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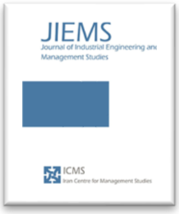

Circular Economy Principles in Food Supply Chains: Innovative Approaches for the Developing World

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Abstract

The global food supply chain, while fundamental to economic development, operates predominantly on a linear 'take-make-dispose' model, driving significant environmental degradation, resource depletion, and food waste. This linear paradigm is particularly unsustainable in the developing world, where the pressures of climate change, population growth, and infrastructural challenges exacerbate food insecurity and ecological damage. While the Circular Economy (CE) offers a transformative vision to address these crises by creating regenerative and restorative systems, the adoption of its principles in the food supply chains of developing countries remains nascent and lacks a clear, context-specific roadmap. This study addresses this critical gap by identifying and prioritizing the key CE principles necessary for a successful transition in these unique contexts. Drawing on the ReSOLVE framework, relevant principles were first identified through a systematic literature review and then validated by experts. Subsequently, a Pythagorean Fuzzy Decision-Making Trial and Evaluation Laboratory (PF-DEMATEL) method was employed to rank these principles, effectively managing the inherent uncertainties and complexities of the decision-making environment. The findings establish a hierarchical foundation for CE implementation, revealing that "Regeneration" of natural ecosystems is the most fundamental principle, as it underpins the long-term viability of all other circular efforts. "Looping" resources back into the system and "Optimizing" processes emerge as the next critical priorities, built upon this regenerative base. Conversely, "Virtualization" and "Exchange" while valuable enabling tools, are found to be less foundational and reliant on established resource management systems. This research makes a novel contribution by providing the first prioritized ranking of CE principles tailored to the food supply chains of developing nations using a robust fuzzy multi-criteria decision-making approach. The resulting framework offers policymakers and industry leaders a clear, actionable roadmap for strategic resource allocation, ensuring that foundational ecological practices are secured before investing in advanced technological solutions, thereby paving the way for a truly sustainable and resilient food future.

Keywords: Circular Economy, DEMATEL method, Developing country, Food Supply Chain, Pythagorean fuzzy set, Sustainability

Paper Type: Original Research

1. Introduction

Functions of food supply chain could put enormous impacts on climate change, helping to create cities, or rebuild biodiversity. It is true that the current food supply chain has facilitated urbanisation, leading to economic development and growing population. However, the true costs of such development to the society are not anticipated. It should be under holistic attention that the linear food supply chain is a kind of fuel for disruption making it unsustainable. Today's food supply chain has an unignorable social and environmental impacts on climate, level of food waste, water resource to inequality and healthy style of living, biodiversity damage, etc. The agrifood supply chain is responsible for about a quarter of greenhouse gas emissions and degradation of the environment (Kumar et al., 2024). This causes air, soil and water pollution to be increased and health of biodiversity puts into danger. Reliance on pesticide and fertilizers more than usual, use of antibiotics in the diets of animals, releasing human waste without special threats and increased use of antimicrobial are among the hazardous scenarios in food security. That is why, even when people pursue healthy diets, their health status is still under harm by the way the food in general is produced (Govindan, 2023). The problem is so deep that the data shows that 78 kg per capita of food is wasted per year around the world, in the scale of 10 kg in South Africa to 189 kg in Nigeria (Hermanussen and Loy, 2024). The history of circular economy in food management reflects a growing awareness of the need to transition away from linear models about production, consumption and wastage. From traditional agricultural practices to modern technological innovations, the circular economy is considered as a vital framework

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for addressing food supply chain challenges such as waste, environmental damages and resource depletion. The importance of food waste reduction is to that much that official international agents are paying attention to its management system. United nations for instance, also have paid attention to food waste reduction in setting Sustainable Development Goals (SDGs). SDGs such as combating world hunger (SDG 2), pursuing sustainable agriculture (SDG 2), ensuring sustainable economic growth (SDG 8), and combating climate degradation (SDG 13) are among the ones, focusing on reducing of food waste (Manzoor et al., 2024). Even International Institute for Standardization (ISO) aimed to set sustainability standards, with a specific focus on a circular economy via its technical committee ISO/TC 323. ISO 59004:2024 includes guidance and principles for implementation of circular economy principles (ISO, 2024). However, Circular Economy (CE) strategies could come fruitful when they offer a vision for a desirable future with a healthy food management function from the ground to the table. CE leads the supply chain to substitute renewable energy sources by the non-renewable energy and minimizes the materials loss through the whole supply chain in each shape by system thinking. CE in food supply chain is a regeneration system seeking to minimize waste by obtaining the highest value out of available resources. It seeks to enhance functions' efficiency of the supply chain in a closed loop to extent product life and reduce waste. CE focuses on sustainable practices to create value by optimized consumption of resources while producing products without sacrificing quality or nutritional value. So, it should be said that while a linear economy uses resources to the maximum level to manufacture products, CE aims to optimize the ecosystem by redesign, reduce, reuse, renew, repair, recycle and retrieve products. These actions not only reduce the usage of raw material and wastes but creates a positive impact in preserving the ecosystem and enhancing social aspects without ignoring the economic aspects (Mhatre et al., 2023). According to the mentioned problems and potential benefits of CE business models, the necessity of transitioning to business models based on CE functions is clear. Albeit, despite the potential advantages of transitioning to a circular economy, there could be several drivers to smooth the steps in this path. Sustainable innovation practices seek integrated changes in not only product design, but also process and marketing approaches in a systematic way focusing on all related processes in supply chain to create sustainable value for different groups of stakeholders (McDowall et al., 2025). To set a roadmap and make the steps of this transition safe with least negative points, scholars of this study are aimed to investigate the sustainable innovative practices that could help in implementation of the CE concept in food supply chain in developing countries. Based on this main objective, the literature would be reviewed in brief in next section. After that, the methodology and research steps are determined to make the path of the study clearer. At last, based on the relationships of these principles, the discussion is mentioned and the final result and suggestions are wrapped up in the conclusion section.

2. Literature Review

2.1 Circular economy in food supply chain management

Although the current food provisioning system is helpful for the economic development of cities while fueling a fast-growing population, the huge cost of such development should be under attention since the linear food production system is a platform for disruption. Scholars have investigated ways to look beyond the current industrial model that refers to "take, make, and use" (Kumar et al., 2023). The concept of a circular economy (CE) in food management has evolved in response to growing concerns over resource depletion, food waste, and environmental sustainability. The idea of closing loops in food systems is deeply rooted in traditional agricultural practices, but the formal integration of CE principles into modern food systems has developed significantly over the last few decades. In pre-industrial societies, food production systems were inherently circular in nature. Early farming methods focused on maintaining soil fertility through crop rotation, composting organic matter, and using animal manure as fertilizer. These practices minimized waste and returned nutrients back to the soil, creating self-sustaining systems (Ghisellini et al., 2016). The Industrial Revolution in the 19th century led to a more linear model of food production. Innovations such as synthetic fertilizers, mechanization, and monoculture farming improved food yields but also created environmental degradation, soil depletion, and significant amounts of waste. The focus shifted from regenerating natural systems to maximizing output, leading to the overuse of natural resources and increased food waste along the supply chain (Kirchherr et al., 2017).The early stages of the modern circular economy emerged in the 1960s and 1970s in response to environmental and resource depletion concerns. Kenneth Boulding (1966) introduced the idea of a "spaceship economy" where resources are finite and must be carefully managed to avoid depletion. This idea laid the groundwork for thinking about resource efficiency and waste minimization in food systems. The concept gained further momentum in the 1980s with the rise of industrial ecology, which promoted closed-loop systems and recycling (Pearce and Turner, 1990). Circular practices became essential for survival, as there were fewer synthetic inputs available (Kneese, 1988). After that, and considering the essence of facing the challenges of waste created in different parts of the supply chain caused by the linear consumption model in which goods are wasted and left in landfills, the concept of CE has been developed and investigated in various studies across different industries, including the food supply chain, to make sustainable development goals attainable. In the late 20th century, growing awareness of environmental issues such as soil erosion, biodiversity loss, and water pollution prompted a re-evaluation of agricultural practices. Sustainable agriculture, which emphasizes ecological health and reducing chemical inputs, gained traction during this period. Practices such as organic farming, agroecology, and regenerative agriculture sought to create closed-loop systems by recycling nutrients and minimizing waste (Gomiero, 2011). These approaches were foundational to the idea of circularity in modern food systems. CE studies explore solutions by which waste can be reintroduced as an input stream for the original product or another product. However, avoiding the formation of waste in the first place is a priority (Payne and Kwofie, 2024). The concept of the circular economy began to explicitly influence food systems in the early 2000s. The European Union and other international organizations promoted the reduction of food waste and the valorization of agricultural by-products as part of broader sustainability goals. This period also saw the development of frameworks like the "food waste hierarchy," which prioritizes waste prevention, food recovery, and recycling (Papargyropoulou et al., 2014). Concepts such as "zero waste" gained popularity, emphasizing the need to rethink how food waste is generated and managed. Food waste became a central focus in discussions of the circular economy in the 2010s. It was estimated that one-third of all food produced globally is wasted, leading to significant economic and environmental losses (FAO, 2019). Circular economy solutions, such as food waste valorization, upcycling, and converting waste into biogas or animal feed, became critical strategies for reducing this waste and creating new value (Mirabella et al., 2014). Innovations in packaging, processing, and storage also contributed to reducing food waste along the supply chain. The application of circular economy modeling extends beyond traditional manufacturing into critical sectors like healthcare, demonstrating its versatility and potential for significant sustainability gains. A compelling example is provided by Shah et al. (2025), who designed a circular economy network for personal protective equipment (PPE) masks in British Columbia, Canada. Their multi-objective optimization model compared the existing linear "take-make-dispose" system with a proposed closed-loop alternative involving disinfection and reprocessing. The results were striking: the CE model not only generated profit compared to the linear model's losses but also drastically reduced carbon emissions and nearly doubled job creation. This case study powerfully illustrates that a well-designed CE network can simultaneously achieve economic, environmental, and social benefits—the triple bottom line of sustainability. For developing countries, this offers a powerful proof-of-concept: even in sectors with stringent hygiene requirements, circular strategies can be designed to enhance resilience, reduce import dependence, and create local employment, moving beyond a narrow focus on waste management to a holistic system redesign. The operationalization of circular economy principles within supply chains has been a recent focus, moving beyond conceptual frameworks to mathematical modeling and strategic analysis. For instance, the design of closed-loop supply chains (CLSCs) is critical for realizing CE goals, as they aim to recapture value from products at the end of their life. Research by Khorshidvand et al. (2023) delves into the pricing and coordination strategies that make such systems viable. Their study on a dual-channel green CLSC demonstrates that incentivized recycling—encouraging consumers to return products through vouchers or discounts—is a powerful tool for enhancing reverse logistics. They find that collaborative strategies and green cost-sharing contracts between supply chain members can significantly improve both profitability and environmental outcomes, outperforming purely decentralized approaches. This highlights that the economic success of CE loops is not automatic but depends on carefully designed incentive structures and inter-firm cooperation, a critical insight for resource-constrained developing countries where such collaboration can pool limited capabilities. A circular economy in the food supply chain relies on natural regeneration systems to prevent the formation of waste as much as possible and create another cycle of feed instead. In a circular economy approach, organic resources such as by-products are not pollutants and should be safely returned to the soil as organic fertilizers. However, some of these by-products could even be used in new food products, the textile industry, or as bioenergy sources. Thus, the circular economy is a systematic solution framework that addresses global challenges such as different types of pollution. It focuses on the elimination of waste and pollution, circulating products and materials at their highest value, and nature regeneration (Bigliardi et al., 2024). In recent years, the circular economy has been increasingly incorporated into food policies around the world. The European Union's Circular Economy Action Plan (European Commission, 2015) promotes sustainable food production systems and waste management practices, emphasizing the need for resource efficiency and closed-loop systems. The Ellen MacArthur Foundation's 2019 report, "Cities and Circular Economy for Food," highlighted the potential for urban food systems to integrate circular principles, including regenerative agriculture, food waste prevention, and nutrient recycling (Ellen MacArthur Foundation, 2019). Procurement of food from sources that are grown regeneratively and local consumption where appropriate could be among the practices that are useful in shifting to a circular supply chain. In a circular economy, food products are meant to be nutritious and should be classified into categories of food and food-related wastes. These are crucial steps in food supply chain management from the perspective of the circular economy and are helpful in reusing what is normally called food waste. Innovations can play a part in eliminating waste. Innovation could also help marketing tools bring healthy products to people's tables on a daily basis. Manufacturers, retailers, and even other stakeholders such as restaurants, schools, and hospitals can direct people's food tastes to support regenerative food systems (Payne et al., 2024).

2.2 ReSOLVE framework in food supply chain management

Creating such a systemic shift is time consuming and needs budgeting. That is why technological innovations are of a significant role in advancing circular food systems. Anaerobic digestion, for instance, converts organic waste into biogas and digestate, which can be used as renewable energy and fertilizer, respectively (Paritosh et al., 2017). Additionally, precision agriculture and blockchain technology have contributed to optimizing resource use, reducing waste, and improving traceability across food supply chains (Kamilaris et al., 2019). As such, it should be mentioned that sustainable innovative practices could make taking steps in this path much easier, while considering ReSOLVE framework (Payne and Kwofie, 2024). The ReSOLVE framework is developed by the Ellen MacArthur Foundation. It was introduced in their 2015 report titled "Growth Within: A Circular Economy Vision for a Competitive Europe." The framework is shaped to provide a strategic approach for businesses and policymakers to transition to a circular economy. ReSOLVE framework takes the basic principles of circularity and append them to the six main actions called Regenerate, Share, Optimize, Loop, Virtualize, and Exchange. Each action represents a core circular business opportunity to modify supply chain to promote the CE. Each element outlines strategies for minimizing waste, improving resource efficiency, and fostering sustainable growth. The framework is widely used by organizations seeking to design and implement circular economy initiatives. Regenerate is the first set of activities mentioned in the ReSOLVE framework, referring to the deployment of new efficient systems to amend the biological resources and shaping a productive chain to enhance earth's biocapacity. For a long time, the focus was on food sustainability which is related to not taking more from the planet than is being put back. However, the impact of climate change, health inequalities and loss of biodiversity created the insight that more ambitious goals are needed. Regenerative practices seek for net positive effects rather than just standing behind by restoring the intertwined food ecosystem. A regenerative food management system would be effective in improving the soil and biodiversity at the start of the food supply chain while improving livelihoods at downstream supply chain. Each of the stages through the supply chain also need to be regenerative too. It is essential to create new smarter ways to produce more nourished food with less consumption of ingredients and energy. Knowing that there will be no healthy foods without a healthy environment, producing food while considering nature preservation and pursing thriving communities is essential. Taking use of frontier technologies in Industry 5.0 such as digital twins, blockchain and Internet Of Things (IOT) to help transition from fossil fuels to renewable energy or giving biological resources back to the nature are among of these kinds of activities. Turning into agroforestry model could also be fruitful in changing the productive system. All of such practices could help in transitioning to CE practices and will allow producers to increase food supplies while creating sustainable returns for everyone (Möller et al., 2025). Share as the second set of activities of the ReSOLVE framework is related to implementation of platforms to make shared consumption of products and services possible. In this way, management of food loss would be easier since people could get a chance to provide their food surplus after party or any other situation to the people in need. Sustainable contribution of shared practices would be obvious based on previous studies in different parts of the supply chain from farmers and stakeholders to the last consumer in the food supply chain (Bloise, 2020). Enhancement of processes of the supply chain to make them optimized regarding use of energy, time, resources, reducing waste production are among the next set of ReSOLVE framework named optimized. As system thinking such as lean concept says, there should be no activity without value adding in the supply chain. Modern technologies such as Internet of Things (IOT) platforms could come handy in management of the food chain while improving food safety (Gonçalves and Maximo, 2024). However, recycling the outputs of a production system are among the next set of activities in the framework called Loop. Development of methods to produce new products out of food residues are under consideration in this section. These valued products can be used in the same productive chain, which is called as closed-loop, or even be used in other productive chains, as is called open-loop in CE approach (Juntupally et al., 2023). Virtualize as the fifth set of activities in food management systems aims to support the implementation of CE principles by focusing on efficiency, transparency, and process optimization in the whole supply chain. These practices leverage digital tools and technologies to virtually manage, monitor, and optimize various processes, reducing waste and promoting the reuse or recycling of resources. Virtualize is based on the concept of virtual platforms to reduce production costs by exchanging old equipment with suboptimal functionalities. The use of artificial intelligence, IOT sensors or GIS (Geographic Information Systems) technologies could help different parts of the supply chain to reduce food wastes by getting the food status under attention in each step of the supply chain (Yaiprasert and Hidayanto, 2023). At last, Exchange as the final category describes the processes of getting new technologies into processes to update ways of doing things. Exchange practices in food management systems seek to implement circular economy principles by focusing on the redistribution, sharing, and repurposing of food resources to maximize their value and minimize waste. These practices encourage collaboration across different sectors of the food supply chain, promoting the efficient use of surplus resources while reducing environmental impact. Exchange practices are integral to the circular economy because they ensure that food and related by-products remain in use for the maximum possible period, preventing them from becoming waste. (Gonçalves and Maximo, 2024).

2.3 Sustainable innovation practices to facilitate CE implementation in food supply chain

Sustainable development goal (SDG) 12.3 is focused on reducing food waste to half at downstream supply chain of retailer and consumer level and also minimizing the losses through food supply chains by 2030 (Iqbal and Kang, 2024). By embedding sustainability intention into innovation, companies can create products, services, and processes that are good for environment, society and also the organization in the long term while diminishing risk factors. By doing so, there would be resources to enhance resilience, and increase sustainability (Mohamed and

Islami, 2024). Sustainable innovation involves creating intentional changes to products, services, and processes through the whole supply chain to generate long-term social and environmental benefits while maintaining economic profits for the supply chain. Sustainable innovation practices in food supply chain management are essential for ensuring that the production, distribution, and consumption of food are environmentally friendly, socially and economically responsible. These practices aim to reduce the negative impacts of food supply chains on the environment, improve social equity, and enhance the efficiency and profitability of the food industry (Adam et al., 2016). Despite it seems great to follow sustainability principles in making innovations, achieving it absorb time, commitment, effort and creativity to build a system. Sustainable innovation can be shaped in three main categories of operational optimization, organizational transformation, and systems building. Enhancement of operational processes efficiency does not help business model to be totally changed. Of course, decision makers should find ways to do the same functions in a way which leads to less harm to the environment and society. Reducing secondary packages or use of renewable energies could come beneficial in this regard. Such approach which is called eco-efficiency can be pursued by adding environmental and social Key Performance Indicators (KPI) to the current set of organizational criteria. Companies can also create disruptive new products and services that fulfill societal needs and are not harmful to the environment. Supply chains with such approach consider sustainability as a business opportunity by focusing on new ways of doing things such as modular design of products. However, when companies come to this stage that understand sustainable innovation involves collaborating with other shareholders or even less related parties, an ecosystem is created to implement sustainable innovations. Here's a detailed overview of key practices:

1. Sustainable sourcing aims to do the procurement of raw materials by considering sources that are environmentally responsible, socially equitable, and also economical (Carter and Rogers, 2008). It could be accomplished by considering following sub-practices:
   - Organic Farming which is about avoiding the use of artificial chemicals of different pesticides or fertilizers. Instead, it focuses on nature related capabilities, such as compost and biological pest control. This approach minimizes soil and water degradation and also helps reduction of the carbon footprint because there would be no need to produce and transport the synthetic inputs anymore (Gomiero et al., 2011).
   - Fair Trade penetrates into the market to ensure that farmers and workers, especially in developing countries, are under suitable working conditions and are of decent job wages. This practice supports local economies, reduces poverty, and follow environmentally friendly farming practices, such as sustainable land management (Smith, 2010).
   - Biodiversity Preservation involves keeping a variety of species within the agricultural ecosystem. Diverse ecosystems are more resilient to diseases, and climate change. For instance, agroforestry integrates lives of trees with crops to support biodiversity while also creating additional revenue streams for farmers (Jose, 2009).
2. Resource Efficiency focuses on reducing the use of water, energy, and raw materials in production processes through the entire supply chain (Shen et al., 2013).
   - Water Management approches such as drip irrigation, which delivers water to the roots of plants, help reduce evaporation and runoff. Rainwater harvesting systems collect and store rainwater to reduce reliance on freshwater sources. Wastewater recycling involves treating and reusing water from processing plants, minimizing water consumption (Hoekstra and Chapagain, 2007).
   - Energy Efficiency in food supply chains includes transitioning to renewable energy sources like solar, wind, or biomass, which reduces the carbon footprint. Improving energy efficiency in machinery and facilities through better insulation, energy-efficient motors, and LED lighting also lowers operational costs and environmental impact (Mouron, Nemecek, Scholz, and Weber, 2006).
   - Waste Reduction can be achieved by optimizing supply chain logistics to reduce food spoilage during transportation. Implementing better storage practices, like temperature-controlled environments, also reduces waste. Furthermore, valorizing by-products, such as using fruit peels for animal feed or compost, enhances circularity (Parfitt, Barthel, and Macnaughton, 2010).
3. Sustainable Packaging is about developing packaging solutions that minimize negative environmental impact throughout the life cycle (Vanderroost et al., 2014).
   - Biodegradable Packaging options, like plant-based plastics, paper, and cardboard, decomposed naturally in the environment. This reduces the plastic waste pollution. Some companies are aimed to develop packaging items from banana leaves or mushroom roots, which decomposes even faster (Siracusa, Rocculi, Romani, and Dalla Rosa, 2008).
   - Recyclable Materials: Packaging that is easily recycled improves sustainability. Single-material packaging that uses only cardboard or PET plastic for instance, facilitates reuse (Hopewell, Dvorak, and Kosior, 2009).
   - Lightweight Packaging: Reducing the weight of packaging items decrease transportation costs and emissions as a result. Lightweight materials need less energy to produce or transport, leading to lower carbon footprints (Jamal et al., 2025).
   - Looping practices involve moving away from a linear economy to a circular economy where resources are reused and recycled (Ghisellini et al., 2016).

- Food Waste Upcycling: Converting food that would otherwise be wasted into new products is a value-added initiative. For instance, fruit pulp leftover from juice production can be used into snacks products, or left grain from brewing can be used in baking (Mirabella, Castellani, and Sala, 2014).
- Closed-Loop Supply Chains: In a closed-loop supply chain, products are designed to be easily recycled, re-used, or remanufactured. For instance, packaging can be produced in a way to be capable of reuse (Guide and Van Wassenhove, 2009).
- Reverse Logistics is about directing the returns from consumers to the manufacturers for recycling other suitable treatments, which is fundamentals for packaging that are challenging to recycle at the consumer level (Govindan, Soleimani, and Kannan, 2015).

4. Sustainable Logistics optimizes the transportation and distribution of food products to minimize carbon footprints and improve efficiency (McKinnon, 2008).
   - Route Optimization: Advanced logistics software uses algorithms to determine the most efficient delivery routes, reducing fuel consumption and emissions (Govindan, Palaniappan, Zhu, and Kannan, 2012).
   - Eco-Friendly Transportation: Alternative fuels, such as biodiesel or use of hybrid vehicle contribute to lower carbon footprints (Ajanovic and Haas, 2010).
   - Local Sourcing reduces the distance food should take to get from farm to the table and significantly decrease transportation emissions. It also supports local economies and provides fresher products for consumers (Kneafsey et al., 2013).
5. Traceability and Transparency seeks to provide all stakeholders with the access to data about the origin, journey, and impact of food products (Bosona and Gebresenbet, 2013).
   - Blockchain Technology: Blockchain creates a transparent and on-time record of every transaction in the supply chain. This enhances traceability, allowing stakeholders to verify the origin of products and ensure that sustainable practices are under attention (Kamilaris et al., 2019).
   - Certification and Labeling: Certifications like Organic, Fair Trade, and Rainforest Alliance assure that products meet essential sustainability standards. Labels are useful in making informed choices by consumers (Jones et al., 2024).
   - Consumer Education: Informing consumers about the sustainability status of products through clear labeling and marketing tools make them capable to have choices that is in the same direction with their system of value (Tobler et al., 2011).
6. Social and Ethical Practices support fair hire of human resources, community engagement, and improving quality of life (Barrientos, 2013).
   - Fair Labor principles provide decent wages and safe conditions for people in the supply chain. This contains opportunities for training and development (Barrientos, 2013).
   - Community Development: Investing in the culture and skills of people in the communities where food is grown or produced ensures long-term sustainability and make the supply chains robust (Kaplinsky, 2000).
   - Gender Equality: Promoting gender equality help women to have equal opportunities in the supply chain, which leads to more diverse visions and drives innovation (Coleman, 2010).
7. Innovation in Farming Techniques point to precision agriculture, vertical farming, and agroecology (Tilman et al., 2011).
   - Precision Agriculture uses technology to optimize farming practices based on real and on-time data to reduce waste and environmental impact while increasing crop yields (Gebbers and Adamchuk, 2010).
   - Vertical Farming involves plant cultivation in vertically layers, often in controlled indoor environments. This method minimizes land and water use while allowing year-round production (Banerjee and Adenaeuer, 2014).
   - Agroecology uses ecological principles to farming to promote biodiversity, natural pest control, and soil improvement (Altieri, 2019).
8. Sustainable Animal Husbandry controls animal lives in ways that minimize environmental impact while enhancing their welfare (Mottet et al., 2017).
   - Rotational Grazing enhances soil health and biodiversity, while decreasing carbon in the soil and copying natural grazing patterns (Teague et al., 2013).
   - Feed Efficiency involves developing styles of diets that maximize nutritional uptake while minimizing environmental impact (Ertl et al., 2015).
   - Animal Welfare Standards ensure that livestock has access to enough space, suitable water, and food, promoting natural behaviors, decreasing antibiotic use, and improving product quality (Fraser, 2008).
9. Collaboration and Partnerships are essential for obtaining sustainability goals (Winn and Pogutz, 2013).
   - Public-Private Partnerships enhances resources and expertise to cultivate innovation and implement large-scale projects, such as developing sustainable agricultural technologies (Hall, 2006).
   - Research and Development is fundamental for creating new sustainable practices and technologies (Goldman et al., 1995).
   - Cross-Industry Collaboration shapes innovative solutions that would be difficult to achieve in other ways or without crowd wisdom (Huxham, 2003).

These practices represent a holistic approach to sustainability in the food supply chain, aiming to balance economic growth with environmental stewardship and social responsibility. Implementing these strategies can help create a more resilient and sustainable food system for the future.

3.Methodology

Considering the essence of transition to the CE business models in food supply chain at minimum possible time frame with minimum resource consumption, scholars of this study are aimed to investigate the sustainable innovative practices that could help in implementation of the CE concept food supply chain in developing countries. Based on this main objective, the literature is reviewed. After that, innovative practices that are determined based on previous studies are provided to the experts to get finalized considering the special status of developing countries. Some of the sustainable innovation practices that could enhance CE capabilities in food supply chain management are categorized by ReSOLVE framework principles and depicted in Table 1, supported by related previous studies.

Table 1. Sustainable innovation practices to imbed CE in food supply chain management

ReSOLVE set of action	Principle	Practice	References
Regenerate	Agroecology	• Input reduction. Decrease of dependency on purchased items from other areas and increase capabilities to become self-sufficient. • Soil health. Secure soil health and functionality to improve plant growth condition by managing organic items and improving soil biological functions. • Animal health. Improvement of conditions allowing the highest productivity to ensure sustainable development and livestock production. Healthy animals are among the causes to help people and environment to become healthy. • Biodiversity. Increase variety of species. Shaping functional diversity and resources of genetics and maintaining overall agroecosystem biodiversity should be under attention at whole. • Synergy. Create synergistic ecological mutual relations and complementarity interactions amongst the animals, plants, soil and water as agroecosystems elements. • Economic diversification. Ensuring that local and farmers have relational financial relationships to shape value added opportunities while make them capable to respond to consumers' demands. • Co-creation of knowledge. Improve co-creation and horizontal share of knowledge by aid of scientific innovation based on experience of local people and focusing on exchanges among farmers. • Social values and diets. Shape food production systems considering the culture, traditions, gender equity of local communities that create nutritious diets based on diversified and seasonally ingredients. This system helps healthy, nutritious and cheaper foods that are also culturally appropriate to be on hand of everyone. • Fairness. Patronage of decent and robust lives for all the stakeholders of the food supply chain, especially small sized food producers, considering fair trade, fair employment situation for all and fair dealing with intellectual property rights. • Connectivity. Enhance trust between producers and consumers through improvement of effective networks. Re-embedding food systems into local economies should be considered. • Land and natural resource governance. Strengthen institutional dealings to improve natural and genetic resources, by attraction support of family farmers, small-scaled businesses and peasants who knows the local capabilities and ecosystem better. • Participation. Support social and non-governmental organisations for more involvement in decision-making by aid of food producers and consumers to encourage local adaptive governance system.	(Wezel et al., 2020; Singh and Singh, 2023; Gonçalves and Maximo, 2023; Floret et al, 2023; Sobczak Bhattacharya, 2024; Mouratiadou et al., 2024)
	Conservation agriculture	• Minimum tillage and soil disturbance. Direct planting to grow crops with minimum soil disturbance since the harvest of the previous crop. • Crop rotations and associations. Alternation of different crops by fields and by years. The alternation of cereals such as maize and wheat followed by legumes for example, beans could be an example. • Permanent soil cover. Soil cover by mulch as an organic material such as decaying leaves, bark, or compost to spread over the soil and around a crop to enrich and insulate the soil.	(Hiloidhari et al., 2023; Nunes et al., 2023; Gonçalves and Maximo, 2023; Hmouda et al., 2024)
	Agroforestry	• Determination of suitable agroforestry products. Determine what can grow on the land and could be sold profitably. This choice should support habitants, photosynthesis system, and biodiversity. • Develop business and marketing strategies. Plan how to market and sell the agroforestry products effectively by considering aesthetic issues, spiritualities, recreations and education enhancement. • Design for synergy. Ensure that the components of the agroforestry system work together in a complementary way to provision water, food, medicine and raw materials.	(Lehmann et al., 2020; Ntawuruhunga et al., 2023; Kumar et al., 2023; Buratti-Donham, et al., 2023; Caicedo-Vargas et al., 2023)

ReSOLVE set of action	Principle	Practice	References
	Integrated Ocean Management	• Ecosystem-based management. Shielding of ecosystem structure and key processes to shape interconnectivity within the system considering air, land, and sea. By use of 3D Methods to produce a mixture of shellfish and seaweeds in a nature-positive way and boost marine biodiversity. • Marketization. The marketization of resource sharing out and enhancement of resource utilization efficiency; External issues of public resources; Stakeholder participation and active social economy. • Space considerations. Social, economic, and environmental values should be integrated into spatial planning approach to deal with interrelationships across domains to do zoning of marine and coastal function, ecological protection area planning, port and waterway planning, and coastal city planning. Well-managed engagement approaches that take into account of the local body of values, scientific, economic and political domains to obtain local stakeholder involvement and indigenous knowledge should be followed. • Good governance. Transparent function system and accountable decision-making process with the cooperation of institutions to enhance integrity and flexibility, executive guarantee, and information and knowledge management to integrate governance system. • Blue economy risks management. Avoidance of ocean/blue economy risks such as illegal, unreported and unregulated fishing and marine pollution through integrated approaches to effective local cooperation on maritime securement. • Research and innovation. Knowledge of the marine system management by dependency on technology-based economy, creative business solutions; and high value products should be pursued.	(Winther et al., 2020; Lohano, and Maqbool, 2022; Xue et al., 2023; Kong et al., 2024; CCICED, 2023; Yu et al., 2023)
Share	Shared hard technologies	• Shared manufacturing ecosystem. Use of shared modern manufacturing facilities with key-enabled technologies to provide rental, sharing, leasing and concession services among manufacturers with similar needs is an innovative way to increase productivity. • Development of platforms to make food donation/sharing possible. Food waste management could be enhanced by application of shared practices. The platform shapes different kinds of supply chain such as B2C, C2C and B2V2C (Business to Volunteer to Consumer) Too Good To Go (TGTG) platform, for instance, is estimated to reduce about 3% of the total food waste in Italy by 2060. However, marketing strategies to enhance social acceptance of such platforms and efficiency of the functionalities should be under attention.	(Jiang, and Li, 2020; Puntillo, 2022; Tedesco et al., 2022; Tsolakis et al., 2023; Gonçalves and Maximo, 2023’ Tsolakis et al., 2023; Ranjbari et al., 2024)
	Shared soft technologies	• Transparency and sharing of results. Focus should be on transparency and blue-print plans as the first step to social and environmental commitment. Results of circular approaches should be shared with stakeholders to shape trust through the society by the companies’ functions and also make knowledge sharing possible. • Community Supported Agriculture (CSA). Encourage local communities to share the risks and rewards of farming by buying shares of a farm's harvest, reducing food miles and minimizing waste. • Food Donation Programs. Establish systems to share surplus food with those in need, minimizing waste and improving food security.	(Lei et al., 2021; Degieter et al., 2022; André, 2024)
Optimize	Process Optimization	• Precision Agriculture. Use advanced technology like drones, sensors, and AI to optimize resource use in farming, leading to higher yields and lower resource consumption. • Optimizing the food processes. Optimize processes of the supply chain to use the least possible energy and water use through the whole supply chain. • Efficient Supply Chain Management. Implement better forecasting, inventory management, and logistics to reduce food waste across the supply chain by aligning supply with demand. • Increase traceability. Decrease food losses by embedding technology achievements into processes. • Continuous improvement. Innovative and exnovative practices via updated technological approach in research and development and Life cycle analysis tools such as a life cycle assessment and life cycle cost analysis to assess the environmental and economic performance are of high importance in agri-food sustainability. Extends life of products with packaging designs and dynamic labelling could be among approaches that help product functionality, user behaviour analysis, displacement, and rebound effects.	(Tedesco et al., 2022; Gonçalves and Maximo, 2023; Hmouda et al., 2024; García-Valderrama et al., 2024)
	Value Optimization	• Cultural value optimization. Enhance social values to make people refuses to buy and sell products with hazardous components. • Circular business models to combine multi-dimensional value system. Deployment of innovative business models in company of governance frameworks to make possible to consider social and environmental costs ingredients into products’ prices while rewarding circular practices should be under attention to optimise of resource values. • Whole system assessment to optimize value. Take a whole system approach to understand challenges and the potential of proposed solutions in a precautionary manner, and optimise material use within the value framework for a sustainable circular economy through a process of continuous improvement guided by whole system assessments using holistic indicators before, during and after the implementation of circular economy practices. • Campaigns on conscious consumption to explain the value. Encouraging different stakeholders to reduce consumption and use green and eco-friendly products is important. People should refuse products or services that are not consistent with environmental legislation system.	(Velenturf and Purnell, 2021; Yin et al., 2023; Opstal et al., 2024; Gonella et al., 2024)

ReSOLVE set of action	Principle	Practice	References
Loop	Biological loops	• Composting. Microbial breakdown of organic items in the presence of oxygen to turn biodegradable by-products into compost. This helps as a soil reinforcement object. The process is biological and returns natural microorganisms such as bacteria and fungi to the land. • Anaerobic digestion. Series of biological processes to breakdown microorganisms into biodegradable intem in the absence of oxygen. The products of this process are biogas, liquid digestate, and solid digestate.	(Tedesco et al., 2022; Jansen et al., 2022; Mir-Cerdà et al., 2023; Bhattacharya, 2024; He et al., 2024)
	Technical loops	• Reuse by valorisation of By-products. Convert food by-products into valuable secondary products, such as using fruit peels for animal feed, brewing waste for bioenergy, or spent grains for baking. • Packaging Circularity. Use recyclable, reusable, or compostable packaging materials to ensure packaging waste is looped back into the production cycle. • Recondition/Remanufacture. Product as service for restaurants and other similar institutes which have regular food consumption. This would help in collecting food residual and is useful in making new foods from upcycled foods. Food formulation using artificial intelligence to make optimized nutrition by least cost is also worthful of attention. • Recycle. Imbedding recycling practices of materials into supply chain functions. For instance, use of technologies to imbed returnable packaging system into supply chain management. Design products for reuse and recycling while full use of regional renewable resources and closed-loops resource cycles of nutrients and biomass are possible as far as possible.	(Kamal et al., 2021; Gupta et al., 2023; Juntupally et al., 2023; García-Valderrama et al., 2024; Jamal et al., 2025)
	Information loop	• Reduce waste and increase effectiveness within existing business and industries. Stimulates consumption of reused products and making the most of food to manage leftover food waste generation (LFWG) behaviour. • Identify new solutions to existing problems/opportunities. Encourages reduction food waste by considering socio-demographic influences. Food scientists and technologists are accountable for developing new food products and enhancing current ones. • Identify future trends and business opportunities. Considering reusable and/or recycled inputs based on consumer demand for plant-based products. Higher commitment to clean food choice and sustainability while maintaining food safety and quality assurance is also another trend which should be under attention.	(Aloysius et al., 2023’ Gonçalves and Maximo, 2023; Setiawati Et al., 2024; McDowall et al., 2025)
Virtualise	Digital Transformation	• Digital Platforms for Food Sharing. Develop apps and platforms that connect individuals and businesses with surplus food to those who need it, helping reduce food waste. • Online Retail and Direct-to-Consumer Models. Use e-commerce to reduce the need for physical retail spaces and intermediaries, which can reduce food waste. • Remote Monitoring and Smart Farming. Utilize IoT devices and data analytics to monitor crop health, soil conditions, and weather patterns remotely, improving yields and reducing waste. • Digital advertising. Use advertising and digital marketing campaigns to attract special customers while holding negative environmental and economic costs low. • Digital twins. A digital twin can replicate an entire food production facility, from processing plants to packaging lines. This virtual model allows operators to monitor and adjust production in real-time, simulating different scenarios to optimize resource use, reduce energy consumption, and minimize waste. By enabling constant improvements in efficiency, the digital twin helps ensure that resources such as water, energy, and raw materials are used more sustainably, aligning with circular economy principles.	(Tedesco et al., 2022; Karimi Alavijeh, N., and Salehnia, 2023; Gonçalves and Maximo, 2023; Yaiprasert and Hidayanto; 2023; Bastos et al., 2024; Möller et al., 2025)
Exchange	Resource Exchange or Collaboration	• Exchange of non-renewable items. Exchange of non-renewable feedstock by renewable and more sustainable chemicals. Also, Exchange of non-renewable energy sources by renewable sources in food processes. • Development of extrusion-based 3D-printing in both formulation and process design. To create food in various shapes and designs with least waste and more sustainable packaging. • Plant-Based and Alternative Proteins. Replace traditional animal-based proteins with plant-based or lab-grown alternatives to reduce the environmental impact of farming. • Biodegradable and Edible Packaging. Develop innovative packaging solutions made from biodegradable materials or edible substances to reduce packaging waste. • Advanced Food Preservation Techniques. Use new preservation methods, such as high-pressure processing or freeze-drying, to extend the shelf life of food products and reduce spoilage and waste.	(Nachal et al., 2019; Tedesco et al., 2022; Tsolakis et al., 2023; García-Valderrama et al., 2024; Mperejekumana et al., 2024)

Based on experts’ opinions, some practices, such as Agroforestry, Shared Hard Technologies, and Plant-Based Proteins, naturally span multiple categories. These cross-functional practices highlight the interdependencies within a circular economy. So, in general, it is clear that the separation of functions in this way is not certain, and according to the country situation and time conditions, the classification can be changed depending on the importance. Agroforestry for instance belongs in Regenerate, but could also fall under Loop as agroforestry involves resource cycling and maintaining ecosystem services. Although, Shared Hard Technologies fits well within Share, focusing on shared manufacturing ecosystems and platforms could also extend into Virtualize, as many of these shared platforms use digital technology to enable sharing. Shared Soft Technologies also align with Share, but can also relate to Virtualize through transparency, data sharing, and knowledge platforms that enable community-supported agriculture and food donation programs. On the other hand, although Value Optimization strongly fits Optimize, especially where cultural value and circular business models are developed to internalize social and environmental costs, could also overlap with Exchange, as circular business models often involve resource sharing and collaboration across systems. Digital Twins could also be seen in Loop as they allow monitoring of resource cycles and performance optimization, but their primary role is in Virtualize. Plant-Based and Alternative Proteins, though categorized in Exchange, it also ties to Regenerate, as alternative proteins reduce the environmental impact of traditional livestock farming, promoting regenerative agriculture and sustainable ecosystems. By observing the opinions of the experts about the categories of practices, it becomes clear that Virtualize and Exchange categories, in particular, have overlapping areas with Optimize and Loop, as digital technologies and resource-sharing platforms are core enablers of efficiency and closed-loop systems. Albeit, Regenerate and Loop tend to focus on biological and technical cycles but can be closely linked through ecosystem management practices like agroecology and ocean management. However, the relationships and also weights of these principles should be determined by Pythagorean Fuzzy DEMATEL technique to see the uncertainty in the opinions of the experts too.

Pythagorean Fuzzy DEMATEL

Subsequently, by applying the Pythagorean Fuzzy DEMATEL technique and soliciting experts' opinions, their relationships were determined. The Pythagorean Fuzzy DEMATEL technique is an advanced decision-making tool that integrates the strengths of Pythagorean fuzzy sets and the DEMATEL method. This approach is particularly useful in situations where decision-making involves complex interrelationships between factors and high levels of uncertainty or vagueness. The foundation of Pythagorean fuzzy sets (PFS) was introduced by Yager in 2013 as an extension of Intuitionistic Fuzzy Sets (IFS). A PF set P on X is expressed by Equation 1.

$$P = \left\{\left(x, \mu_P(x),\ v_P(x)\right) \intercal\ x \in X\right\} \tag{1}$$

PFS expands the membership and non-membership relationships in a fuzzy set by allowing the sum of the squares of the membership (μ) and non-membership (v) degrees where they each should be less than 1 and also fulfill the equation 2.

$$0 \leq \mu^2 + v^2 \leq 1 \tag{2}$$

Where:

- μ is the membership degree of an element.
- v is the non-membership degree of the element.

This equation allows for more flexibility than traditional fuzzy sets or intuitionistic fuzzy sets. Also, Yager and Abbasov (2013) pointed to the hesitation margin (π) to define the uncertainty remaining after determining μ and v which is given by equation 3.

$$\pi = \sqrt{(1 - \mu^2 - v^2)} \tag{3}$$

So, $\alpha = (\mu_\alpha, v_\alpha)$ is called as a PF number and $\pi = \sqrt{(1 - {\mu_\alpha}^2 - {v_\alpha}^2)}$ shows hesitancy degree. This parameter allows decision-makers to express hesitancy, making PFS a more flexible approach to uncertainty. This additional flexibility compared to IFS allows for a wider and more expressive range of uncertainty handling, making PFS particularly useful in situations where the uncertainty is more complex. Pythagorean fuzzy sets allow decision-makers to express their opinions with more flexibility, especially in cases of higher uncertainty. This makes them a suitable candidate for integrating into the DEMATEL methodology to analyze interrelationships among criteria in decision-making problems under uncertainty. Incorporating Pythagorean fuzzy sets into DEMATEL enhances the ability of the method to handle vagueness and uncertainty in human judgment, which is noticeable in real-world decision-making scenarios. PF-DEMATEL is particularly beneficial in decision environments where expert evaluations involve significant uncertainty, ambiguity, or hesitation. The DEMATEL method is used to establish cause-and-effect relationships between factors by analyzing the influence of each factor on the others. The basic steps of the DEMATEL method involve creating an initial direct-relation matrix, normalizing it, and calculating the total influence matrix (Giri et al., 2022). A total of 23 people who must have two characteristics (first, be familiar with the subject and second, have work experience) were selected as targeted non-probability sampling. All the experts are working in the industry, whose operational definition can be seen in Table 2.

Table 2. Operational definition of experts in the present study

Row	Specification	Characteristics	Number	Relative frequency %
1	Gender	Male	16	68%
		Femail	7	32%
2	Degrees	Bachelor	4	21%
		Master	13	56%
		PhD	6	23%
3	Years of experience in the food industry	5-10	6	25%
		10-15	15	67%
		15<	2	8%

Direct Influence Matrix (A): The experts provide pairwise comparisons between the criteria to create the direct influence matrix A, where each element a_ij represents the influence of criterion i on criterion j. Experts of this study are asked to provide their opinions based on linguistics influence variable and relative PFNs depicted in Table 3 as mentioned in study of Niu et al., 2024.

Table 3. Linguistic influence variables and relative PFNs

Influence level	Abbreviation	PFNs
Very low	VLI	(0, 0)
Low	LI	(0.1, 0.9)
Medium low	MLI	(0.2, 0.8)
Medium	MI	(0.4, 0.6)
Medium high	MHI	(0.5, 0.5)
High	HI	(0.7,0.5)
Very High	VHI	(0.9,0.1)

The matrix A is represented as:

$$\tilde{A}^{(\varphi)} = \left(\widetilde{a_{\iota\jmath}}^{(\varphi)}\right)_{m*n} = \begin{array}{cc} & \begin{array}{ccc} C_1 & \dots & C_n \end{array} \\ \begin{array}{c} A_1 \\ \vdots \\ A_n \end{array} & \begin{pmatrix} \widetilde{a_{11}}^{(\varphi)} & \widetilde{a_{11}}^{(\varphi)} & \widetilde{a_{11}}^{(\varphi)} \\ \vdots & \ddots & \vdots \\ \widetilde{a_{m1}}^{(\varphi)} & \widetilde{a_{m2}}^{(\varphi)} & \widetilde{a_{mn}}^{(\varphi)} \end{pmatrix} \end{array} \tag{4}$$

Where $\widetilde{a_{\iota\jmath}}^{(\varphi)} = \left(\widetilde{\mu_{\iota\jmath}}^{(\varphi)}, \widetilde{v_{\iota\jmath}}^{(\varphi)}\right)$ shows the opinion of expert E φ about the influence of criterion AI on criterion Cj. To do aggregation of experts' opinions, equation 5 should be under attention.

$$\left(\sqrt{1 - \prod_{j=1}^{n}\left(1 - \left(\mu_{a_{ij}}\right)^2\right)^{1/n}}, \prod_{j=1}^{n}\left(v_{a_{ij}}\right)^{1/n}\right) \tag{5}$$

Normalized matrix: In the second step, the matrix is normalized to ensure that all elements are between 0 and 1. To do normalization, knowledge matrix should be obtained using equation 6.

$$KM = 1 - O.5 * \left(\frac{1-|\mu^2-v^2|}{1+|\mu^2-v^2|} + (\pi)^2\right) \tag{6}$$

π is the hesitancy degree as determined by equation 3. Normalized matrix is calculated using the equation 7. ReSOLVE actions to be considered for instance, π would be as Table 4 in this study.

Table 4. π values of the ReSOLVE actions

	Regenerate	Share	Optimize	Loop	Virtualize	Exchange
Regenerate	0.095	0.896	0.095	0.095	0.095	0.095
Share	0.497	0.095	0.367	0.500	0.490	0.400
ptimize	0.548	0.896	0.943	0.638	0.247	0.247
Loop	0.216	0.095	0.155	0.095	0.095	0.095
Virtualize	0.500	0.490	0.490	0.497	0.095	0.406
Exchange	0.500	0.500	0.510	0.497	0.490	0.095

$$N = \frac{KM_{ij}}{max_{1\le i\le m}\left\{\sum_{j=1}^{n} KM_{ij}\right\}} \tag{7}$$

Total relationship matrix: This matrix is determined by equation 8 as below where I is an identity matrix. Also, total relationship matrix of ReSOLVE actions is shown in Table 5 and Ri m Cj are determined.

$$T = \left(t_{ij}\right)_{n*n} = N * (I - N)^{-1} \tag{8}$$

Now, relationships among the set of criteria could be determined by considering Rj and Cj .

Rj = sum(T, row-wise)
Cj = sum(T, column-wise)

Table 5. Total Relationship Matrix of the ReSOLVE actions

	Regenerate	Share	Optimize	Loop	Virtualize	Exchange	R
Regenerate	0.05	0.66	0.39	0.10	0.45	0.59	2.25
Share	0.31	(0.84)	(0.24)	0.34	0.62	0.83	1.02
Optimize	0.37	0.03	(0.04)	0.31	0.34	0.46	1.47
Loop	0.15	0.49	0.39	0.09	0.41	0.54	2.08
Virtualize	0.08	0.59	0.41	0.13	(0.99)	0.49	0.72
Exchange	0.08	0.59	0.41	0.11	0.53	(0.98)	0.74
C	1.04	1.53	1.33	1.09	1.36	1.93	

The difference (R - C) indicates the net influence of a criterion, while (R + C) shows the prominence or importance of the criterion in the system. Subjective weight of each criterion could also be determined by application of equation 9.

$$w_j^{subjective} = \frac{R_j+C_j}{\sum_{j=1}^{n}(R_j+C_j)} \tag{9}$$

So, weights of the ReSOLVE actions to implement efficient circular economy concept in food supply chain in developing countries would be as is shown in Table 6.

Table 6. Weights of ReSOLVE actions

	R-C	R+C	W
Regenerate	1.16	3.31	20%
Loop	0.95	3.20	19%
Optimize	0.06	2.86	17%
Share	(0.57)	2.59	16%
Virtualize	(0.80)	2.24	14%
Exchange	(0.79)	2.27	14%

With the same approach, practices of the set of actions could also be determined. Their related detailed way of calculation is not considered here to come to the reader short. However, their weights based on their effectiveness in making food supply chain circular in developing countries and in their own category of ReSOLVE set of action are discussed in the next section.

4. Discussion

As is observed by weights showed in Table 5, Regenerate could get the highest priority in helping food supply chain to become circular in developing countries and is putting effects on the other set of actions more than receiving effect. It could be said that Regeneration is foundational for long-term sustainability in developing countries, where people are often heavily relied upon natural resources for living. Without regenerating ecosystems, other circular economy practices would not be totally effective due to degraded environments. Agroecology, Conservation Agriculture, Agroforestry, Integrated Ocean Management as the practices of Regeneration, focus on retrieval of natural ecosystem, improving resilient biodiversity against climate change or land degradation. In developing countries, these practices fully impact food security, soil fertility, and ecosystem status as a whole, which are crucial for rural communities dependent on agriculture and fishing. Increased agricultural productivity and resilience, improved food security and poverty reduction would be on hand as such (Mouratiadou et al., 2024). With the same approach, weights of practices of the Regenerate could also be determined. Based on experts' opinions, Agroecology gets the highest priority (equal to 40%) among the practices of Regeneration. Agroecology shapes an integrated systematic approach to optimizes resource consumption and also regenerates ecosystems. Its capability to integrate biodiversity system while improving soil health, and trying to reduce external inputs makes it highly relevant and effective approach in low-resource settings in developing countries. It can be scaled across different farming approaches, enhancing sustainability at multiple levels through the supply chain (Caicedo-Vargas et al., 2023). Agroforestry comes next with the weight of about 30% gets the second rank. It enhances the circularity of the food supply chain by integrating different trees with crops and livestock considering their special needs of plant breeding. So, it supports nutrient cycling and helps reducing soil degradation, while increasing biodiversity variety. The multifunctionality of agroforestry systems aims to recycle organic items back into the soil. In developing countries, agroforestry creates the added value by diversifying farmer incomes. This kind of functionality makes it a highly adaptable practice (Singh and Singh, 2023). Conservation agriculture on the other hand, with weight of about 20% is also vital for resource conservation, especially soil and water health, which are essential elements in sustainable food production of developing countries. It focuses on maintaining long-term resilient soil productivity while minimizing external chemical fertilizers (Tilman et al., 2011). Although highly impactful, it is somehow narrowly focused on soil management system compared to agroecology and agroforestry, hence it has lower weight. However, Integrated Ocean Management gets the least weight in this group which is about 10%. Integrated Ocean Management is essential for coastal and sea food systems, especially in area where fishing and aquaculture are main contributors to nutrition and income generation system. It also helps promote sustainable fisheries and reducing relative waste, aligning with circular economy principles. Even so, it has a limited scope compared to the agricultural practices in developing countries (Xue et al., 2023). The second priority among the ReSOLVE set of action belongs to Share with practices of Shared Hard Technologies and Shared Soft Technologies. The reason based on experts' opinions is that Sharing technologies, both hard technologies such as machinery and tools and soft technologies such as knowledge and software, enables obtaining resources and creating innovative functions without the need for individual ownership. This is particularly important in developing countries, where capital for investment is lower and limited. Actually, Sharing could be fruitful in reducing costs for local societies and increasing chance of access to modern technologies. Still, Shared Hard Technologies with weight of 60% are of more importance compared to Shared Soft Technologies (weight of 40%) based on experts' opinions of this study. Shared hard technologies are mostly linked to the physical and capital-intensive infrastructure such as cold storage facilities, processing machineries, transportation systems, and renewable energy solutions. These technologies are critical for reducing food waste and directly improve post-harvest handling in the food supply chain (Jiang and Li, 2020). As such, hard technologies have an immediate and tangible effect on reducing food waste, particularly in post-harvest stages, which is a significant dilemma in developing countries. According to the FAO (2019), up to 40% of food is wasted at post-harvest stage due to inadequate infrastructure, such as lack of cold storage and processing facilities. Shared hard technologies directly point to this issue by creating access for farmers and small businesses to critical tools that are otherwise unaffordable individually. Developing countries often suffer from updated infrastructure, especially in rural areas, and shared hard technologies can be a solution to this gap. By resource pooling approach, farmers and local food businesses that are of low-income stream can reduce costs and increase productivity. Better transportation, storage, and processing capabilities will be possible by shared hard technologies (Tedesco et al., 2022). On the other hand, shared soft technologies point to knowledge, skills, digital platforms, and data-sharing systems, such as collaborative digital tools for farm management, weather forecasting apps, online market platforms, and knowledge-sharing networks for sustainable practices. These technologies are necessary to build capacity and improve decision-making processes. Soft technologies play a supporting role in ensuring the effective use of hard technologies (André, 2024). For example, digital applications for crop forecasting or soil health observation can optimize the operation of shared machineries or storage facilities, but they do not directly shape the needed infrastructure to decrease the amount of food spoilage or transport inefficiencies. While crucial for knowledge transferring and decision-making, soft technologies have a more indirect impact on circularity. They complement hard technologies but cannot be considered as a replacement for the physical infrastructure required to reduce waste and increase efficiency in the food supply chain (Lei et al., 2021). Optimize with the practices of Process Optimization and Value Optimization gets the third priority among the ReSOLVE set of actions. Optimizing the processes and value chains improvements reduce waste, increase productivity, and improves the financial stability of food supply chains. In developing countries, where resources are often limited, process optimization can significantly reduce costs and enhance productivity. That is why Optimization has a considerable impact on food supply chain, especially in resource-limited environments as is noticeable in developing countries. By improving efficiency and reducing waste, these practices directly contribute to economic sustainability in developing countries (Hmouda et al., 2024). Of course, Process Optimization gets higher priority in comparison to Value Optimization in this study with the weights of 60% to 40%. Process optimization considers the efficiency of the whole food supply chain, involving cultivation, harvesting, transportation, processing, and distribution. This includes adopting technologies and policies that reduce waste, enhance productivity, and make better use of resources such as water, energy, while limiting use of fertilizers and pesticides. Process optimization such as approaches like precision agriculture, irrigation systems, and supply chain management enhances efficient use of resource by minimizing losses and waste during production, transportation, and storage. This is particularly crucial in developing countries, where post-harvest losses due to inefficiencies in the infrastructures are high. Also, Process optimization is relatively easy to get scale across different parts of the supply chain and can be effective to both small and large food producers (Gonella et al., 2024). This characteristic is important for developing countries with diverse agricultural practices. However, while value optimization is with its own special impacts, it often requires noticeable investment in processing facilities, technology, and marketing tools to create new products from waste or by-products. This makes it less immediately scalable in rural regions that are not equipped with adequate infrastructure. So, Process optimization is the higher priority due to its direct impact on enhancement of resource efficiency and reducing food losses across the supply chain. It considers the immediate inefficiencies that are usual in developing countries, making it a critical first step in circularity. Albeit, value optimization is an important practice for creating new revenue streams and repurposing waste. But it comes after process optimization since it needs a certain level of infrastructure and investment which makes it less immediately impactful in resource-constrained world of developing countries (Opstal et al., 2024). Based on the experts' opinions of this study, Loop with practices of Biological Loops, Technical Loops, Information Loops got the 4th rank among all. Biological and technical loops focus on reusing organic materials while recovering resources such as composting and recycling. In information loops, data and knowledge are constantly shared and refined. In developing countries, looping biological resources, such as converting food waste to compost, is critical to addressing resource limitation and creating closed-loop supply chains. Albeit, Loops are important for reducing waste and extending the lifespan of resources, which is particularly crucial in areas with limited access to new resources (Setiawati et al., 2024). Biological and Technical loops can create self-sustaining supply chains that are highly valuable in developing countries. However, Biological loops get higher weight in comparison to Technical Loops in this study (weights of 65% vs 35%). Biological loops refer to the natural processes in which organic items, such as food and agricultural waste, and compostable packaging are sent again to the ecosystem via processes like composting, anaerobic digestion, and other forms of organic recycling. This function regenerates soils, produce bioenergy, and keeps the nutrient cycle. In developing countries, agriculture forms the cornerstone of the economy, and biological loops are directly intertwined to the sustainability of farming systems (Juntupally et al., 2023). By returning organic items to the farming land, nutrients are regenerated and soil health enhanced. This is essential for small-scaled farmers who rely on natural fertility rather than expensive artificial inputs. Implementing biological loops can be with low-cost and scalable in rural settings, where organic waste from farms can be processed into compost or used as biogas. These processes are accessible even to farmers and can be implemented with on hand technology. However, Technical loops usually require more advanced infrastructure for recycling and repairing technical products like machinery, packaging, and equipment. In many developing countries, the recycling system is underdeveloped, and waste management industry is not matured. This makes it harder to establish effective technical loops compared to biological loops, which can be implemented at smaller scales. Also, while technical loops are important for creating circularity in industrial settings, they have less immediate relevance to the agricultural sector, which dominates the economies of many developing countries. The impact of technical loops in the food supply chain is often more obvious in packaging and food processing equipment, areas where infrastructure investment is out of question but not always available. In addition, one of the most important aspects of technical loops in the food supply chain is the recycling of packaging materials. However, recycling systems in many developing countries are still in nascent steps, putting the effectiveness of technical loops under constraints in the short term (García-Valderrama et al., 2024). Virtualize that gets the 5th rank is about the adoption of digital technologies such as remote sensors, digital marketplaces, blockchain, IOT to manage and optimize agricultural and food systems. In developing countries, digital technologies can address infrastructure and market access gaps by providing more accurate on-time data, improving access to markets, and enabling more efficient resource use. It is time consuming in enhanced market access, improved data collection and transparent analysis approach, better decision-making, and increased efficiency. While digital transformation is important, its effectiveness in developing countries depends on current infrastructure, internet access, and technological improvement. Therefore, while it has unignorable potential, it cannot achieve its full-fledged impact unless foundational challenges are overcome (Gonçalves and Maximo, 2023). Exchange got the last priority in this study. Resource exchange and collaboration across societies at various scales can help overcome resource scarcity and foster innovation. In developing countries, where financial and natural resources may be limited, collaboration can optimize resource use, share risk, and improve overall resilience. Efficient resource allocation, stronger local economies, and enhanced innovation through collaboration could be shaped as a result. Nevertheless, while collaboration and resource exchange are of high value-added approaches, they often rely on well-developed infrastructure. Without systematic foundational practices like regeneration or optimization, their direct impact may be limited. Of course, when functioning effectively, collaboration can exponentially enhance resource efficiency and innovation (García-Valderrama et al., 2024). To get the highest value of this prioritization, it is recommended that the known business models get under attention to analyse their alignment with the cause-and-effect hierarchy and the specific challenges of developing countries. By leveraging innovative business models, particularly in developing countries, companies and organizations through the supply chain can more effectively align with the ReSOLVE framework to maximize resource productivity, sustainability, and economic opportunities (Puntillo, 2022). Food Waste-as-a-Service (FWaaS) for instance, focuses on reducing food waste through services that collect, process, and repurpose food residuals which otherwise could be totally wasted. In developing countries, food waste is a significant dilemma due to inefficiencies in logistics system, storage, and distribution. FWaaS can contribute to shaping biological loops, where food waste is recycled or upcycled into compost, animal feed, or bioenergy. So, this business model aligns strongly with the Loop and Optimize categories as got the second and third rank in this study, since it could reduce waste and recover valuable resources from food that would otherwise be lost. FWaaS can address inefficiencies in the food supply chain, improving resource recovery, and reducing environmental pollution caused by food waste. This model also creates employment opportunities in the waste management and recycling sectors, which can drive local economic development. Food waste is a critical issue in developing countries and FWaaS has a strong potential for reducing waste while contributing to circular economy goals at the same time (McDowall et al. 2025). Pay-Per-Use (PPU) business model is also helpful. PPU models allow product or service receivers to pay only when they use it, rather than purchasing it. The application of model is more usual in industrial technologies, where the cost of purchasing is out of range for small businesses in developing countries. PPU is in the same direction of the Share and Optimize set of actions that seek reducing the financial pressure on users and promoting sustainable use of resources. It can also prevent overproduction, which reduces waste and ensures that products and resources are used only when is necessary. PPU can be particularly beneficial in resource-limited economies where financial burdens for ownership of equipment or technology is noticeable. By use of technology or services without huge costs, the adoption of resource-efficient technologies is possible and circular practices are followed as such. PPU points to economic challenges and resource limitations in developing countries, focusing on the efficient use of technology and reducing waste. However, its success is related to having access to shared infrastructure and sufficient demand (Möller et al., 2025). Product Life Extension (PLE) could be helpful in shaping circular food supply chain by considering the lifespan extensions of products through repair, maintenance, refurbishing, or remanufacturing of food processing equipment, packaging, or agricultural tools. PLE suits the Loop and Optimize objectives since it can help to keep products in use as long as possible, while reducing the need for new purchase of resources and minimizing waste. In developing countries, purchasing new equipment may not always be possible or financially feasible. PLE can ensure that products keep their functional status for longer periods. Extending the life of equipment reduces the financial pressure on businesses and simultaneously promote more sustainable approaches (Abbas et al., 2023).

5. Conclusion

The implementation of circular economy principles in developing countries requires a clear understanding of the practices that will yield the most significant and early return impact, particularly considering the special environmental, social, and economic issues these areas face. By addressing the most fundamental practices, developing countries can transition towards more sustainable and regenerative systems in food supply chain management. To prioritize these practices in helping the food supply chain to get circular in developing countries, their alignment with waste reduction, resource regeneration, and ecosystem sustainability should be considered. Regenerate with main principles of Agroecology, Conservation Agriculture, Agroforestry, Integrated Ocean Management is determined as fundamental in developing countries, where economies are often unsustainable and heavily dependent on natural resources. Agricultural productivity, water and climate resilience are totally influenced by the health of ecosystems. Regenerative practices not only retrieve soil health and enhance biodiversity but also create a basement upon which other CE practices can be developed. In regions where local societies depend on agriculture, the importance of these practices cannot be ignored. Regeneration is the basic element of sustainability in food management system that could ensure long-term viability and resilience while facing environmental pressures. Establishing loops of Biological Loops, Technical Loops, Information Loops that close material cycles has been determined with the second rank in this study as critical in helping resources to be reused rather than wasted. In developing countries, biological loops are crucial for creating a self-sustaining system in management processes of farming and food supply chain. The implementation of technical loops, such as recycling and reusing materials, further reduces reliance on new scarce resources. These loops also cultivate innovation to allow valuable materials to be continuously cycled through the economy. Looping supports the regeneration of ecosystems by decreasing external artificial resources and following the flow of nutrients within natural systems. Optimize which could be mainly about Process Optimization and Value Optimization got the third priority in this study. It focuses on improving resource efficiency and reducing waste in the production and distribution processes. In developing countries, where infrastructure and resources are limited, optimizing processes aim to use resources efficiently and reduce both costs and environmental impacts. Value optimization helps maximize the economic and social benefits of food systems by ensuring that food is used effectively throughout their lifecycle. This practice supports environmental sustainability and economic robustness and is a critical component of CE implementation in these areas. Sharing technologies got the next priority and seek to reduce economic burdens and increase access to vital resources. In developing countries, ownership of expensive equipment may not be feasible for many. So, sharing systems make possible the more equitable distribution of resources and greater collaboration among communities. Shared technologies facilitate the adoption of regenerative and resource-efficient practices, fostering a more inclusive approach to sustainable development. This practice depends on current infrastructure and collaboration system, making it somewhat secondary to foundational practices like regeneration and looping. Virtualization through digital technologies support CE by enhancing the efficient decision-making. In developing countries, digital transformation enables on-time data collection and analysis, leading to more vision-based resource management. However, the impact of virtualization is limited by getting access to reliable digital infrastructure and technological literacy, making it less critical compared to regeneration and looping in current situation of developing countries. Despite this, it remains a valuable tool for efficient resource use in more advanced stages of CE implementation. At last, Exchange which is pointing to Resource Exchange or Collaboration is vital for ensuring the sustainable use of resources and promoting innovation. In developing countries, where resources may be limited, exchanging knowledge, materials, or services between communities can address regional shortages and promote innovation. While exchange is an important enabler of circular practices, its effectiveness is dependent on the foundational systems of regeneration, looping, and optimization. As such, it ranks lower in priority but remains a critical practice for maximizing resource use in the longer term. So, it should be said that the successful implementation of the circular economy in developing countries relies on prioritizing the most impactful practices to help them to get to the maximum value in least period. Regeneration and Looping stand at the forefront due to their capabilities in ensuring the sustainability of ecosystems. Optimization follows closely, as it enhances the efficiency of resources in constrained environments. Practices like Sharing, Virtualizing, and Exchanging play important supporting roles but are effective when integrated into a holistic system already developed in strong regenerative and looping practices. By focusing on these key priorities, developing countries can move toward a circular economy that promotes sustainability, resilience, and economic development, particularly in their food management systems. Finally, for future studies it is suggested to investigate the scalability of regenerative agricultural practices in resource-limited and climate-vulnerable regions of developing countries. Assessment of the potential and challenges of implementing Pay-Per-Use (PPU) models for agricultural technologies in developing countries could be helpful too. It is helpful to see how indigenous knowledge systems and traditional practices can be integrated into circular economy models, particularly in agricultural and food management sectors. Investigation of the development of circular packaging solutions in food supply chains, focusing on reducing plastic waste and promoting reuse or biodegradability could be helpful too.

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