Food Waste and Circular Economy

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The world's population is expected to grow at an increasing rate, leading to increased food consumption and waste production. Even though food waste represents one of the most challenging economic and environmental issues of the 21st century, it also provides a vast array of valuable resources. Eight broad themes emerged in circular economy: (1) anaerobic digestion of food waste for circular economy creation; (2) food waste systems and life cycle assessments for circular economy; (3) bio-based circular economy approaches; (4) consumer behavior and attitudes toward circular economies; (5) food supply chains and food waste in a circular economy; (6) material flow analysis and sustainability; (7) challenges, policies, and practices to achieve circularity; and (8) circular economy and patterns of consumption.

Keywords: food waste ; circular economy ; recycling

1. Introduction

Food consumption and waste generation are expected to increase as the world population increases. Hence, managing food waste is one of the global challenges of the 21st century due to its adverse effect on the environment and economy. In addition to government policies and legislation, the continuous growth of food waste has led to a significant change in waste management approaches, from landfill disposal to waste treatment through reduction, recycling, and reuse, and a shift to energy and resource recovery from waste. The focus has been on the recovery of materials and energy from food waste, as well as their applications in electricity generation, fuel production, and agriculture in the context of sustainability, circular economy, and environmental protection. According to the Food and Agriculture Organization (FAO), approximately one-third of all food produced for human consumption is lost or wasted [1]. The three dimensions to investigate the impacts of food waste include environmental, social, and economic. Nevertheless, the main challenge is that the magnitude of food waste and its impacts have not been well investigated and quantified. Understanding the scale of food waste can help develop informed policies and strategies that aim to reduce food waste. FAO asserted that the causes of food waste are country-dependent due to the prevailing local conditions. The report argues that in low-income countries, food waste happens at the production, postharvest handling, storage, and processing stages. This waste is the consequence of mainly managerial and technical limitations [2]. Gustavsson et al. cites poor infrastructure, technology, and financial limitations as some of the causes of food waste and loss [1]. Other causes of food waste, such as overproduction, are cited in the paper of Beretta et al. [3].

On the other hand, in high- and middle-income countries, food waste occurs in the distribution and consumption stages of the food value chain. Over and above that, local consumer behavior and government policies have a bearing on the levels of food waste in both developing and developed countries. Against this background, there is a need for concerted global efforts to measure the magnitude of food wasted along the food value chain; at the farm (agricultural production), distribution channels (transportation and retail), and consumer level, in order to harness the untapped benefits of food waste reduction. More developed countries are shown to have low food waste compared to less developed countries. For example, South Korea has increased its recycled food waste from 2% in 1995 to about 95% in 2021. Dumping food in a landfill was banned in 2005, and compulsory food waste recycling was introduced in 2013. The government has also approved the use of recycled food waste as fertilizer, although some becomes animal feed [4].

2. Theme 1: Anaerobic Digestion of Food Waste for the creation of a circular economy

One efficient use of food waste recorded is fertilization, which has been an increasing focus of research in recent years. According to the literature studies, the method utilized in producing fertilizer from food waste has been anaerobic digestion. The food waste is broken down in this process, releasing biogas, while producing organic matter, thereby contributing to a circular economy. Pérez-Camacho et al. [5] investigated the lifecycle environmental impacts of substituting feedstock with food waste in traditional anaerobic digestion. They found out that the substitution resulted in less green house gas emissions (GHG) and argued that this benefits the circular economy policies, especially the tax on landfilling with food waste. In another study reported by Stoknes et al., a novel technological approach was developed for processing organic waste into new food [6]. Organic waste is first converted into digester residue, subsequently used as the main mushroom and vegetable fertilizer component. As a result of using the digestate and substrate as a fertilizer for the first time, the commercial crops produced higher yields. To corroborate the study of Stoknes et al. [6], there was an investigation by Cheong et al. [7], in which the use of food waste as a digestate fertilizer for the cultivation of leafy vegetables was studied. The result showed improved yields when food waste was used as a digestate fertilizer, and also observed an increase in chlorophyll content. More recent studies have investigated the bioconversion of food waste into fatty acids [8][9][10][11]. They argued that bioconversion of food waste through anaerobic digestion is an invaluable aspect of the circular economy, and supports the implementation of a food waste management hierarchy.

3. Theme 2: Food Waste Systems and Life Cycle Assessment in the Circular Economy

Literature on this theme offers direction on the lifecycle assessment of food waste, and the challenges that impede attempts to employ closed-loop designs in food waste management. Kowalski et al. [12] carried out a study that quantified material recovery from meat waste in incineration. They used a material flow analysis approach to assess the incineration process of creating hydroxyapatite (HA) ash from meat bone waste. They also suggest that the recovery of HA can be used to produce food-grade phosphoric acid, and the production of food-grade mono and di-calcium feed phosphates. Tonini et al. [13] reported that food waste constitutes the largest proportion of the municipal waste generated in Europe, and quickly pointed out that suboptimal environmental performance is associated with its management. They quantify the sustainability and investigate five alternative household food waste management scenarios for the case of the Amsterdam metropolitan area. Their results indicate that separate collection of food waste and anaerobic digestion are the most preferred strategies to improve the sustainability and circular economy. Results from de Sadeleer et al. [14] analyzed and compared two waste management systems for household food waste: recycling by anaerobic digestion and incineration. Their study employs material flow analysis in combination with lifecycle analysis. They found that recycling food waste using anaerobic digestion performs better in recycling rates and GHG emissions than incineration. In a similar manner, Laso et al. [15], Haupt et al. [16], and Edwards et al. [17] all investigated the lifecycle component of the food waste and circular economy nexus. These studies highlight the challenge that food waste systems are incapable of quantifying the efficiency of a system to turn food waste into a valuable resource.

4. Theme 3: Bio-Based circular economy approaches

In contrast to theme 1, which considered how to deal with waste disposal by using aerobic digestion, this theme examines how to turn low-value waste into high-value food ingredients. For example, Jagtap et al. [18] studied the use of black soldier fly larvae (BSFL) as a bioreactor to convert organic food waste into high-value animal feeds. They postulated that zero waste could be achieved by localized conversion of in-field crop losses to an animal feed using BSFL, which offers opportunities to develop a circular economy. Other studies that investigated converting low-value waste to high-value waste include Przybylski et al. [19], and Song et al. [20]. In the same line of thought, Ebeneezar et al. [21] conducted a systematic evaluation investigating how including food waste can be converted through biological processes into proteins and lipid-rich animal feeds. They concluded that sustainability targets could be achieved by adopting innovative and cost-effective technologies for rearing BSFL.

Moreover, they assert that using BSFL for food valorization would help stem climate change and provide a pathway towards achieving a green and circular bio-economy. Furthermore, Barbi et al. [22] investigated the use of insects for the valorization of seasonal agri-food. Their study aimed to investigate “specific combinations of agri-food leftovers, focusing on their availability in a defined geographical area (Regione Emilia-Romagna, Italy), as rearing substrates for Black Soldier Fly (BSF) larvae”. They concluded that the use of BSF in bioconversion of food waste could be improved by “using tailored combinations of available leftovers, calculated through Mixture Design, thus overcoming the negative effects of nutritionally unbalanced substrates”.

5. Theme 4: Consumer’s behavior, attitudes towards circular economy

Consumers’ behavioral responses toward food waste, interest in the circular economy concept, and cultural norms, are essential indicators of whether circular economy initiatives will succeed [23]. In other words, for a circular economic agenda to be promoted, advanced and actualized changes are required from the consumers themselves. In support of these assertions, Borrello et al. [24] hypothesized that consumer willingness is important in closed food loops to reduce food waste. In their study, the questionnaire methodology approach was adopted to gather knowledge and establish an understanding of consumers' attitudes towards active participation in a circular economy. They found out that many consumers were willing to participate in a circular designed loop. Interestingly, it was discovered that some reward schemes, such as an increase in discounts of animal products, indicated a positive willingness of consumers to take part in a circular economy. This suggests that consumers need to be motivated through incentives/rewards in order to participate in a circular designed loop.

On the contrary, consumers indicated that they are ready to give away a significant portion of the discount in exchange for collecting organic waste from their homes, instead of bringing the organic waste to retailers. In a complementary study, Sadhukhan et al. investigated the life cycle environmental impacts of moving from livestock to a plant-based diet [25]. Their analysis indicated that the highest environmental impact saving could be achieved through the displacement of livestock by plant-based (beans and lentils), for protein sourcing. This suggests that consumers should be encouraged to adopt more vegan/vegetarian diets instead of meat-based ones. Through an exploratory approach, Sousa et al. investigated consumers' perception of the circular economy to identify consumers' recognition of products from the food industry [26]. Their results suggested lack of a clear understanding of consumers' attitudes towards the circular economy, hence a need to promote and disseminate circular economy principles to the general populous for better integration, participation, and acceptance. In another study by Aschemann et al. the consumers' perspective on the upcycle by-product use in agri-food systems was investigated [27]. They found that the acceptance of waste-to-value food products among consumers depends on the individual person, the context, and the product. An interesting study by Coderoni et al. analyzed millennials' willingness to buy food with upcycled ingredients [28]. They argue that upcycled food as a new food category faces several challenges in the food waste management hierarchy, and is not readily accepted by the public.

6. Theme 5: Food Supply Chain and Food Waste in the Circular Economy

This will cover literature that examines food waste as it is produced, processed, distributed, retailed, and consumed, along the food value chain. The food value chain also consists of all other key stakeholders, such as policy makers who influence food waste along the food value chain. Dora et al. investigated the leading causes of food loss and waste along the food value chain [29]. They proposed and developed a waste utilization framework through the circular economy and proposed a model for achieving depollution. Batista et al. identified the barriers to implementing circular in the food supply chain [30]. Moreover, they underscored the importance of digital technologies, such as blockchains to removing circular economy barriers in the food supply chain. A performance evaluation study by Kazancoglu et al. showed that reverse logistics activities in the food supply chain could contribute to green performance by reducing food waste and losses [31]. The researchers argue that companies must distinguish between value-adding and non-value-adding activities, and should set targets to reduce the non-value activities of the reverse-logistics processes, such that environmental impacts are reduced. Other investigations which focused on the interrelations of the food supply chain and the circular economy were conducted by Russo et al. [32], and Secondi et al. [33]. Respectively, these studies investigated the use of waste products in closed-loop supply chains, reuse of food waste in manufacturing, and the recovery and optimal design of the food value chain for sustainability.

7. Theme 6: Material flow analysis and sustainability

This theme addresses material flow analysis as a method that can be implemented to manage natural resources, co-products, and by-product valorization. The Italian meat industry accounts for 15% of national agri-food value and produces different types of waste, of which food loss and waste constitute a substantial and increasing proportion [34]. The researchers concluded that material flow analysis assists in the analysis of material cycles and eco-efficiency indicators, and in assessing the efficiency and circularity of agri-food systems. Andreopoulou documented that in view of attaining sustainability, food actors need to adopt digital sharing platforms such as the "Internet of Things" (IoT) to promote a circular economy [35]. Gretzel et al. pointed out that the environmental sustainability of tourist destinations is an issue of concern, because of increasing food waste in the tourism sector [36]. Hebrok and Heidenstrøm [37] investigated how the material infrastructure of food handling practices presents opportunities for reducing food waste. They focused on five food handling practices that cause food waste: acquiring, storing, assessing, valuing, and eating. Teigiserova [38] conducted a systematic research that focused on the use of inedible and unavoidable food residues and waste that can be used in the production of bio-based compounds, which could substitute synthetic chemicals.

8. Theme 7: Challenges, policies and practices to achieve circularity

This theme focuses on the challenges, policies, and practices that can be put into practice to achieve circularity. Camilleri [39] argued that there is scope for regulatory authorities and policymakers to encourage hospitality practitioners to engage in a circular economy. Their study suggested that catering businesses can implement several responsible initiatives by introducing preventative measures and recycling practices to curb food loss and waste. McCarthy et al. [40] discussed the challenges of waste management in the horticultural sector and presented the circular economy as a possible solution to curbing food waste. They specifically focused on value adding as a potential remedy to transform food waste for reuse. Bas-Bellver et al. [41] studied revalorizing vegetable waste (carrot, leek, celery, and cabbage) from the fresh and ready-to-eat lines of the cooperative into functional ingredients. They used hot air drying or freeze drying, and considered other factors, like storage conditions, before drying. They obtained about 25 vegetable powders, and hot air drying produced stable powders, which could then be used in the food industry as coloring and flavoring. Loizia et al. [42] investigated how the circular economy can be applied in optimizing the production of biogas using food waste. Their study is important in encouraging the use of food waste in treatment plants, diversion of food waste from landfills, and the use of food waste as a secondary energy resource.

9. Theme 8: Circular economy and patterns of consumption

This theme summarizes the nexus between consumption patterns that can foster circular economy practices. Fogarassy et al. [43] studied the pro-circular behavior that can increase the consumption of organic food. Mylan et al. [44] argued that it is important to understand why people use or consume particular goods or services, how this might be altered, and what drives waste production. Central to their study is the mobilization of insights from a socio-technical perspective on consumption, which underscores interactions between routine activities, mundane technologies, and culture in reproducing patterns of consumption. Another important aspect is to gain insights into how carbon footprint could be used to understand the tendencies of sustainable consumption better [45].

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