of antioxidants, fiber and oils from these wastes creates valuable components for nutraceutical, food and cosmetic industries. Modern companies sell flours, made of upcycled waste such as coffee grounds or fruit peelings, and colorants made of vegetable waste. These processes turn what was waste into valuable ingredients, aligning waste reduction with high-value product creation.

In conclusion, technological innovations ranging from low-tech composting to high-tech biotech are adding more tools to the circular economy's toolbox when it comes to the food industry. Millions of tons of organic waste are being diverted from landfills every year while generating revenue. The next section demonstrates how such innovations lead to the emergence of the full-fledged "circular industries," which are based on food waste.

"Circular Industries" Based on Food Waste

Waste treatment itself is creating new sectors of the economy. For example, energy companies are collaborating with farmers and cities to create biogas plants (see above). Composting companies supply organic fertilizers to gardening companies and farms. Newly emerging insect feed companies (BSF farms) supply insect meal to fish and poultry farmers. Companies also develop bioplastics from food waste (e.g., potato starch and oils are used to make biodegradable films). The cosmetics and nutraceutical industries also extract active ingredients from food waste (e.g., antioxidants are extracted from berry pulp, and caffeine is extracted from coffee grounds). Each of these industries creates its own circle by transforming waste inputs into new commercial products. Green entrepreneurs are vital to the success of such industries. These individuals forge connections within the value chains – e.g., a biotechnology company connecting food waste from urban areas to a factory producing fertilizer. Such organizations grow and develop, thereby providing employment for people along the chain (from collectors, plant operators to researchers). In other words, circular food industries are an example of converting environmental advantage into economic gain.

Case Studies of Circular Food Innovations

<i>Innovation</i>	<i>Country</i>	<i>Technology</i>	<i>Main Outcome</i>
<i>Bio 2 watt</i>	South Africa	Anaerobic Digestion	Renewable Electricity
<i>Takachar</i>	India	Pyrolysis	Biochar
<i>Nolla</i>	Finland	Zero Waste restaurant	Consumer awareness
<i>Recycling Works</i>	USA	Composting	Organic Fertilizer

A few real-world examples illustrate the above concepts:

Bio2Watt (South Africa): As mentioned earlier, Bio2Watt's 4.8 MW farm-based biogas plant converts dairy manure and food waste into electricity to run a brewery (Afrik21, 2021). It decreases methane emissions from manure and generates renewable energy, serving as an example of sustainable waste-to-energy venture.

Takachar (India): Takachar's mobile pyrolysis technology transforms agricultural residues into biochar. Their pilot projects demonstrate 95-98% reduction of smoke emissions (compared to field burning) and a 30-50% increase in income of farmers (Afrik21, 2021). This technology solves one air pollution issue and builds a profitable circular economy for smallholder farmers at the same time.

Recycling Works (USA): This Massachusetts-based composting company recycles food waste from households and businesses by means of aerated composting technology. Compost produced by Recycling Works is then sold to landscapers and farmers. By providing a handy service and producing a high-value product, Recycling Works managed to recycle tons of food waste per year.

Nolla (Finland): This zero-waste café designs menus which make full use of all the ingredients (like brewing beer out of leftover bread, using leftover vegetables in soup, etc.) and buys ugly food. The café encourages customers to either carry their own containers or share food that is left over. Nolla produces almost no waste at all. It is a model which has inspired many more cafes. Though on a small scale, Nolla demonstrates the role of the customer in circular economy: the customer pays extra for sustainability.

It is evident that circular approaches to food are possible on any scale and in any setting. Collaboration and measuring are typical features of each approach described above. Each of them is measured (number of tonnes of waste prevented, emissions reduced, income made), there are always partnerships involved (farmer, municipality, NGO, etc.).

Benefits of Circular Food Systems

The advantages of adopting circular approaches in food systems are manifold:

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Environmental Advantages: The foremost advantage is that less methane will be emitted from landfills. Moving food waste into compost or digester reduces GHG emissions from landfills substantially (UNEP, 2024). Furthermore, using waste to generate energy does not involve the use of fossil fuels. According to some researchers, net negative emissions can be achieved from anaerobic digestion if well-managed (Xu et al., 2023). Since waste is minimized, circular systems utilize land and water resources more efficiently. According to UNEP, 28% of freshwater and 26% of arable land is wasted on food that is not eaten (UNEP, 2024). Nutrient runoff is minimized when waste is properly composted instead of being thrown away.

Economic Advantages: With circular food systems, new business opportunities arise. Products have value: enterprises earn from selling animal feed, fertilizers, biogas, or bioproducts. Municipalities save money on waste management (by 30–50%). Good returns on investments are observed in the area of waste reduction programs (Champions 12.3, n.d.). New “green” enterprises appear and thus, there is job creation. For instance, Denmark’s transition to organic waste collection and anaerobic digestion brought about job creation and saved money for municipalities on landfills. Localizing supply chains (e.g. producing compost locally) can also reduce import dependence (for fertilizers and animal feed) and keep money in communities.

Social Benefits: Circular food systems deliver social benefits. Food security is improved by recovering edible surpluses. Compost and biofertilizers may increase the yield of crops among smallholder farmers. Clean air (resulting from reduced burning of waste) is beneficial for people’s health. Social projects such as urban gardens and community kitchens that use recovered food and compost improve social connections and education. Jobs created as a result of the implementation of circular food systems (such as in food recovery and processing facilities) tend to be local and inclusive. The systems teach responsible citizenship. Thus, circular food systems are in line with people, planet, and prosperity. They contribute to the achievement of multiple Sustainable Development Goals at once.

Challenges and Barriers

Despite all the advantages, there are a number of barriers to the circular transition

Infrastructural Challenges and Scale: Lack of appropriate infrastructure is one of the main problems that need to be solved in many regions. In low-income countries, a huge amount of food never arrives to urban areas because of lack of transportation and poor storage conditions. Organic waste is often commingled with general municipal solid waste, which makes it hard to recover it.

Regulatory/Policy Obstacles: Current regulations can actually stand in the way of creating a circular economy. Strict food safety regulations can deter donations of surplus food. Permits to establish composting and biogas sites can take much time and money to be obtained. Standards for the utilization of recovered products (such as digestate) are missing in some countries. Without proper policy tools (bans on landfills, financial instruments, standards), there will be no incentives for companies to invest in circular solutions.

Viability/Economics: Some of the circular technologies are currently economically non-viable. Upgrading food waste into bioplastics and biochemicals can cost more than manufacturing using traditional technologies. Waste collection at a smaller scale is too expensive and labour-intensive. Technological solutions (such as AI sorting or advanced reactors) require significant investments and skills that are not available to small business owners or municipalities. Circular inputs might be undervalued by the market since virgin inputs are often cheaper and not taxed for their negative impact on the environment.

Behavioural and Social Factors: Individual behavioural factors and socio-cultural factors are critical to the situation. For instance, if consumers desire cosmetically appealing produce and if consumers value convenience over reducing waste, there will be food waste. Educating consumers is necessary for changing their behavioural tendencies. Moreover, certain technologies may face social resistance (for instance, consuming insects as animal feed). It is necessary to raise public awareness but this process takes time.

Coordinating Among Various Stakeholders: Food systems are complex in terms of various players that they encompass: farmers, processors, retailers, waste managers, government, and non-government organizations. The problem lies in coordinating the interests of all these actors. For example, it is necessary to create contractual agreements in order to ensure that farmers will provide certain amount of waste and processors will buy it. Partnership between the public and private sector can facilitate the process but coordination mechanisms are required.

Policy Implications and Recommendations

To overcome these barriers, coordinated policy and strategic actions are needed:

Policies and Actions by Governments: Governments can define the targets (e.g., to reduce FLW by half by 2030 according to the SDGs) and include them in their climate and development strategy. Regulations are another tool that may help (e.g., forbid the presence of organic materials in landfills or provide tax benefits for implementing circular processes). Food donation should be made easy and promoted (providing immunity and tax relief). Investments in infrastructure (composting facilities, biogas plants, and collection systems) are needed, especially in developing countries. Public procurement (schools, hospitals) may be used as a demand creator for recycled goods (e.g., using compost or imperfect produce).

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Actions by Industry: Companies must audit and reduce their waste. Retailers may apply dynamic pricing or food donation agreements to prevent unsold items. Manufacturers can recycle and reuse the by-products (e.g., sell the wheat bran to bakeries). Hotels should teach their staff about waste reduction and collaborate with charities for leftovers. Companies should monitor and report the waste (as per sustainability standards) and invest in circular innovations (new packaging or processing solutions). The collaboration of actors in supply chains, like that of farmers in organizing the collection of residue in biogas production, should be encouraged using industrial associations.

Consumer Awareness: Campaigns to raise public consciousness are critical to altering consumer attitudes. Clear date labeling can prevent misunderstandings about the differences between "sell by" and "use by" dates, hence reducing waste. Education (in schools and communities) to help plan meals, store food, and compost waste can be effective. Community efforts (shared gardens, back-yard composting projects), as well as use of digital platforms (applications to share excess food, etc.), can engage the consumer. Behavioral adjustments (small portion sizes, doggy bag requests from restaurants) can be encouraged cumulatively to reduce waste.

Further Research and Collaboration: Research efforts need to continue on technology and behavior issues. Academics need to research new waste conversion technologies (like new enzymes for waste valorization) and do life cycle analysis for the most sustainable practices. Social scientists need to determine what motivates consumers' and industry behavior changes. International cooperation (using UN platforms such as Champions 12.3, working groups at the FAO, etc.) can contribute to best practices dissemination and harmonization of metrics for food waste (following recommendations of the Food Loss and Waste Accounting and Reporting Standard). Finally, coupling food waste reduction initiatives with the climate and biodiversity agendas may bring more investment and policymaking efforts.

Combining the policy, innovations, and public awareness efforts, actors can promote scaling of circular activities. There is an opportunity for countries to specify food waste reduction in the framework of Nationally Determined Contributions that will be revised in 2025 in the context of the Paris Agreement. Zero waste objectives should be set by cities worldwide and improved urban food systems should be developed. In summary, harmonization of policy frameworks with circular principles (recommended by UNEP (2024) and others) would promote adoption of these approaches.

Future Research Directions

Several other directions are worth pursuing. Digitalization appears to be a very interesting area: How does one utilize AI and blockchain technologies for improving the efficiency of food flows and minimize waste? There is a need for a study of circular business models. For instance, comparative case study analysis of alternative models (such as food-sharing apps and subscription services for meals) may shed light on their applicability. One needs to perform behavioral research in order to learn more about attitudes and norms that will help develop the right education campaign. One should carry out a life-cycle analysis to compare the true level of sustainability of different alternatives (such as insects vs. conventional feed) using standardized methodologies.

CONCLUSION

This chapter has shown that circular approaches to food waste offer viable pathways from **"waste" to wealth** in sustainable food systems. By embracing circular economy principles – minimizing waste, reusing by-products, and recycling nutrients – stakeholders can turn a global problem into an opportunity. As the UNEP (2024) Food Waste Index highlights, even small percentage reductions in waste yield large climate and economic gains. Circular food systems enhance resource efficiency (saving land, water, and energy), improve food security, and generate green growth through new industries. Moreover, they advance multiple SDGs: reducing hunger, cutting poverty (through jobs), and protecting ecosystems.

Such achievements would only be possible through cooperation on a broad scale. It is essential that governments formulate ambitious targets (such as cutting the quantity of waste produced by half by 2030; UN General Assembly, 2015), implement supportive policies and create an environment conducive to the realization of the circular economy objectives. Enterprises need to develop innovative and invest in circular technologies. Citizens should change their habits and practice sustainable approaches. Green entrepreneurs will play a major role in the process of transformation with their new technologies and business models. The key in changing the current food system lies in a common understanding of a food secure and carbon-neutral future.

The move from the linear "produce-consume-dispose" approach to the circular "produce-recover-regenerate" approach is the hallmark of a new era of sustainable food systems management. Through the use of innovation in technology, governance, entrepreneurship, and collaboration, the waste generated could be converted into an asset that will contribute towards environmental sustainability, economic resilience, and social well-being at the same time. Therefore, circular food systems are

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more than just about managing waste; they are a means to develop resilient food systems and accomplish multiple Sustainable Development Goals.

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