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Circular Economy Strategies for Sustainable Waste Management in the Food Industry

Gıda Endüstrisinde Sürdürülebilir Atık Yönetimi için Döngüsel Ekonomi Stratejileri

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ANAHTAR KELİMELER

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ÖZ

Gıda endüstrisi, atık oluşumuna ve doğal kaynakların tükenmesine önemli bir katkıda bulunmaktadır. Bu zorlukların üstesinden gelmek için döngüsel ekonomi yaklaşımı, gıda endüstrisinde sürdürülebilir atık yönetimi için umut verici bir çerçeve sunuyor. Bu makale, atık azaltma, yeniden kullanım, geri dönüşüm ve kaynak geri kazanımı dahil olmak üzere döngüsel ekonomi stratejilerini gözden geçirmekte ve bunların gıda endüstrisinde çevresel etkileri azaltma ve ekonomik faydaları artırma potansiyellerini araştırmaktadır. Makale ayrıca düzenleyici engeller, tüketici davranışı ve pazar talebi dahil olmak üzere gıda endüstrisinde döngüsel ekonomi stratejilerinin uygulanmasıyla ilgili zorlukları ve fırsatları tartışıyor. Son olarak, makale, en iyi uygulamaları ve öğrenilen dersleri vurgulayarak, gıda endüstrisindeki döngüsel ekonomi girişimlerinin vaka incelemelerini sunuyor. Döngüsel ekonomi stratejileri, gıda endüstrisinde sürdürülebilir atık yönetimine kapsamlı ve entegre bir yaklaşım sunar ve bunların başarılı bir şekilde uygulanması, gıda değer zinciri boyunca işbirliği ve yenilik gerektirir.

ABSTRACT

The food industry is a major contributor to the generation of waste and the depletion of natural resources. In order to address these challenges, the circular economy approach offers a promising framework for sustainable waste management in the food industry. This article reviews circular economy strategies, including waste reduction, reuse, recycling, and resource recovery, and explores their potential for reducing environmental impacts and increasing economic benefits in the food industry. The article also discusses the challenges and opportunities associated with implementing circular economy strategies in the food industry, including regulatory barriers, consumer behaviour, and market demand. Finally, the article presents case studies of circular economy initiatives in the food industry, highlighting best practices and lessons learned. Circular economy strategies offer a comprehensive and integrated approach to sustainable waste management in the food industry, and that their successful implementation requires collaboration and innovation across the food value chain.

1. Introduction

The food industry is one of the most significant contributors to global waste generation. The production, processing, and distribution of food items result in a considerable amount of waste, including food waste, packaging waste, and processing waste. The challenge of waste management in the food industry has become a critical issue, as it not only affects the environment but also has economic and social implications (Torres-León et al., 2018).

The food industry is facing several challenges when it comes

to waste management. The first challenge is the sheer volume of waste generated (Marchant, 2021). According to the Food and Agriculture Organization (FAO), about one-third of the food produced in the world for human consumption is lost or wasted each year, which amounts to about 1.3 billion tons (FAO, 2011). This waste has a significant impact on the environment, contributing to greenhouse gas emissions, land degradation, and water pollution. The second challenge is the cost of waste management. The disposal of waste requires significant resources, including transportation, processing, and landfill

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or incineration facilities. These costs are often passed on to consumers, who end up paying higher prices for food products (Abdel-Shafy & Mansour, 2018). The third challenge is the social impact of waste. Food waste has a significant impact on food security, as it reduces the availability of food for those in need. Additionally, food waste also contributes to the depletion of natural resources, such as water and land, which affects the livelihoods of communities that depend on these resources (Benton et al., 2021).

To address these challenges, the food industry needs to adopt circular economy strategies for sustainable waste management. The circular economy is an economic model that aims to keep resources in use for as long as possible, by reusing, repurposing, and recycling them. The circular economy model focuses on reducing waste and using resources more efficiently, which can lead to significant economic, social, and environmental benefits (Negrete-Cardoso et al., 2022).

Circular economy strategies for sustainable waste management in the food industry can take various forms. One approach is to reduce food waste at the source by implementing more efficient production and distribution systems, as well as better food preservation techniques (Gonçalves & Maximo, 2022). Another approach is to repurpose waste materials, such as using food waste as animal feed or composting it to create fertilizer (David, 2021). Another circular economy strategy is to redesign packaging to be more sustainable and recyclable. This can include using biodegradable materials, reducing the amount of packaging used, and designing packaging that is easier to recycle (Meherishi et al., 2019). Finally, circular economy strategies can also involve developing new business models that encourage more sustainable practices. For example, some companies are experimenting with circular supply chains, where products are designed to be easily disassembled and repurposed at the end of their lifecycle (Aarikka-Stenroos et al., 2022). Other companies are exploring new revenue streams by turning waste into value-added products, such as using food waste to create bioplastics or biofuels (Tsang et al., 2019).

So, the food industry must address the challenge of waste management to ensure sustainability in the long run. The circular economy provides a framework for sustainable waste management, by promoting resource efficiency, reducing waste, and creating new business opportunities. By adopting circular economy strategies, the food industry can reduce its environmental footprint, lower costs, and contribute to a more sustainable future.

2. Concept of circular economy

The concept of circular economy has gained increasing attention in recent years, as a response to the urgent need for more sustainable waste management practices (Velenturf & Purnell, 2021). The circular economy is an economic system that aims to minimize waste and make the most out of

resources by keeping them in use for as long as possible. It is based on the principles of reducing, reusing, and recycling resources and materials to create a closed-loop system, in which waste is minimized and materials are kept in use for as long as possible (US EPA, 2021). This system is designed to promote the efficient use of natural resources and reduce the negative impact of human activities on the environment (Winans et al., 2017). In the food industry, circular economy strategies can offer a range of benefits, from reducing food waste and greenhouse gas emissions to creating new revenue streams and improving brand reputation. This article will provide an overview of the concept of circular economy, its principles, and the advantages of its application in waste management practices in the food industry.

Figure 1. A basic concept of circular economy.



Definition and Principles of Circular Economy

Circular economy is an economic system that is restorative and regenerative by design. This is an economic model that aims to design out waste and pollution, keeping materials in use for as long as possible (Ellen MacArthur Foundation, 2022). It is an alternative to the traditional linear economy, which follows the 'take-make-dispose' approach (Wautelet, 2018). The Ellen MacArthur Foundation, a leading advocate for the circular economy, defines it as "an economy that is restorative and regenerative by design, aiming to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (Ellen MacArthur Foundation, 2022). The circular economy aims to close the loop of the traditional linear economy by promoting the efficient use of natural resources, reducing waste generation, and extending the life of products and materials (Kara et al., 2022). It aims to create a closed-loop system, where waste is minimized, and resources are conserved, reused, and recycled (Jørgensen & Pedersen, 2018). The concept is based on three main principles: (1) designing out waste and pollution, (2) keeping products and materials in use, and (3) regenerating

natural systems (Vural Gursel et al., 2022).

The first principle focuses on preventing waste and pollution at the source, by designing products and processes that are more efficient, durable, and recyclable (Geissdoerfer et al., 2017). This principle emphasizes the importance of designing products and systems that are sustainable and environmentally friendly (Velenturf & Purnell, 2021). This involves a shift from the traditional linear model of production and consumption, in which resources are extracted, used, and disposed of, to a more circular model, in which resources are reused and recycled (Garcés-Ayerbe et al., 2019). It involves the use of eco-design, which focuses on the environmental impact of products and systems from their conception to their end of life. By designing out waste and pollution, we can reduce the negative impact of human activities on the environment (Rosen & Kishawy, 2012).

The second principle emphasizes the importance of keeping materials in use for as long as possible, by promoting reuse, repair, and recycling. This involves a shift from a "take-make-dispose" approach to a "reduce-reuse-recycle" approach, in which waste is minimized and resources are kept in use. By keeping products and materials in use, we can reduce the amount of waste generated and conserve natural resources (Kirchherr et al., 2023).

The third principle focuses on the need to regenerate natural systems, by designing processes that are restorative and regenerative, rather than degrading and polluting (Alcalde-Calonge et al., 2022). This involves a shift from a linear model of production and consumption to a closed-loop system, in which waste is minimized and natural systems are restored (Jørgensen & Pedersen, 2018). It involves the use of sustainable practices, such as sustainable agriculture and forestry, to promote the health of ecosystems and ensure their resilience (Wilson & Lovell, 2016).

3. Advantages of Circular Economy Approach to Waste Management in the Food Industry

The application of circular economy strategies in waste management practices in the food industry can offer a range of advantages, including:

3.1. Reducing Food Waste

The food industry is a major contributor to global food waste, with an estimated one-third of all food produced globally being lost or wasted every year (UNEP, 2021). Circular economy strategies can help to reduce food waste by promoting more efficient production and distribution systems, as well as by diverting food waste from landfills and converting it into new products, such as compost or animal feed. This helps to reduce waste by promoting the efficient use of natural resources and extending the life of products and materials. By reducing waste, we can conserve natural resources and reduce the negative impact of human activities on the environment (Rashid & Shahzad, 2021).

3.2. Lowering Greenhouse Gas Emissions

Food waste is also a significant source of greenhouse gas emissions, contributing to climate change (Tubiello et al., 2021). When food waste ends up in landfills, it decomposes and emits methane, a potent greenhouse gas that is about 25 times more effective at trapping heat in the atmosphere than carbon dioxide (Yasmin et al., 2022). According to the United Nations, food waste is responsible for around 8% of global greenhouse gas emissions (Environment, 2021). By implementing circular economy strategies, such as reducing food waste, recovering food for human consumption, and recycling food waste into energy, we can significantly reduce greenhouse gas emissions in the food industry (Ingrao et al., 2018). Additionally, promoting the use of renewable energy sources, such as solar or wind power, in food production, processing, and transportation can also help to reduce emissions (Chen et al., 2022). Overall, taking steps to address food waste and promote sustainable practices in the food industry can play a crucial role in mitigating the effects of climate change (Usmani et al., 2021).

3.3. Creating New Revenue Streams

Implementing circular economy strategies can help businesses in the food industry find new opportunities for revenue generation by identifying value in waste materials and by-products (Poconi et al., 2022). By converting food waste into biogas or biofuels, businesses can create new sources of energy and sell them to customers, thereby generating additional revenue streams. In addition to energy production, businesses can also create new products and services from waste materials (Korbag et al., 2021). For example, food waste can be used to create fertilizers or animal feed, which can be sold to farmers. Alternatively, food waste can be turned into new food products, such as sauces or jams, which can be sold to consumers. These products can be marketed as sustainable and environmentally friendly, providing an additional selling point for businesses (Senanayake et al., 2021). By embracing circular economy strategies, businesses in the food industry can not only reduce waste and improve sustainability, but also unlock new revenue streams and create new opportunities for growth (Barros et al., 2021).

3.4. Improving Brand Reputation

By implementing circular economy strategies, food industry businesses can showcase their commitment to sustainability and environmental responsibility, which can enhance their brand reputation among consumers and stakeholders (Barros et al., 2021). This is particularly important as more and more consumers are becoming environmentally conscious and are actively seeking out products and services from companies that prioritize sustainability. Adopting circular economy strategies such as reducing food waste, implementing sustainable sourcing practices, and using renewable energy sources can help businesses improve their environmental

footprint and demonstrate their commitment to sustainability. This, in turn, can lead to increased customer loyalty, improved brand reputation, and a positive impact on the bottom line (Patwa et al., 2021). In today's business environment, where companies are increasingly expected to operate in an environmentally responsible manner, embracing circular economy strategies can help food industry businesses not only reduce waste and improve sustainability but also enhance their reputation and appeal to customers who prioritize sustainability (Ahmad et al., 2021).

3.5. Conserving natural resources

Circular economy strategies in the food industry can help to conserve natural resources by promoting the efficient use of resources and reducing waste. For example, sustainable sourcing practices can help to reduce the environmental impact of food production by minimizing the use of natural resources such as water and energy. Additionally, reducing food waste can help to conserve resources by ensuring that the resources used to produce food are not wasted (Wunderlich & Martinez, 2018). Circular economy strategies can also promote the reuse and recycling of materials, further conserving natural resources. For example, food waste can be recycled into compost, which can be used as a natural fertilizer for crops. Similarly, materials used in food packaging can be recycled or reused, reducing the need for new materials and conserving natural resources (Peng et al., 2023). By embracing circular economy strategies in the food industry, businesses can help to conserve natural resources, reduce waste, and promote sustainability, ensuring the availability of resources for future generations (Poponi et al., 2022).

3.6. Creating jobs

Implementing circular economy strategies in the food industry can create new job opportunities, particularly in the areas of recycling, repair, and refurbishment (Morsetto, 2020). For example, the recycling of food waste into biogas or biofuels requires specialized equipment and expertise, creating new job opportunities in this sector. Similarly, the repair and refurbishment of food processing and packaging equipment can also create new jobs (Bhatia et al., 2023). Circular economy strategies can also create new job opportunities in the areas of sustainable sourcing and production. For example, businesses that prioritize sustainable sourcing practices may need to hire experts in sustainable agriculture or forestry. Similarly, businesses that use renewable energy sources may need to hire workers with specialized skills in this area (Rizos et al., 2016). By embracing circular economy strategies in the food industry, businesses can create new job opportunities, particularly in local communities, where these jobs are often needed the most. This can have a positive impact on the local economy, promoting sustainable development and enhancing the quality of life for local residents (Kaur et al., 2022).

3.7. Encouraging innovation

Implementing circular economy strategies in the food industry can encourage innovation and the development of sustainable products, services, and business models that are more sustainable and efficient. This can lead to the emergence of new industries and the creation of new jobs, promoting sustainable economic growth and development (Hysa et al., 2020). For example, the conversion of food waste into biogas or biofuels requires innovative technologies and processes, creating opportunities for the development of new products and systems (Hafid et al., 2022). Similarly, the development of sustainable packaging solutions or new food products made from recycled materials can lead to the creation of new business models and industries (Guillard et al., 2018). Circular economy strategies also encourage businesses to think creatively about how they use resources, which can lead to the emergence of new approaches to production and distribution. For example, businesses may explore new ways to reduce waste or to use by-products and waste materials as inputs for other products or services (Awan & Sroufe, 2022).

4. Challenges in the food industry waste management

The food industry generates a significant amount of waste, including food waste, packaging waste, and wastewater. Effective waste management is a critical challenge for the industry due to several factors (Sinha & Tripathi, 2021). Firstly, food waste is a significant challenge for the food industry. This can occur at any stage of the supply chain, from production to consumption, and can result from overproduction, expiration of food products, or inefficient logistics. This can lead to economic losses for businesses and contribute to environmental problems such as greenhouse gas emissions and landfill waste (Jeswani et al., 2021). Secondly, packaging waste is another challenge for the food industry. Packaging is used to protect and preserve food, but it can also result in significant amounts of waste. The disposal of packaging waste can be challenging, and the use of non-biodegradable materials can lead to environmental problems such as pollution and litter (Kakadellis & Harris, 2020). Finally, wastewater management is also an issue for the food industry. Wastewater from food production facilities can contain high levels of organic matter, nutrients, and other pollutants, which can pose a risk to the environment if not properly managed (Shrivastava et al., 2022). Overall, the food industry faces significant challenges in managing waste effectively. Addressing these challenges requires a multi-pronged approach, including reducing food waste, promoting sustainable packaging solutions, and implementing effective wastewater treatment strategies.

4.1. Food waste generation and its environmental impacts

Food waste is a significant problem globally, with a staggering amount of food being discarded every day. It is estimated that nearly one-third of the food produced worldwide, equivalent to 1.3 billion tons, is lost or wasted annually (RESET, 2018). Food waste occurs at all stages of the food supply chain, from production to consumption, with different reasons such as spoilage, damage, and overproduction. The generation of food waste has numerous environmental impacts. First and foremost, it leads to the depletion of natural resources, such as water, land, and energy, that were used in the production of the wasted food. This, in turn, exacerbates the pressure on the environment, leading to soil degradation, water scarcity, and deforestation (Ishangulyyev et al., 2019).

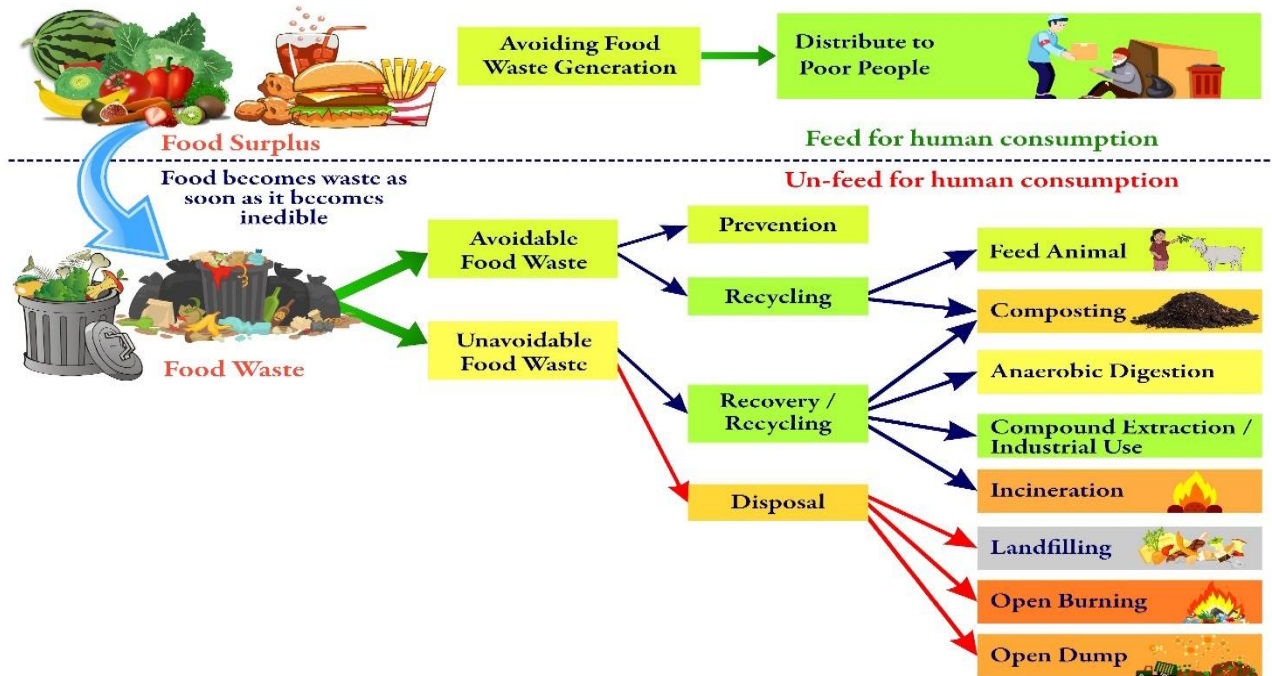
Moreover, food waste emits a significant amount of greenhouse gases (GHGs), contributing to climate change. When organic matter decomposes in landfills, it releases methane, a potent GHG that is 25 times more potent than carbon dioxide. The amount of GHGs emitted by food waste is estimated to be 3.3 billion metric tons of carbon dioxide equivalent annually, making it one of the most significant sources of anthropogenic GHG emissions (Nordahl et al., 2020).

In addition, food waste contributes to the loss of biodiversity. Agriculture, forestry, and fisheries are among the most significant drivers of biodiversity loss, and food waste exacerbates this problem. When food is produced but not consumed, it leads to a waste of the natural resources that were used to produce it, such as water, land, and energy. This, in turn, puts pressure on ecosystems, leading to a decline in biodiversity (Read et al., 2022).

Another impact of food waste is the loss of economic value. When food is discarded, it represents a significant loss of resources and economic value. According to the Food and Agriculture Organization (FAO), the economic cost of food waste is estimated to be \$1 trillion annually. This is not only a waste of resources but also represents a missed opportunity to provide food to those in need (Kotykova & Babych, 2019).

Moreover, food waste has social impacts, particularly in developing countries. In many parts of the world, food waste occurs primarily at the production and distribution stages due to inadequate infrastructure and insufficient storage facilities. This leads to a lack of food security and economic losses for small-scale farmers and food producers (Santeramo, 2021).

Figure 2. Various stages of food waste management.



In conclusion, food waste generation has numerous environmental impacts, including the depletion of natural resources, emission of greenhouse gases, loss of biodiversity, and loss of economic value. It also has social impacts, particularly in developing countries, where inadequate infrastructure and storage facilities lead to a lack

of food security and economic losses. Therefore, reducing food waste is critical to address the global challenges of climate change, resource depletion, and food security. It requires a concerted effort from all actors along the food supply chain, from producers to consumers, to reduce waste and adopt sustainable practices (Morone et al., 2019).

4.2. Current waste management practices and their limitations

Waste management is the process of collecting, treating, and disposing of waste materials. The current waste management practices vary depending on the country, region, and local context. However, most of these practices have limitations that need to be addressed to ensure sustainable waste management.

One of the most common waste management practices is landfilling. Landfills are sites where waste is buried in the ground, often covered with soil or other materials to reduce odors and prevent the release of contaminants (Siddiqua et al., 2022). While landfilling is a relatively low-cost option, it has several limitations. One of the most significant limitations is that landfills take up valuable land that could be used for other purposes. Additionally, landfills can produce leachate, a liquid that contains contaminants such as heavy metals and organic compounds that can pollute nearby groundwater and surface water (Swati et al., 2018). Landfills can also emit methane, a potent greenhouse gas that contributes to climate change, and other air pollutants that can harm human health (Mar et al., 2022).

Another waste management practice is incineration. Incineration is a waste management practice that involves burning waste to produce energy or dispose of it. While incineration can reduce the volume of waste and generate energy, it also has significant limitations (Rahman & Alam, 2020). One of the most significant limitations is that it emits air pollutants such as dioxins, furans, and heavy metals, which can harm human health and the environment (Tait et al., 2020). Incineration can also be expensive to operate, as it requires high capital investment and maintenance costs. Furthermore, incineration produces ash, which can contain hazardous waste and requires careful disposal to prevent further environmental damage (Shilkina & Niyazov, 2018; Incineration, 2000).

Recycling is another common waste management practice that involves processing waste materials to produce new products. Recycling has many benefits, including conserving resources, reducing energy consumption, and reducing waste (Rashid & Shahzad, 2021). However, it also has limitations. One of the most significant limitations is that not all waste materials can be recycled (Goossens et al., 2019). For example, certain plastics cannot be recycled or can only be recycled a limited number of times. Additionally, the recycling process can be energy-intensive and require significant investment in recycling facilities (Pleissner, 2018). Furthermore, the effectiveness of recycling programs depends on the cooperation of the public, which can be difficult to achieve (Fogarty et al., 2021).

Composting is a waste management practice that involves the decomposition of organic waste to produce compost, a nutrient-rich soil conditioner. Composting has many benefits, including reducing the volume of waste,

conserving resources, and reducing greenhouse gas emissions (Ayilara et al., 2020). However, it also has limitations. One of the most significant limitations is that composting requires specific conditions to be effective, such as the right temperature, moisture, and oxygen levels. Achieving these conditions can be challenging, particularly on a large scale (Waqas et al., 2023). Furthermore, composting may not be suitable for all types of organic waste, such as waste containing pathogens or hazardous substances.

Finally, waste reduction and avoidance are waste management practices that aim to reduce the amount of waste generated. This involves minimizing waste at the source, such as through product design and packaging reduction, and promoting sustainable consumption patterns. While waste reduction and avoidance have many benefits, they also have limitations (Ferronato & Torretta, 2019). One of the most significant limitations is that they require significant behavioural and societal changes, which can be challenging to achieve. Furthermore, the effectiveness of waste reduction and avoidance programs depends on the cooperation of multiple actors, including producers, consumers, and policymakers (Whitmarsh et al., 2018).

In conclusion, current waste management practices have limitations that need to be addressed to ensure sustainable waste management. Landfilling, incineration, recycling, composting, and waste reduction and avoidance all have advantages and disadvantages. The choice of waste management practice depends on local context, waste characteristics, and sustainability goals (Ardrá & Barua, 2022). Therefore, it is crucial to adopt a holistic approach to waste management that considers the entire waste management system, including waste generation, collection, treatment, and disposal. This requires the cooperation of multiple stakeholders, including government, industry, civil society, and the public, to adopt sustainable waste management practices that protect human health and the environment.

5. Circular economy strategies for sustainable waste management in the food industry

Circular economy strategies for sustainable waste management in the food industry can include several approaches. One is to minimize waste generation by optimizing production processes and reducing losses during transportation and storage. Another is to reuse waste materials as inputs in other industries or products. For example, food waste can be converted into biogas or compost, which can then be used as a source of energy or fertilizer. Additionally, recycling and repurposing of packaging materials can also be effective strategies to reduce waste (Ghisellini et al., 2016). Overall, a circular economy approach can help the food industry move towards more sustainable waste management practices, reducing environmental impacts and generating economic benefits (Rico Lugo et al., 2023).

5.1. Prevention strategies

Prevention strategies are one of the most effective ways to address the issue of waste management in the food industry. By reducing the amount of waste generated in the first place, companies can minimize their environmental impact and save costs associated with waste disposal. Prevention strategies can take many forms, but two of the most common approaches are reducing food waste and minimizing packaging (Lemaire & Limbourg, 2019; Al-Obadi et al., 2022).

Reducing food waste is an important prevention strategy in the food industry. Food waste occurs at all stages of the food supply chain, from production and processing to distribution and consumption. By implementing measures to reduce food waste, such as optimizing production processes, improving storage and transportation, and educating consumers on how to minimize waste, companies can significantly reduce the amount of food waste generated (Martin-Rios et al., 2022). This not only benefits the environment but can also help companies save money by reducing the need for waste disposal and lowering production costs.

Another important prevention strategy is minimizing packaging. Packaging is a necessary part of the food industry to ensure that products are protected during transportation and storage. However, excessive packaging can contribute to waste and environmental harm. To minimize packaging waste, companies can implement measures such as using eco-friendly materials, reducing the size and weight of packaging, and promoting the use of reusable or recyclable packaging materials (Musicus et al., 2022). These measures can help companies reduce their environmental impact and promote a circular economy approach to waste management (Geueke et al., 2018).

So, prevention strategies are a crucial element in the pursuit of sustainable waste management in the food industry. By reducing food waste and minimizing packaging, companies can significantly reduce their environmental impact, save costs, and promote a circular economy approach to waste management (Cristóbal et al., 2018). With the increasing focus on sustainability and environmental responsibility, prevention strategies are likely to become even more important in the future.

5.2. Recycling strategies

Recycling strategies play a significant role in sustainable waste management in the food industry. Recycling can reduce the amount of waste sent to landfills and incinerators, conserve natural resources, and create economic opportunities (Omari et al., 2023). There are several recycling strategies that can be employed in the food industry, including composting, anaerobic digestion, and recycling of packaging materials.

Composting is a recycling strategy that involves the decomposition of organic waste materials, such as food scraps and yard trimmings, into a nutrient-rich soil

amendment called compost (Cerda et al., 2023). Composting can help divert organic waste from landfills and reduce greenhouse gas emissions by preventing the decomposition of organic waste in landfills. Additionally, compost can be used as a soil amendment to improve soil quality and support plant growth (Sánchez, 2022).

Anaerobic digestion is another recycling strategy that involves the decomposition of organic waste in the absence of oxygen, producing biogas and digestate (Xu et al., 2018). Biogas is a renewable energy source that can be used to generate electricity and heat, while digestate can be used as a fertilizer (Uddin et al., 2021). Anaerobic digestion can help divert organic waste from landfills, reduce greenhouse gas emissions, and generate renewable energy (Zhang et al., 2017).

Recycling of packaging materials is also an important recycling strategy in the food industry. Packaging materials, such as plastic, paper, and glass, can be recycled into new products, reducing the demand for virgin materials and conserving natural resources (Mahesh Kumar et al., 2016). Companies can implement measures such as using eco-friendly packaging materials, promoting the use of reusable packaging, and implementing recycling programs to reduce the environmental impact of packaging waste (Marsh & Bugusu, 2007).

Overall, recycling strategies are an essential component of sustainable waste management in the food industry. Composting, anaerobic digestion, and recycling of packaging materials can help divert waste from landfills, conserve natural resources, and create economic opportunities. By implementing these strategies, companies can reduce their environmental impact and move towards a more circular economy approach to waste management (Geueke et al., 2018).

5.3. Recovery strategies

Recovery strategies are an important aspect of sustainable waste management in the food industry. Recovery strategies involve extracting valuable compounds from waste materials to create new products, reducing waste and creating economic opportunities. One example of a recovery strategy in the food industry is the extraction of valuable compounds from food waste (Kumar et al., 2017). Food waste is a significant problem in the food industry, and it is estimated that up to one-third of all food produced is lost or wasted. However, food waste contains valuable compounds that can be extracted and used to create new products (Dhua et al., 2022). For example, food waste can be processed to extract bioactive compounds, such as antioxidants, which can be used in the cosmetics, pharmaceutical, and food industries (Panzella et al., 2020). Another example of a recovery strategy in the food industry is the production of animal feed from food waste. Food waste can be processed to create animal feed, which can help reduce the environmental impact of livestock production by reducing the need for feed made from virgin materials (Murugesan et

al., 2021). In addition to these examples, recovery strategies can also include the production of renewable energy from waste materials. For example, food waste can be used to produce biogas through anaerobic digestion, which can be used to generate electricity and heat (Hamad et al., 2014).

Overall, recovery strategies play an important role in sustainable waste management in the food industry. By extracting valuable compounds from food waste, companies can reduce waste, create economic opportunities, and promote a more circular economy approach to waste management (Scarano et al., 2022). As the food industry continues to focus on sustainability and environmental responsibility, recovery strategies are likely to become even more important in the future.

6. Case studies of circular economy strategies in the food industry

Circular economy strategies have gained traction as a critical approach to sustainable waste management in the food industry. Companies are adopting circular economy strategies to reduce waste, conserve natural resources, and create economic opportunities. Successful implementation of these strategies requires an understanding of the benefits and challenges they present. In this article, we will review some case studies of circular economy strategies in the food industry and explore the benefits and challenges of these strategies (Scarano et al., 2022).

Case Study 1: Starbucks is a multinational coffee company with a commitment to sustainable waste management. The company has adopted circular economy strategies to reduce waste and create economic opportunities. One of the most successful circular economy strategies that Starbucks has implemented is the recycling of coffee grounds. Starbucks recycles used coffee grounds to create a nutrient-rich compost that is used to grow coffee, tea, and other plants. This circular economy approach has reduced waste, conserved natural resources, and created economic opportunities for Starbucks (Eshelman, 2022). The company has also partnered with other organizations to promote sustainable waste management practices, including composting and recycling. Some of the benefits include reduced waste, conserved natural resources, new economic opportunities, improved environmental sustainability, and enhanced corporate social responsibility. Some of the challenges include difficulty in implementing composting and recycling programmes, a lack of consumer awareness about composting and recycling, and limited infrastructure for composting and recycling (Tsai et al., 2020).

Case Study 2: Nestle, a multinational food and beverage company, has implemented circular economy strategies to reduce waste and conserve natural resources. One of the most successful circular economy strategies that Nestle has implemented is the recycling of plastic packaging (Espinoza-Orias et al., 2018). Nestle has committed to using 100% recyclable or reusable packaging by 2025. The company has also invested in the development of new

recycling technologies to reduce waste and conserve natural resources (Meier, 2018). Additionally, Nestle has partnered with other organizations to promote sustainable waste management practices and reduce the environmental impact of its operations (Eugénio et al., 2022; Galli et al., 2020).

Case Study 3: Danone, a multinational food and beverage company, has implemented circular economy strategies to reduce waste and conserve natural resources. One of the most successful circular economy strategies that Danone has implemented is the use of recycled plastic in its packaging. Danone has committed to using 100% recycled plastic in its packaging by 2025 (*Circular Economy Model - Danone*, 2019). The company has also partnered with other organizations to promote sustainable waste management practices and reduce the environmental impact of its operations. Additionally, Danone has implemented innovative packaging solutions to reduce waste and improve the recyclability of its packaging (*Water Stewardship - Danone*, 2019).

India has a large and diverse food industry, and circular economy strategies have been implemented by companies across the sector. Here are a few Indian case studies of circular economy strategies in the food industry:

Case Study 4: Mother Dairy is a leading milk and dairy products company in India. The company has implemented circular economy strategies to reduce waste and create economic opportunities (Livemint, 2022). One of the most successful circular economy strategies that Mother Dairy has implemented is the conversion of milk waste into biogas. Mother Dairy has installed a biogas plant at its milk processing facility in Ghaziabad, Uttar Pradesh, which converts milk waste into biogas. The biogas is then used as fuel for the company's operations, reducing its reliance on fossil fuels. This circular economy approach has reduced waste, conserved natural resources, and created economic opportunities for Mother Dairy (Casallas-Ojeda et al., 2021). But the main challenges include the high capital investment required for installing a biogas plant and the difficulty of sourcing raw materials for biogas production.

Case Study 5: ITC Limited is a leading food and beverage company in India with a commitment to sustainable waste management. The company has implemented circular economy strategies to reduce waste and create economic opportunities. One of the most successful circular economy strategies that ITC Limited has implemented is the use of agricultural waste as a raw material for its operations (*Sustainability at ITC*, 2022). ITC Limited sources agricultural waste, such as rice husk and wheat straw, from farmers in its supply chain and uses it as a raw material for its operations (*ITC's Agri Commodities and Rural Services*, 2022). This circular economy approach has reduced waste, conserved natural resources, and created economic opportunities for farmers and ITC Limited (*ITC Intensifies Its 360-Degree Interventions towards Waste Management*, 2022; *ITC Raw Materials & Products*, 2022).

Case Study 6: Chintan Environmental Research and Action Group is an Indian non-governmental organization that works on waste management and environmental sustainability. The organization has implemented circular economy strategies to reduce waste and create economic opportunities in the informal waste sector (Chintan, 2023). Chintan has implemented a project called "Kabad se Jugad" (From Waste to Innovation) in Delhi, which involves training waste pickers to create new products from waste materials, such as paper, plastic, and metal. The products are then sold to consumers, creating economic opportunities for waste pickers and reducing waste. But the main challenges include limited infrastructure for waste collection and management in some regions and limited consumer demand for recycled products (*Beat Plastics Pollution*, 2018).

Overall, these case studies demonstrate that circular economy strategies can be successfully implemented in the food industry. These strategies have a range of benefits, including waste reduction, conservation of natural resources, economic opportunities, and enhanced corporate social responsibility. However, implementing circular economy strategies can also present challenges, including difficulty in implementing composting and recycling programs, lack of consumer awareness, and limited infrastructure for composting and recycling. To address these challenges, companies can collaborate with other organizations, invest in innovative technologies, and educate consumers about the benefits of circular economy strategies (Kumar et al., 2022; Nattassha et al., 2020). By adopting circular economy strategies, companies can reduce their environmental impact, promote sustainable waste management practices, and create economic opportunities.

7. Conclusion

Circular economy strategies are crucial for sustainable waste management in the food industry. The food industry generates a significant amount of waste, including food waste, packaging waste, and other materials, which can have negative impacts on the environment, human health, and the economy. Implementing circular economy strategies can help reduce waste, conserve natural resources, and create economic opportunities. The importance of circular economy strategies for sustainable waste management in the food industry cannot be overstated. The food industry is a significant contributor to global waste and environmental problems, and it is essential that companies take responsibility for their waste and implement strategies to reduce it. By adopting circular economy strategies, companies can reduce their environmental impact, conserve natural resources, and create economic opportunities.

Future research directions in this area include:

Developing more efficient and effective circular economy strategies for sustainable waste management in the food industry. There is still much room for improvement in terms of waste reduction, recycling, and recovery.

Conducting more research on the economic benefits of circular economy strategies for the food industry. While circular economy strategies can be costly to implement initially, they can also create economic opportunities in the long run.

Increasing consumer awareness and education about the benefits of circular economy strategies. Consumers play an important role in waste reduction and recycling, and it is important to educate them about the benefits of circular economy strategies.

Encouraging more collaboration and partnerships between companies, governments, and non-governmental organizations to promote circular economy strategies in the food industry. Collaboration can help overcome the barriers to implementation and create more effective and sustainable strategies.

In conclusion, circular economy strategies are essential for sustainable waste management in the food industry. These strategies can help reduce waste, conserve natural resources, and create economic opportunities. While there are still challenges and barriers to implementation, the benefits of circular economy strategies are clear. As the food industry continues to focus on sustainability and environmental responsibility, circular economy strategies are likely to become even more important in the future.

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