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Circular Economy: a new opportunity for food waste and loss reduction in the food industry

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INTRODUCTION

Despite its economic importance, the current food industry has a significant challenge: food waste and loss. The latter has various implications for the economy, as important resources are wasted, for the people, as millions go hungry and undernourished, and, finally, for the environment, as food waste causes land degradation, wasted water, and pollution.

Incorporating circular economy principles into the food supply chain has the potential to address these concerns while also generating a more sustainable and resilient system. Indeed, the Circular Economy concept seeks to reduce waste, maximize resource usage, and preserve the value of products, materials, and resources inside closed-loop processes. As a result, has grown in popularity in recent years, providing a potential answer to critical challenges such as waste generation, resource depletion, and environmental damage.

The importance of this study stems from the increased awareness of the negative repercussions of food waste and unsustainable resource management techniques in the food supply chain. Thus, the purpose of this research is to investigate the benefits and obstacles of implementing circular economy strategies within the food supply chain in order to generate long-term solutions for the sector.

The study's aims are divided into three categories. Firstly, it seeks to look into how circular economy techniques improve resource efficiency in the food supply chain. Second, it aims to measure how well circular economy strategies reduce food waste in the industry. Finally, it seeks to identify the key barriers to applying circular economy approaches in the food sector.

However, it is critical to recognize the study's potential shortcomings. Because of the specific context and scope of the research, generalizability may be limited. The availability and accessibility of data may also limit the complete evaluation of circular economy strategies and their impact. Furthermore, the study may contain biases and limitations as a result of its dependence on existing literature and secondary data, which may impair the credibility of the sources and methodology used.

The study will go into the notion of circular economy in the first chapter, exploring its principles, global landscape, and distinctions from the current linear economy. Furthermore, the relationship between the concept of circular economy and sustainability will be investigated. The second chapter will delve into the serious issue of food waste, including its scope, causes, and repercussions for both the environment and society. The research will look into consumer behavior and the psychology of food waste production, as well as policy initiatives to reduce it. Finally, the study will look into the many circular business models and potential industrial uses of food waste, highlighting real-world examples and addressing the complexity inherent in the shift to a circular food industry.

Finally, the purpose of this research is to investigate how circular economy techniques might improve the food supply chain by focusing on waste reduction, resource efficiency, and environmental sustainability. It aims to close a research gap in the food industry and give vital insights for businesses, governments, and researchers, allowing for the adoption of more sustainable and resilient practices in the pursuit of a better future.

CHAPTER 1: THE CIRCULAR ECONOMY

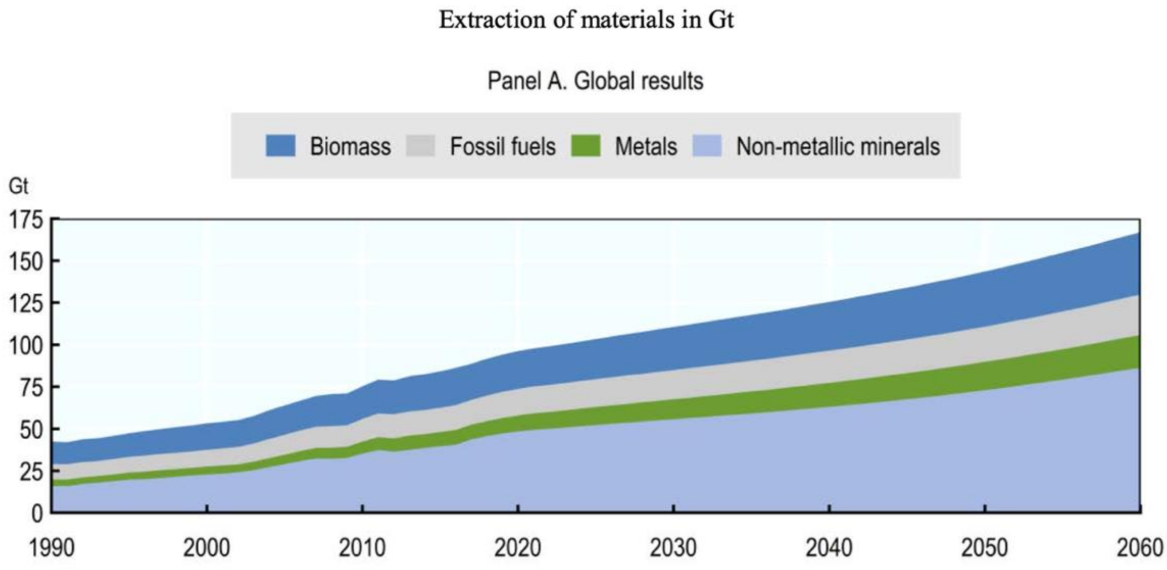
1.1 The Linear Economy and its implications

The global economy has encountered exponential changes over the past few centuries, from the Industrial Revolution to the rise of the internet. Since then, these developments have resulted from a linear economy based on a "Take-Make-Use-Dispose" model (Andrews, 2015).

The linear economy begins with the extraction of raw materials from the surrounding environment. Subsequently, these materials undergo a process of transformation through various manufacturing techniques, resulting in the creation of products that are sold to consumers afterwards. The length of this phase exhibits considerable variation depending on the type of product and consumer behavior. Certain objects, such as disposable items, possess a significantly limited duration of utility while others, such as automobiles and household appliances, exhibit a prolonged duration of usability. The last phase entails the disposal process, wherein products that have become obsolete or unwanted are eliminated (Stahel, 2016). This phase of the product lifecycle is characterized by the loss of materials and energy, as the resources of the discarded products are not recovered or effectively utilized. (Korhonen et al., 2018).

As many nations continue to prioritize economic development, production, consumption, and resource extraction continue to rise. According to the OECD (2019), the use of primary materials, which are defined as novel materials derived from mining and resource exploitation, varies by country and is inversely proportional to its level of development. Examples include fossil fuels for Russia, metals for Australia and Chile, and biomass for sub-Saharan Africa. From 1990 to 2017, their demand increased by more than twofold. This increase is attributable to multiple factors, including population growth, economic expansion in OECD nations, and rising living standards in emergent economies such as India. In the coming decades, countries with rapid population growth such as emerging nations, will lead the expansion of the global GDP. Moreover, the global population is projected to reach 10.2 billion in 2060, an increase of 2.7 billion from 2017's 7.5 billion, alongside a tripling of global GDP. This increase will result in a doubling of primary material consumption by 2060, particularly in economies with rapid growth. (OECD, 2020)

Figure 1: Global material extraction projection



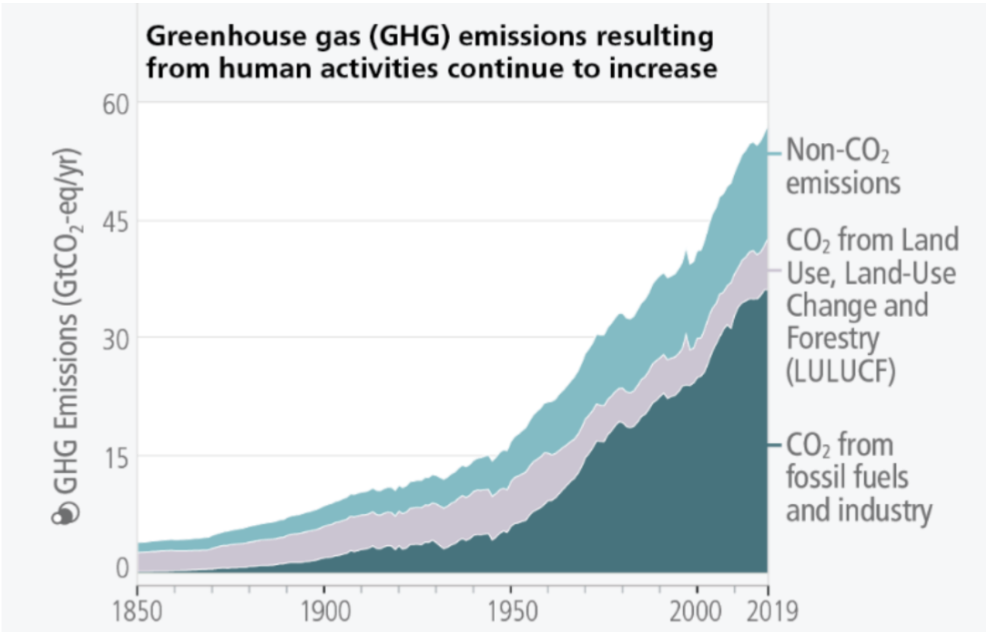
Source: OECD

Despite having driven the global economy, the intensive use of resources, from extraction to consumption and disposal, has proven to be unsustainable. Indeed, this model has several environmental implications, including the depletion of natural capital and the diminution of its value (Murrey et al., 2017). Staudt et al. (2013), identified different categories that have considerably contributed to the damage of natural systems, among which there are resource extraction, land-use and land-cover change (LULCC), and pollution. These categories have led to the loss of biodiversity, degradation of ecosystems, and climate change.

The IPCC's (2023) recent report emphasized the escalation of global warming resulting from the release of greenhouse gas emissions (GHG). The energy sector is accountable for nearly half of greenhouse gas (GHG) emissions, with industry, agriculture and other land use, transportation, and building sectors following suit. The release of hazardous substances is not solely confined to the atmosphere, as human activities also contribute to the pollution of water and soil. According to Havugimana et al. (2017), soil pollution is primarily caused by the presence of solvent, petroleum hydrocarbons, and heavy metals, which can be traced back to various manufacturing and mining activities. Additionally, soil that is contaminated with pollutants poses a potential risk for the contamination of freshwater and marine ecosystems. Landrigan et al. (2020) reported that a combination of pesticides, fertilizers, toxic metals, and chemicals is transported to the marine environment via rivers and runoff.

The presence of these pollutants has adverse impacts on both the marine ecosystem and human health, as they disrupt photosynthesis and contaminate seafood. As previously stated, the alteration of natural systems is occurring through land-use and land-cover change, which involves the conversion of natural habitats for agricultural purposes and the development of infrastructure. Habitat fragmentation and loss have resulted in the deprivation of habitats for numerous species, leading to the potential extinction of approximately one million plants and animals (WWF, 2022).

Figure 2: Greenhouse gas emissions from human activities



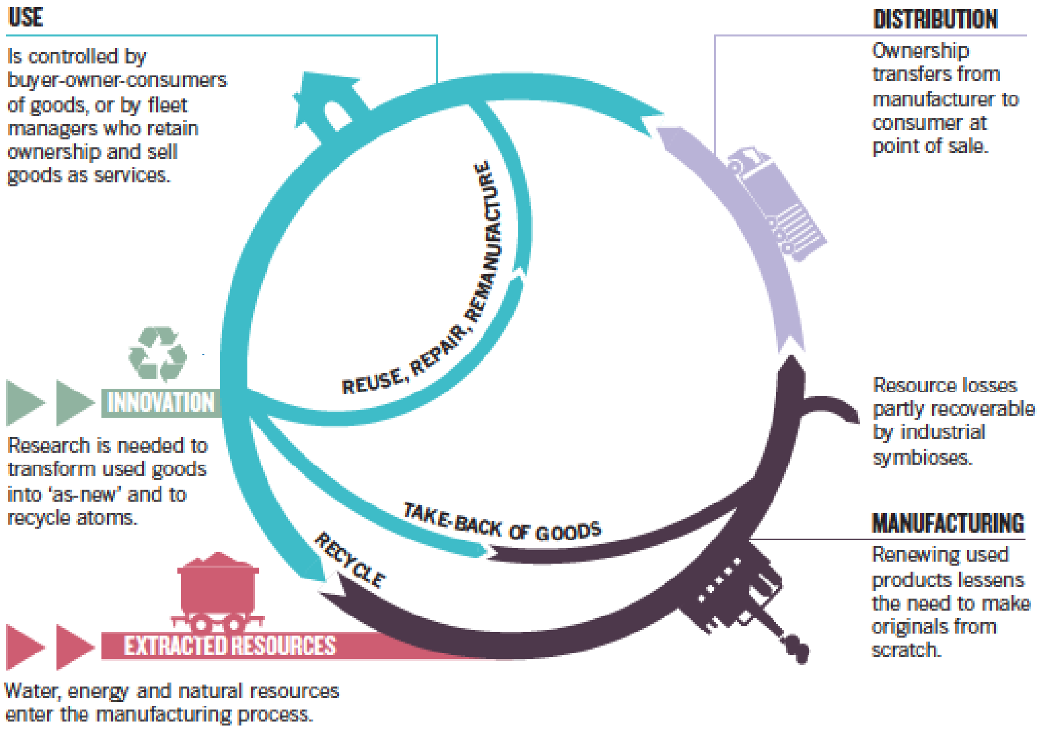
Source: IPCC

1.2 The concept of the Circular Economy

The Circular Economy (CE) has emerged as a viable alternative to the conventional model of the linear economy. As pointed out by Murray et al. (2017), the precise etymology of the term remains uncertain; however, two distinct connotations can be derived. The initial descriptive aspect pertains to the contrasting nature of the circular economy in comparison to the linear economy. On the other hand, the subsequent linguistic aspect pertains to the word “circular” which is associated with the cyclical processes observed in nature and the notion of recycling. An economy that is circular differs from a linear economy as it does not have any detrimental effect on the environment, but instead restores the damages already made and reduce the quantity of waste that is produced.

Characterized by a closed loop, it achieves value through redesign processes and improvements in resource use. The rate of change is seen as fundamental, which the Circular Economy tries to restore, slowing down the flows of materials to their natural levels thanks to improved manufacturing and maintenance. (Murray et al., 2017)

Figure 3: Circular Economy framework



Source: Nature publishing

Due to the multitude of definitions on the Circular Economy, several authors have conducted analysis highlighting commonalities and differences among them. Studies made by Kalmykova et al. (2018), highlighted the presence of common principles including stock optimization, waste management and eco-efficiency, as well as differences within the scope of Circular Economy in term of resources. Furthermore, an analysis conducted by Kirchherr et al. (2017) of more than one hundred definitions underscored the existence of divergent interpretations among scholars regarding the concept of the circular economy. The findings suggests that this divergence can be attributed, at least in part, to the varying perspectives on how to define the circular economy. Some authors limit the concept of Circular Economy (CE) to the act of recycling, while others include the ideas of reduction and reuse as well.

As a result, a novel proposition for the definition of the circular economy was put forth, which is articulated as follows: "[CE] is an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generation" (Kirchherr et al., 2017)

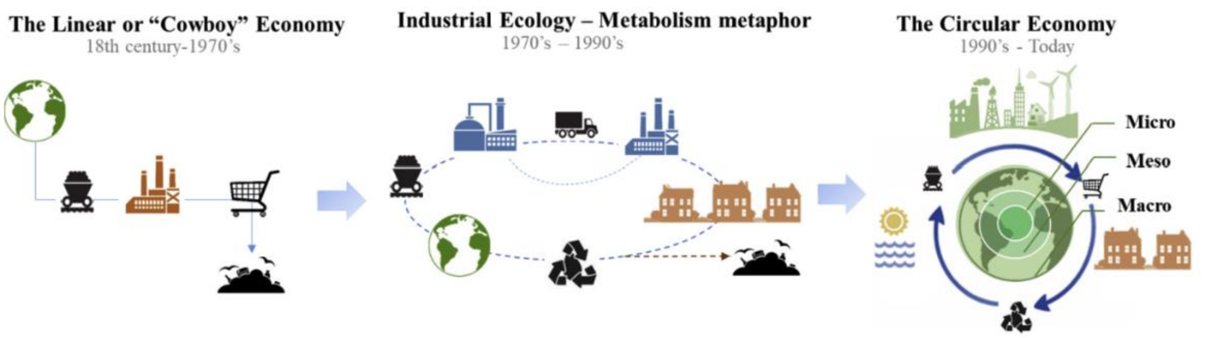
According to Ghisellini et al. (2016) the origins of the Circular Economy trace back to the work made by several authors about industrial ecology, environmental and ecological economics. Studies conducted in the 60's by the ecological economist Boulding introduced an interest on the environment, questioning the linear economic model, also known as "Cowboy" Economy. In his book called "The Economics of Spaceship Earth" Boulding provided a description of an economic system that can be alternatively referred to as a "spaceman" economy, wherein the economy was self-contained and operated within its own boundaries. This approach conceptualized the Earth as a singular spacecraft with finite resources, where humans could only re-establish a symbiotic relationship with the cyclical ecological system, making a perpetual reuse of materials.

Subsequently, during the 1990s, scholars Pearce and Turner introduced the notion of the circular economy in their book titled "Economics of Natural Resources and the Environment." Based on prior research conducted by Boulding, the two economists presented a critique of the conventional open-ended economic model, highlighting its propensity for waste generation. The authors argued the possibility of transitioning from an open-ended system to a closed system, drawing inspiration from the principles outlined in the laws of thermodynamics.

Defined as a discipline that studies the interdependencies and interrelationships among industrial systems and the natural environment, also Industrial Ecology builds on concepts presented in Boulding's work. Intersecting multiple disciplines, such as the natural sciences, engineering, and the social sciences, the objective is to replicate the operational mechanisms of ecological systems through the establishment of closed-loop systems, wherein the by-products generated from one process are transformed into valuable resources for another process.

The field of industrial ecology frequently involves the quantitative analysis of material and energy flows within society, as well as their interactions with the natural environment, including resource extraction and emissions. These analyses concentrate on various levels and scopes, ranging from eco-industrial parks and urban areas to nations and the global scale. Industrial ecology encompasses various methods and approaches, including material flow analysis, environmentally extended input-output analysis, and industrial symbiosis. (International Society for Industrial Ecology, n.d.)

Figure 3: The path to the Circular Economy



Source: Prieto-Sandoval et al., 2018

The concept of the Circular Economy does not trace back only to the aforementioned schools of thought. Indeed, the following theoretical frameworks have contributed as well to its development:

Blue Economy: According to its creator, Gunter Pauli, the Blue Economy is founded upon the principles of ecosystem regeneration, guided by a framework of abundance and self-sufficiency. Drawing inspiration from the natural world, this system operates in a state of symbiotic harmony with its surrounding environment, without producing waste or emissions. The economic model under consideration promotes for the creation of new employment opportunities and the enhancement of social cohesion by leveraging existing natural resources. This is achieved through the adoption of strategies that aim to increase productivity while minimizing the use of resources. These strategies encompass various analytical tools such as material flow analysis, environmentally extended input-output analysis, and industrial symbiosis. (The Blue Economy, 2022)

Biomimicry: The concept of “biomimicry” gained widespread recognition following its introduction by Janine Benyus, an American biologist and author, in her publication titled “Biomimicry: Innovation Inspired by Nature” in 1997. Biomimicry can be conceptualized as a methodology for innovation, wherein human design challenges are addressed through the examination of natural models and subsequent imitation or inspiration of their designs and processes. The primary objective is to develop innovative products and processes in a sustainable manner, with the aim of enhancing the quality of human life. Simultaneously, this pursuit also seeks to foster a deeper comprehension of the natural world. (Biomimicry Institute, 2023)

Cradle To Cradle (C2C): The concept was developed by architect William McDonough and chemist Michael Braungart in their book titled “Cradle to Cradle: Remaking the Way We Make Things.” The authors’ design framework is founded upon three principles that draw inspiration from natural systems: the utilization of all resources as potential sources, the adoption of clean and renewable energy sources, and the recognition and appreciation of diversity. The first principle sees waste produced by one system as food for another; what is no longer necessary can be reintegrated into the soil as biological nutrient or repurposed as technical nutrient for the creation of new products, without any detrimental effect for nature. The second principle advances the possibility for human activities to use renewable energy sources such as solar and wind, just as it is already done in nature. Regarding diversity, this should be promoted and emphasized as each design works best when takes into consideration the local environment. The main goal of the Cradle to Cradle (C2C) approach is to establish and execute a regenerative system that uses the already available resources multiple times, and instead of minimizing waste does not produce any of it. (William McDonough, 2022)

Cradle to Cradle, along with other theoretical frameworks such as Industrial Ecology, are regarded as idealistic visions, despite being one of the most essential concepts for the Circular Economy. According to Khoronen et al. (2018), C2C and Industrial Ecology seek to implement a single system based on complete recycling and the use of only renewable resources, which is impossible. Instead, it is possible to preserve resources using nature’s cycles, as the flow of materials from the economy should enable nature to incorporate them into its own cycles.

1.3 Circular Economy principles

In addition to the various definitions of the concept of the Circular Economy, there are also a number of fundamental principles associated with it. Two different groups can be distinguished: the first relates to the adoption of the 3Rs (Reduce, Reuse, Recycle) as guiding principles, while the second relates to the so-called Sustainable Design Strategies (Prieto-Sandoval et al., 2018).

Reduce: It denotes the reduction of resource consumption and waste generation across all processes. Several strategies can be employed to achieve this goal, including enhancing production processes to minimize resource utilization and promoting shifts in consumer behavior towards more sustainable consumption patterns. The implementation of waste reduction strategies at the origin can effectively contribute to the preservation of natural resources, the conservation of energy, the mitigation of pollution, and the realization of economic advantages for both businesses and consumers (U.S. EPA, 2023).

Reuse: According to the European Commission (2008) the practice of reuse is defined as "any operation by which products or components that are not waste are used again for the same purpose for which they were conceived". Some examples of reuse can be replenishing a bottle of water or buy second-hand clothes (European Commission, 2008).

Recycle: The process of recycling entails the transformation of waste into novel materials or products, contributing to the conservation of resources, the preservation of energy, and the mitigation of pollution. Nowadays, there are several ways in which recycling can be supported such as purchasing products made from recycled materials, or that can undergo recycling. It is crucial to acknowledge that not all materials possess the capability to undergo recycling, and it is worth noting that the recycling process itself may occasionally result in adverse environmental consequences. Therefore, it is of utmost significance to ensure that recycling is executed in a manner that is both appropriate and efficient (U.S. EPA, 2023).

If a hierarchy is established among the three principles, recycling should be considered the final stage in the Circular Economy process. This is because the other two principles, namely reduce and reuse, are more cost- and energy-efficient than recycling alone. Moreover, the value of resources is better preserved prior to recycling, as it is lost upon combustion (Khoronen et al., 2018).

In the second group of principles, that of sustainable design stategies, can be found the ones presented by The Ellen MacArthour Fundation, a global authority in advocating the Circular Economy. Three key principles are defined: eliminate waste and pollution, circle product and materials and, regenerate nature.

The first principle posits that waste arises from the manner in which items are manufactured, as a significant proportion of them are designed with the intention of being discarded. This statement contradicts the principles of the natural world, where the concept of waste is absent. In the context of the circular economy, a fundamental principle dictates that materials ought to be reintegrated into the economic system once they have fulfilled their intended purpose. Indeed, it is feasible to avoid waste by prioritizing design of products (Ellen MacArthur Fundation, n.d.)

The second principle recommends maximizing the use of commodities and materials as products, components, and basic materials. Consequently, the materials' value is maintained and nothing is lost. The technical and biological cycles depicted in the Cradle to Cradle concept serve as a source of inspiration for maintaining items in circulation. In the technical cycle, products retain their full value more effectively if they are kept intact. This can be accomplished through reuse, renovation, and restoration cycles. In the biological cycle, however, items that decompose and cannot be used again, such as food waste, are reintroduced back into the economy. Thanks to composting or anaerobic digestion, the valuable nutrients contained in organic materials can be used to help the land recover and cultivate more food or renewable materials such as cotton and wood. In a nutshell, products must be manufactured with the technical or biological cycles in mind so that they can be utilized as much as possible in the economy. (Ellen MacArthur Fundation, n.d.)

The third and last principle, that of regenerating nature, highlights the ability of the circular economy to help nature renew itself. By keeping goods and materials in circulation, less land is required to extract new raw materials, and it is progressively possible to separate economic activity from material extraction. This means that increasing amounts of land can be returned to nature and restored. In a circular economy, the land used to obtain materials will be devoted primarily to the growth of resources that can be used multiple times, as opposed to the extraction of materials that can be used only once. (Ellen MacArthur Fundation, n.d.)

1.4 China and EU: two different perspectives on CE policies

Governments and international organizations are designing and implementing policies to encourage the adoption of circular practices based on the principles presented above. In this perspective, China and the European Union can be regarded as global leaders.

China's decision to adopt the Circular Economy is influenced by a number of factors. These include the adverse state of the environment caused by accelerated economic growth, the inadequacy of resources to meet rising demand, and the potential to enhance national security by prioritizing sustainable energy resources (Su et al., 2013). In China, the Circular Economy concept was introduced in 1998, and the State Environmental Protection Administration was the first government agency to promote and initiate initiatives involving circular practices, such as eco-industrial parks, the following year (Yuan et al., 2006). However, the Chinese government did not officially recognize CE as a new development strategy until 2002, with the goal of attaining a harmonious balance between sustainable social and economic development and environmental conservation. After 2002, the government issued several laws to promote the circular economy, including the "Cleaner Production Promotion Law" of 2003, the "Law on Pollution Prevention and Control of Solid Waste" of 2005, and the "Circular Economy Promotion Law" of 2009.

Two government agencies, the Ministry of Environmental Protection and the National Development and Reform Commission (NDRC), regulate the micro, meso, and macro implementations of circular practices in China. At the micro level, businesses are encouraged to adopt Cleaner Production auditing, whereas large polluters are obligated to do so. Moreover, at the local level, a public disclosure system divides businesses into five performance-based categories. At the meso level, the primary objective is the establishment of an eco-industrial network for the environmental and regional production system's benefit (Su et al., 2013).

The Tianjin Economic-Technological growth Area (TEDA), which was selected by the National Development and Reform Commission in 2005 as a demonstration of the growth of the circular economy, serves as an example. In 2008, TEDA was nominated as one of the first National Demonstration Eco-Industrial Parks (Shi et al., 2010). The region currently hosts 523 investment initiatives by 117 Fortune 500 companies, totaling 66.48 billion dollars (TEDA, n.d.). At the macro level, the objective is to create eco-cities, eco-municipalities, and eco-provinces.

The European Union (EU) has prioritized the advancement of a circular economy to uphold its dedication to resource efficiency and environmental preservation. The concept of environmental protection was initially established in 1986 with the implementation of the Single European Act. This conception was then reaffirmed by the Treaty of Lisbon, which also emphasized the European Union's commitment to achieving sustainable development (Massai, 2012). These treaties served as a legal foundation for the subsequent adoption of circular economy and sustainable resource utilization measures. In recent years, the implementation of resource-efficient measures has been attributed to a consistent rise in resource costs, particularly from 2002 to 2011 (Domenech; Bahn-Walkowiak, 2019).

The initial significant measure undertaken was the implementation of the first European circular economy action plan in 2015 (European Commission, 2015). The plan, which targeted the entire product life cycle, included several actions, such as: a revision of the eco-design directive for energy products to include reuse, reparability, and recycling among the product requirements; a strategy to address the issue of recyclability and biodegradability in plastics; as well as efforts to promote innovative circular projects through funding. Along with the action plan, the European Commission revised its legislative proposals on waste management, which included a common goal to recycle 65 percent of municipal waste and 75 percent of packaging waste by 2030, and to reduce landfills. A year after the adoption of the first circular economy package, more than four million people were employed in relevant enterprises. Moreover, activities based on circular principles generated over $100 billion in added value and attracted over $15 billion in investments.

In 2020, the European Union adopted a new action plan for the circular economy in response to the positive results obtained. The plan outlines four primary objectives: increasing the sustainability of products, facilitating consumers to make more informed decisions, reducing waste, and transforming resource-intensive industries into circular drivers (EC, 2020). In order to make this possible the Commission outlined multiple actions, that include:

- Broader application of the Eco-Design framework
- "Right to Repair" for consumers
- A circular initiative to prolong the product life of electronics and ICT

- A new strategy to promote innovation and competition in the textile market while ensuring reuse and recycling
- A sustainable strategy to promote circular practices in the built environment

The comparative study conducted by McDowell et al. (2017) examined the policies for circular economy (CE) in China and Europe, with the aim of identifying the differences and similarities between the two regions. The authors identified three major differences between the two policy frameworks:

The first distinction concerns the problems that the CE aims to solve. The increased industrialization and growth in China have resulted in significant environmental damage, thus necessitating the adoption of a circular economy as a fundamental solution. On the other hand, in the EU the foundation of the circular economy primarily revolves around innovation and economic progress, placing relatively little emphasis on environmental goals. Hence, it is perceived as a strategic reaction aimed at promoting regional development. Moreover, European policy documents tend to prioritize materials and waste management, whereas environmental pollution receives comparatively less attention when compared to the policy documents of China.

The second distinction concerns the objectives of the policy activity. Differently from China, the EU plan places more emphasis on consumption and product design. In fact, the action plan presents several initiatives aimed at promoting innovative consumption patterns that effectively mitigate material demands. The promotion law of China does incorporate provisions for eco design; nevertheless, it falls short in terms of the extent and breadth of European eco-design and durability measures. China's aims are mostly oriented at exerting less influence on purchasing habits. One plausible explanation is that the industrial sector in China surpasses that of Europe in terms of scale, hence leading to a greater emphasis on environmental concerns within their strategic frameworks.

Additionally, the European approach mostly neglects considerations of space and location, whereas the Chinese model places significant emphasis on that. Firstly, Chinese environmental policy actively promotes the implementation of CE principles in land-use planning. This is evident in the provisions outlined in the CE Promotion Law highlighting the importance of integrating residential, agricultural, and industrial activities in a manner that is ecologically sensitive and sustainable. Secondly, a notable feature of Chinese regulations is the identification and funding allocation towards provinces, cities, or zones as CE pilots or demonstrations.

Lastly, differences can also be observed in terms of targets and indicators to measure progress toward CE. In the European context, targets are established as objectives for member states, and they entail the imposition of penalties onto those that fail to meet them. An example are the recycling and landfill targets contained in the 2015's action plan. On the other hand, despite the Circular Economy action plan calls for a set of specific indicators to be established, it relies upon already existing sets such as the Resource Efficiency Scoreboard and the Raw Materials Scoreboard. The former has a hierarchical structure of indicators, with the first one being resource productivity, while the latter incorporates an indicator known as the end-of-life recycling input rate, which quantifies the percentage of inputs utilized by an industry that originate from recycled sources.

China has implemented a target responsibility system to facilitate the advancement of the circular economy. China offers a complete set of indicators at three distinct levels: micro (specifically at the firm level), meso (specifically within eco-industrial parks), and macro (specifically at the city or province level). These factors are crucial for conducting experimental trials in a regional pilot zone. In order to obtain classification, industrial parks and towns are required to submit an action plan that outlines the projected development of crucial indicators. The obligation to monitor and report on the indicators is limited to companies that have applied for designated status. The successful execution of these pilot initiatives necessitates the utilization of a standardized set of national indicators to interpret, compare, and assess progress. These indicators should be relevant to the geographical scope of the programs, aligning with China's multifaceted strategy.

The measures and objectives demonstrate the contrasting approaches to Circular Economy between Europe and China. China possesses a diverse range of pollution emission and abatement metrics, as well as notable water coverage. These metrics demonstrate their effectiveness on various geographical scales, hence exemplifying the successful implementation of China's well-organized CE system. In contrast, the objectives of the Circular Economy in Europe are tailored to specific waste streams and primary emphasis of key indicators lies in the evaluation of raw materials and resource productivity. Additionally, they demonstrate Europe's keenness towards innovation and economics in the field of CE.

1.5 Sustainability and the limits of Circular Economy

As demonstrated in earlier sections, the issues generated by the linear economy have prompted scholars, governments, and businesses to explore elsewhere for a sustainable answer, which they have found in the circular economy. Nonetheless, the notions of circular economy and sustainability have both similarities and distinctions. To gain a better understanding, it is necessary to place the definition of Circular Economy beside that of sustainability. The Brundtland Report from 1987 comes in handy, describing sustainability as "development that meets the needs of the present without compromising future generations' ability to meet their own needs" (Brundtland, 1987).

Elkington (1997) demonstrated the broad scope of sustainability by introducing the so-called triple bottom line, in which the social, economic, and environmental components are interconnected. Based on these three elements Khoronen et al. (2018) proposed three goals of the Circular Economy for a sustainable development: the reduction of virgin inputs, waste and pollution, as environmental objective; the reduction of resources and emission costs, as well as the creation of new employment and business opportunities, as economic objective; and finally, a shared economy based on practices of renting and leasing, as societal objective.

The analysis conducted by Geissdorfer et al. (2017) highlighted similarities as well as differences of the sustainability and CE concepts.

In terms of parallels, both concepts highlight the need of generational commitments motivated by environmental risks, as well as the importance of enhancing both individual and collective decision-making to achieve development. Furthermore, they both employ multidisciplinary or interdisciplinary methods to better include non-economic factors in development, that often lead to the conclusion that system design and innovation are the most important ways to reach their goals.

The concepts under consideration exhibit also distinct objectives, motivations, prioritizations, beneficiaries, timelines, and views of duties. Firstly, both CE and sustainability are related with distinct objectives. While it is evident that the Circular Economy strives for a closed-loop system that eliminates all resource inputs, waste, and emissions leakage, the objectives of sustainability are indefinite.

This phenomenon is also evident in the primary motivation that underlies each thought. The motivations underlying sustainability are derived from historical trajectories, exhibit a wide range of diffusion, and frequently incorporate elements of reflexivity and adaptivity. The Circular Economy instead, is primarily driven by the recognition that there is potential for improved resource utilization, waste reduction, and emission mitigation through the implementation of circular systems.

The Circular Economy exhibits a distinct emphasis on economic systems that prioritize environmental benefits as a key focus. On the other hand, the notion of sustainability was first conceived as an approach that gives equal importance and balance to all three dimensions. In this respect Murray et al. (2017) advanced a critic to the Circular Economy arguing that it does not take into consideration the societal aspect of sustainable development and it is not make clear how it intends to contribute to this aspect. Furthermore, there might be unintended consequences for the environment caused by both the application of sustainable practices such as the use of rare materials for green technologies, and by the longevity of products, that may require large amounts of energy to break them into manageable parts.

Going back to the distinctions between CE and sustainability highlighted by Geissdorfer et al. (2017), there is also a discernible distinction in agency, which refers to an individual's or entity's ability to influence the comprehension and subsequent implementation of changes within a given system. Although agency is distributed in the context of sustainability, the Circular Economy places a strong focus on the roles of governments and businesses.

Furthermore, there are significant differences in the commitments, ambitions, and interests that underlie the utilization of these terminologies. The primary emphasis appears to lie in the alignment of interests among stakeholders in the context of sustainability. In contrast, the Circular Economy places greater importance on financial benefits for enterprises, as well as reduced resource use and environmental degradation.

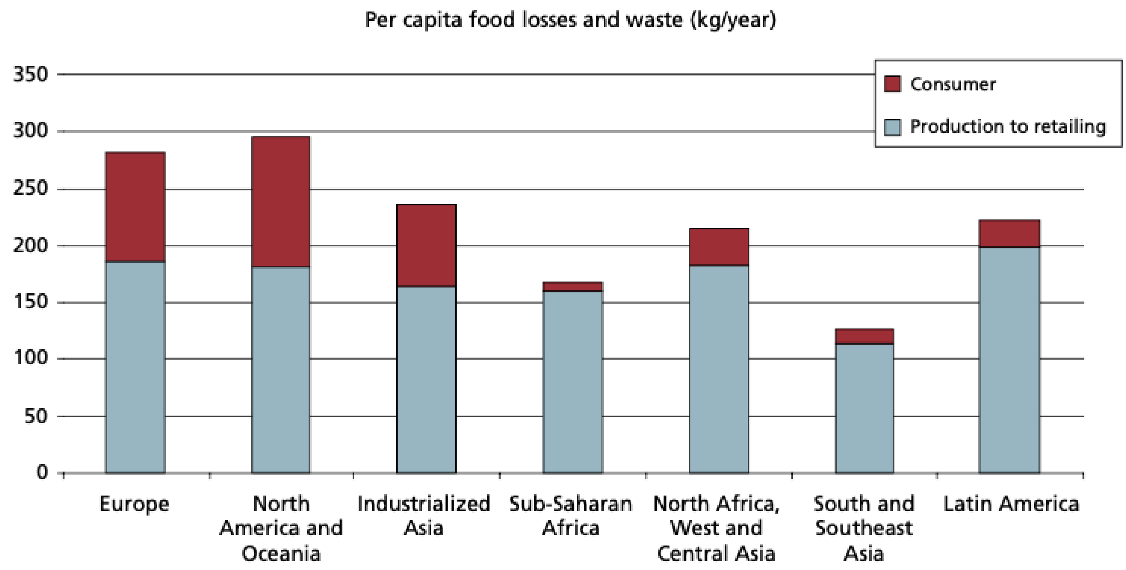
In a nutshell, as the Circular Economy focuses more on the economic and environmental aspect, differently from sustainability which encompasses also the societal aspect, the CE seems more attractive for businesses and policy makers than other approaches.

CHAPTER 2: FOOD LOSS AND WASTE

2.1 Food Loss and Waste: Extent and Causes

In a research carried out by the Food and Agriculture Organization (FAO) in 2011, around 1.3 billion tons of food produced for human use are lost or wasted annually across the whole supply chain (FAO, 2011). In Europe and North America around 300 kg/year of food per capita is lost, while around 170 kg/year of food per capita is lost in sub-Saharan Africa and South-east Asia, accounting for almost a third of the total per capita production of food (FAO, 2011). As the research shows, in already developed countries food is wasted at the retail and consumer level, differently from developing countries where lower levels of food are wasted at consumer level as it gets lost mainly in the early stages of the supply chain.

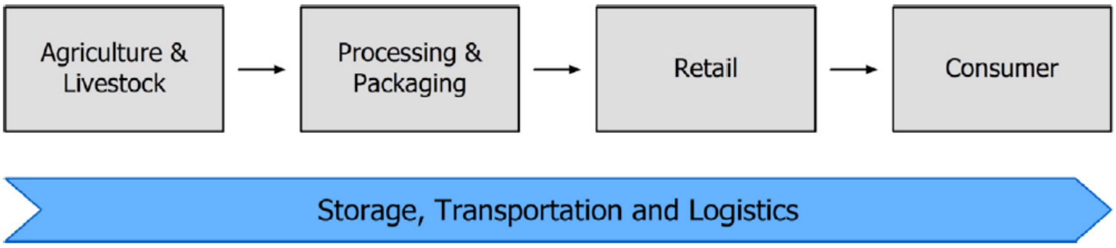
Figure 4: Per capita food loss and waste at different consumption stages



Source: FAO, 2011

Examining the food supply chain (FSC) is crucial for understanding where food is lost or wasted. However, it is important to define the terms "food waste" and "food loss" first, in order to gain an adequate comprehension. The former is defined as food intended for human use that is discarded. This can be due to food spoilage or other factors such as overproduction and individual habits (FAO, 2013). The latter is defined as the reduction in quantity or quality of food that was once intended for human consumption, mainly caused by inefficiencies within the food supply chain (FAO, 2013).

Figure 5: Food Supply Chain



Source: Raak et al., 2017

Parfitt et al. (2010) identified three key variables that influence food waste trends, particularly in developing and transitioning countries: urbanization and the decline of the agricultural sector, dietary changes, and trade globalization.

According to the authors, there has been a major shift away from agriculture as a source of employment throughout the years, as more and more people have moved to cities. Because of this urbanization trend, longer and more complicated food supply chains (FSCs) are required for sustaining urban populations. However, the development of supply chains has immediate and long-term implications for global food waste.

Furthermore, as household incomes improve, particularly in BRIC countries, people's diets change away from basic carbohydrate items and toward a more diverse consumption pattern that includes fresh fruits and vegetables, dairy, meat, and fish. This shift to more perishable, shorter-shelf-life items is linked to increasing food waste and increased demand for land and other resources.

Finally, while globalization provides opportunity for agricultural exports, it also poses obstacles for domestic market development, as greater competition from low-cost imports of higher-quality products can have an impact on local farmers. Furthermore, trade liberalization has resulted in the rapid expansion of international supermarket chains in many transitioning economies, altering the dynamics of food supply chains further (Parfitt et al., 2010).

2.1.1 Overproduction

The problem of overproduction is one of the primary factors leading to food waste in the early stages of the food supply chain. Messner et al. (2021) shed light on the factors driving and repercussions of this issue, particularly within the horticulture supply chain, in their study. Overproduction, according to the experts, is a common practice in the horticultural business, driven by three key factors.

To begin, overproduction is employed as a method to offset potential risks connected with unexpected weather patterns, growth cycles, and market fluctuations, so providing growers with a safety net. Second, the horticultural industry's intrinsic riskiness pushes producers to take calculated risks in order to explore new business opportunities. Furthermore, increasing agricultural yields is seen to be critical for profitability in this industry.

The competitive structure of the marketplace, which is defined by a high concentration of enterprises and an excess supply of goods and services, exacerbates the problem of overproduction. Growers must acquire supply contracts with major supermarkets, which serve as the key entry point into large-scale markets. Farmers pledge to meeting year-round demand, even if it means incurring financial losses, to ensure a regular and abundant supply and prevent competitors from taking advantage of future shortages.

In order to prosper in this competitive climate, many growers use intense cultivation of a restricted number of crops, taking advantage of economies of scale. This technique increases market availability of specific fruits and vegetables while increasing vulnerability to external variables such as pests and illnesses. Growers also strive to optimize profits throughout the short growing season, typically accepting low profit margins to match market pricing. The absence of market openness and data on actual demand complicates decision-making even more, with manufacturers relying primarily on advice from supermarket buyers.

Growers have the problem of managing surplus products within a confined timeline and geographical area as market values rapidly decrease as a result of overproduction. Their main goal is to reduce economic losses through cost-recovery optimization or cost-effective disposal solutions. However, the current supply chain infrastructure frequently falls short of these objectives. As a result, excess food is frequently discarded or used in other ways, such as livestock feed or compost.

2.1.2 Logistical operations and food processing

Food waste and loss in the supply chain can be caused by both logistical operations and food processing. According to Raak et al. (2017), all logistics steps in the food supply chain provide a mechanical risk to the food. This can happen in a variety of ways, beginning with basic package deformation, which might cause the product to be rejected or make it less desirable to consumers. Fresh food is easily damaged, squashed, or scratched during transport, leaving it more vulnerable to bacteria. As a result, if the damage is severe enough, the food cannot be used.

Some defects, even little ones, can cause food spoiling, such as insect bites during harvest or small holes made during cleaning, making it easier for organisms that cause food to spoil to attack it. The presence of bacteria in raw materials is not an issue in and of itself, as long as they are treated properly to prevent spoilage. As a result, when it comes to raw or barely cooked foods, microbial activity must be reduced sufficiently to maintain the food edible. The most typical approach is cooling, which must be done throughout the supply chain. If this process is not followed correctly, it might result in a lot of food waste.

The causes identified by the researchers during the processing stage, can be divided into two different groups: intentional losses and unintentional losses.

Table 1: Processing-related FLW

Intentional losses		**Unintentional losses**	
R&D	Losses resulting from the use of raw materials for research and development	Power blackouts	Uncontrolled changes or product deterioration may occur
		Equipment defects	Failure of refrigeration or heating compromises the safety of products.
Cleaning losses	Losses caused by product residues on equipment	Residues	Residues from food cutting can cause food loss
		Human errors	Incorrect oversight or ingredient handling can result in food waste
Samples for QC and analysis	Once used, product samples used for quality control are discarded.	Sources of safety hazards	Imperfect seals and foreign body contamination lead to food waste.

Source: authors' own, adapted from Raak et al., 2017

2.1.3 Consumer behavior

Food waste is a problem that affects the entire supply chain, including the customer. According to Schanes et al. (2018), numerous consumer behaviors influence the amount of food wasted in households.

Overprovisioning has been highlighted as one of the most significant causes of food waste. People buy more food than they need because of promotional offers, food stockpiling to prepare for unanticipated situations, varying culinary preferences among household members, and food packaging that frequently contains larger quantities than are actually required.

Along with overprovision, the type of store where groceries are purchased and the frequency with which they are purchased influence consumer food waste output. Food waste is highest when people shop only in large supermarkets and decreases when people buy more frequently and in varied shopping facilities, such as small shops and local markets.

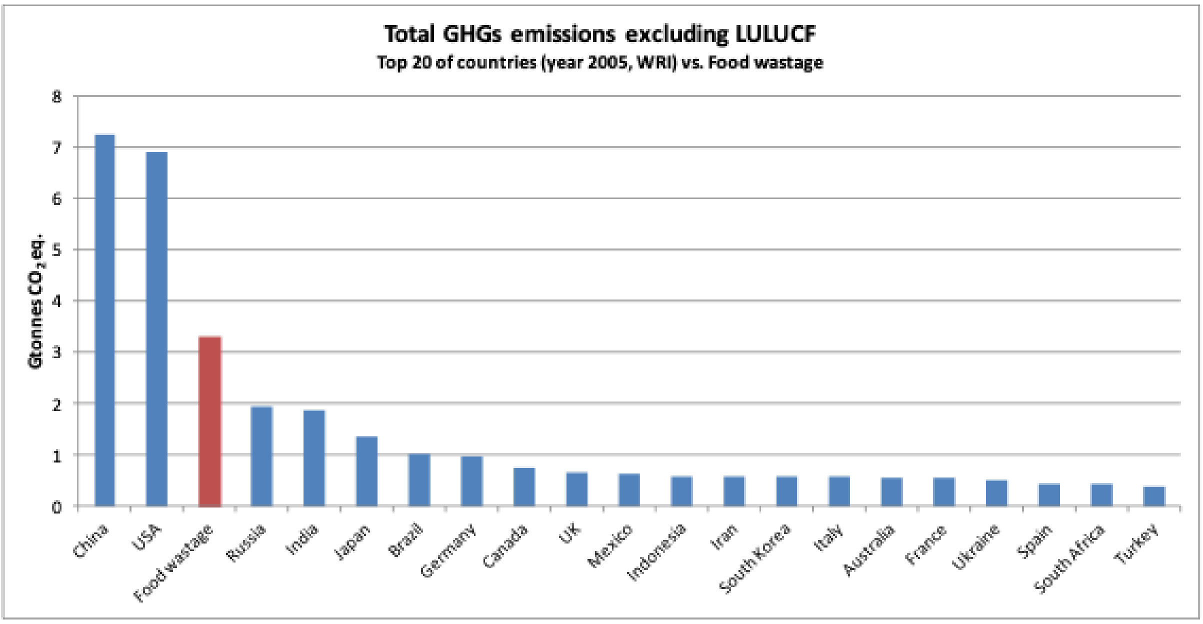
Eating habits are also important, as those who spend more money eating out in restaurants waste more and feel less guilty about it. Eating out is frequently decided on the spur of the moment, resulting in purchased goods and/or leftovers spoiling and being wasted as a result of more convenient or time-saving options such as going to restaurants. As a result, there appears to be an inconsistency between food purchased and food consumed within a specific time window. Because of the unpredictability of eating patterns caused by unexpected dinner invites or impulsively spending time with friends, foods go uneaten and are thus wasted.

Even if there is no obvious relationship between age and the amount of food wasted, Quested et al. (2013) argued that the elderly over 65 years old waste 25% less food than younger people because they perceive food waste to be wrong. The authors think that this viewpoint stems from previous experiences that elderly individuals had in comparison to younger generations, such as shortages of food during WWII (Quested et al., 2013).

2.2 Environmental, Social and Economic implications

Food waste and loss have social, economic, and environmental implications that resonate globally. Perhaps the most critical implications of food waste and loss are environmental. In 2013, FAO examined the carbon footprint caused by food waste in the report called “Food Wastage Footprint – Impacts on natural resources”. According to the data, the generation of food waste resulted in about 3.3 gigatonnes of carbon dioxide equivalent emissions on a global scale. When viewed from a different perspective, food waste is the third largest contributor to global CO2 equivalent emissions, behind only China and the United States.

Figure 6: Top 20 GHG emitting countries



Source: FAO, 2013

Cereals have the highest carbon footprint in terms of food waste, accounting for around 35% of the total amount. Nitrous oxide and fossil CO2 are produced as a result of the presence of nitrogen fertilizer. Furthermore, the growing of rice, a frequently consumed grain worldwide, results in the release of methane into the atmosphere due to the practice of flooding fields. The production of meat and dairy products is the second most significant contributor to carbon footprint, accounting for 21% of total emissions. This is primarily due to methane emissions produced by ruminant animals such as sheep, goats, and cattle during digestion. Emissions from the manufacture of mineral fertilizers used in pig and poultry breeding also add to the overall carbon footprint (FAO, 2013).

Furthermore, the wastage of food amplifies resource scarcity, affecting both agricultural inputs and outputs. Wasted food implies the misallocation of valuable resources like arable land, freshwater, and energy. These resources, which are already in high demand for food production, face increased pressure due to inefficiencies. In the case of water, approximately 24% of the global water used in agriculture is associated with the production of food that is eventually wasted (Kummu et al., 2012). Worldwide food waste accounts for 250 Km^3 of wasted water, which correspond to 38 times the blue water footprint of domestic water use in the United States. Low-income regions are responsible for almost the 75% of the total wasted water, with Southeast Asia alone accounting for 38% (FAO, 2013). Additionally, the total amount of food wastage globally has occupied 1.4 billion acres of agricultural land, which is about one third of the world's agricultural land area; meat and dairy products are the highest contributors (FAO, 2013). Such resource depletion contributes to rising costs, potentially leading to food price spikes and economic instability (Godfray et al., 2010).

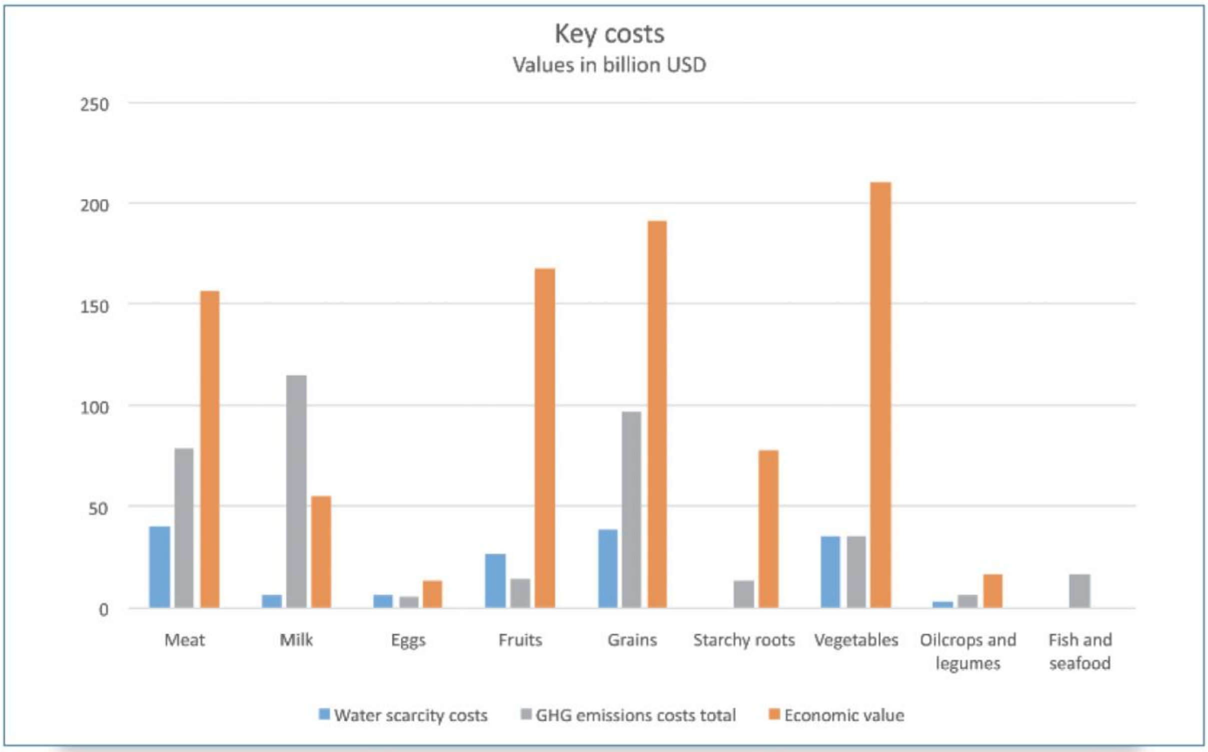
Food production is a major driver of habitat destruction and biodiversity loss. As agriculture expands to meet growing food demands, it often encroaches on natural habitats, contributing to deforestation and habitat degradation. Food waste compounds this problem by intensifying the pressure on ecosystems. The overuse of resources in food production, combined with inefficient food distribution, directly harms biodiversity and disrupts ecosystems (Tscharntke et al., 2012).

Food waste and loss perpetuate a paradox of plenty amid scarcity, as the massive amount of food wasted presented at the beginning of this chapter, goes in contrast to the approximately 9% of the global population who suffer from undernourishment, highlighting the social injustice of food waste. Inequitable distribution exacerbates hunger, particularly in developing regions, deepening the global food security crisis (FAO, 2019).

Beyond the evident challenge of hunger, food waste reinforces economic disparities and poverty. Households and individuals who waste food unknowingly squander their financial resources. The United States, for instance, loses $161 billion worth of food annually at the consumer level, adding financial stress to families and reducing overall economic well-being (ReFED, 2016). Such wasteful behavior also challenges cultural and ethical values around resource stewardship, leading to social stigmatization and a sense of irresponsibility (Russell & Young, 2017).

Food waste has a global economic impact of about $1 trillion each year. Vegetables are the primary contributors to the cost associated with food loss, accounting for 23% of the overall expenses. This is closely followed by meat, fruits, and grains. In relation to meat, the proportion of food waste costs is influenced by the elevated producer cost per kilogram of meat. The primary factor influencing the overall cost of grains is the significant proportion of food that is wasted. In the context of fruits and vegetables, both prices and quantities make a balanced contribution. Furthermore, with regards to geographical allocation, the primary contributions consist of developed regions in Asia, as well as South and Southeast Asia.

Figure 7: Food waste costs by commodity group



Source: FAO, 2014

Social and environmental implications come with a cost as well. The latter is worth roughly 700 billion dollars, while the former is worth over 900 billion dollars. Some of the most important environmental and social costs include: 394 billion dollars in CO2 equivalent emissions, 153 billion dollars in severe health consequences from pesticide exposure, and 164 billion dollars in water scarcity every year. Environmental, social, and economic costs sum up to 2.6 trillion dollars every year. (FAO, 2014)

2.3 Initiatives and policies to reduce food waste

Governments throughout the world have acknowledged the critical problem of food waste and have adopted thorough efforts to address it. These initiatives cover all areas of the food supply chain and include both legislative actions and public awareness campaigns.

Setting food waste reduction objectives is one key government endeavor. For example, the United States has set a target of halving food loss by 2030 as part of its "2030 Food Loss and Waste Reduction Goal." This campaign supports company, community, and individual involvement (USDA, 2015). Similarly, Sweden intends to handle half of home, retail, and restaurant food waste naturally, with the other 40% used for energy recovery (Bagherzadeh et al., 2014).

Legislation is another powerful instrument that governments use to decrease food waste. The Food Waste Recycling Law of Japan aims to reduce and eliminate food waste while also encouraging its recycling into fertilizer and animal feed (Bagherzadeh et al., 2014). The General Food Law Regulation sets definitions, principles, and duties for all stages of the food supply chain in the EU. In 2016, France passed legislation prohibiting stores from abandoning unsold food and mandating the gift of excess food to charities and food banks, therefore addressing both food waste and poverty (The Guardian, 2016).

Government contributions extend to food redistribution programs, covering the gap between excess food sources and charity groups' and food banks' requirements. Recognizing the importance of public awareness campaigns in influencing consumer behavior, governments initiate projects to educate people about the environmental, economic, and social consequences of food waste. As shown by UK's "Love Food Hate Waste" campaign (Love Food Hate Waste, n.d.), many ads also include practical recommendations for minimizing waste at home.

Tax breaks encourage firms to actively participate in food waste reduction activities, boosting corporate responsibility and waste reduction. Investing in research and data collecting is critical for understanding food waste trends and implementing effective reduction measures, with governments sponsoring research programs and data collection operations to give useful insights to policymakers and stakeholders.

Food waste prevention initiatives are being included into public procurement legislation, promoting sustainability in public institutions such as schools and hospitals. For example, the French government intends to give training in food waste reduction at agricultural high schools and hospitality schools (Bagherzadeh et al., 2014).

Furthermore, governments encourage agricultural food waste reduction by connecting agricultural policies and subsidies with waste reduction goals. Farmers are urged to reduce food losses during production and harvesting by using strategies such as enhanced storage systems and crop rotation (FAO, 2019).

In conclusion, governments throughout the globe are addressing food waste via a variety of tactics, including goal setting, legislation, support for redistribution programs, consumer education, and commercial incentives. These extensive projects represent a realization of the serious social, economic, and environmental consequences of food waste, as well as the need to reduce it.

CHAPTER 3: CIRCULAR BUSINESS MODELS AND THEIR APPLICATION IN THE FOOD INDUSTRY

3.1 Circular Business Models

New rigorous policies on emissions and waste generation, changes in customer tastes, and hazards associated with presently used supply chains are all causes for corporations to reconsider their business models, opening the path for the adoption of circular ones.

The advent and distribution of new technologies has also had a major impact on the creation and expansion of circular business models (OECD, 2019b). The internet and digital devices, for example, have played an important role in lowering transaction costs and dangers associated with sharing commodities, allowing real-time monitoring of product performance, and aiding the dematerialization of consumer goods. Furthermore, advances in conventional manufacturing technology and automated material sorting facilities have strengthened the commercial rationale for circular models (OECD, 2019b).

Companies will profit from less reliance on already limited virgin resources, more incentives to innovate, increased operational efficiency, and greater customer connections (BCG, 2018). Furthermore, a shift to a Circular Economy might result in 4.5 trillion dollars in GDP growth by 2030 (Lacy and Rutqvist, 2015).

Tonelli and Cristoni (2018) defined four types of circular business models in their paper "Strategic Management and The Circular Economy":

Zero-Cost Innovation: This business strategy stresses the reduction of environmental effects from manufacturing processes and goods, which may benefit the environment. Positive innovation necessitates a full change of manufacturing processes, including the removal of harmful materials and the substitution of environmentally suitable equivalents. This business model is used by a wide range of organizations, including those who manufacture environmentally friendly materials, create creative goods for the general public, use green inputs in their own operations, and promote net-zero practices in their supply chains. Environmentally concerned customers prepared to pay a premium, as well as cost-effectiveness, are two sources of profit for these businesses. This type is suitable for a wide range of sectors, particularly those subject to strict environmental laws, such as oil and gas. Strong R&D activities, adoption of the Cradle2Cradle approach, and engagement with supporting organizations and consultants to aid the transition are key intervention areas.

Servitization: It is a business strategy that entails shifting away from conventional product sales and ownership and toward providing service-based solutions or Product-Service Systems (PSSs). This move has gained traction in recent years as a result of technical developments that make servitization simpler and less expensive, as well as a rising desire to avoid pricing wars in crowded sectors. PSSs are classified into three types: product-oriented services such as insurance and maintenance contracts, use-oriented services such as leasing, renting, and sharing, and result-oriented services such as pay-per-service-unit and outsourcing (Tukker, 2015). Servitization offers ongoing income streams, increases client loyalty, and is appropriate for pricey items that need maintenance. It has been used effectively in a variety of businesses, with a higher reaction among younger clients. Predictive analytics, communication technology, and monitoring tools, for example, play a critical part in the mainstreaming of servitization, enabling businesses to monitor and provide superior services.

Product Life Extension: The product life extension business model focuses on developing items that are built to last and are of high quality. Companies that stress longevity and quality in their marketing efforts include Patagonia, Miele, and Rolls Royce. This concept includes operations such as re-use, repair, refurbishing, and re-manufacturing to extend the life cycle of a product. Companies reinvent consumption patterns and encourage sustainable consumption by lowering discard and replacement rates. Profits are generated by charging a premium for high-quality items, add-ons, upgrades, repairs, and refurbishing services. Additional advantages include increased client loyalty and greater understanding of consumer preferences. This paradigm is appropriate for complicated assets in B2B specialist markets, yet modular design may handle consumer electronics concerns. Circular design principles for easy disassembly, efficient reverse cycle channels, and external partnerships for take-back and sorting operations are among the implementation options.

Product Residual Value Recovery: This approach focuses on recovering value from items that cannot be extended by reuse, repair, remanufacturing, or refurbishment. It entails a variety of recycling procedures, such as reducing old goods into lower-quality things, converting discarded products into raw materials, and producing energy from recycled materials. Another sophisticated strategy is industrial symbiosis, in which trash from one firm becomes raw material for another. This strategy is best suited for sectors that rely on scarce raw materials such as glass, paper, and plastic. Because of anaerobic digestion, food is also viable for this business strategy. Setting up reverse cycle routes for collecting byproducts and waste, making strategic judgments regarding in-house knowledge vs outsourcing, and utilizing supporting technology and infrastructure are all critical areas for execution.

These business concepts, as Tonelli and Cristoni argue, may be employed alone or in combination. Furthermore, unlike linear business models, they allow organizations to generate new income streams, maintain a competitive edge, save expenses, and get a better understanding of their consumer base.

As underlined by Bocken et al. (2016), the combination of circular business models and circular product design is a critical step in the quest of broad adoption of circular practices by enterprises. These circular designs are divided into two categories by the researchers: design to slow loops and design to close loops. Two essential design concepts stand out in the former group. To begin, "Designing Long-Life Products" is concerned with the development of items that are intended to be used for lengthy periods of time. This strategy prioritizes emotional durability by creating goods that foster long-term relationships with people. It also emphasizes physical durability, using materials that can endure wear and tear while providing dependability for the duration of the product's designated lifetime when properly maintained. Second, "Design for Product-Life Extension" aims to extend the useful life of items by including service loops. This includes making maintenance and repair easier, allowing consumers to effortlessly maintain the product's condition. It also includes upgradeability to adapt goods to changing demands, standardization and compatibility to guarantee smooth connection with other products, and disassembly and reassembly to encourage the reuse of materials and components.

The Cradle-to-Cradle design concept, which advocates a circular approach to product design, serves as inspiration for design techniques targeted at closing resource loops. This philosophy presents two key techniques. The first, "Design for a Technological Cycle," is suitable for service-delivery products. Its fundamental goal is to build goods in such a way that their ingredients, known as "technical nutrients," may be continuously and securely recycled into new materials or products. To maintain material quality, "primary recycling" or "tertiary recycling" is required. "Upcycling" is preferred over "downcycling" to preserve material value and prevent the linear movement of resources from production to disposal. The second technique, "Design for a Biological Cycle," is intended for consumption items that are generally eaten or deteriorate over time, resulting in resource loss. Products are created utilizing safe and biodegradable components known as "biological nutrients," which may naturally disintegrate and produce food for natural systems. This technique promotes the formation of a new material cycle, hence boosting sustainability and resource efficiency. Both design methods, as well as the critical aspect of disassembly and reassembly, play a critical role in enabling the flow of materials across various cycles and pushing forward the idea of a circular and resource-efficient economy.

3.2 Giving new life to food waste: endless potential for food waste

Several studies have revealed different applications for food waste as well as the potential use of circular techniques in the food supply chain. The waste hierarchy structure proposed by Papargyropoulou et al. (2014) is beneficial as a starting point for gaining a better understanding of food waste management.

Figure 8: Food Waste Hierarchy

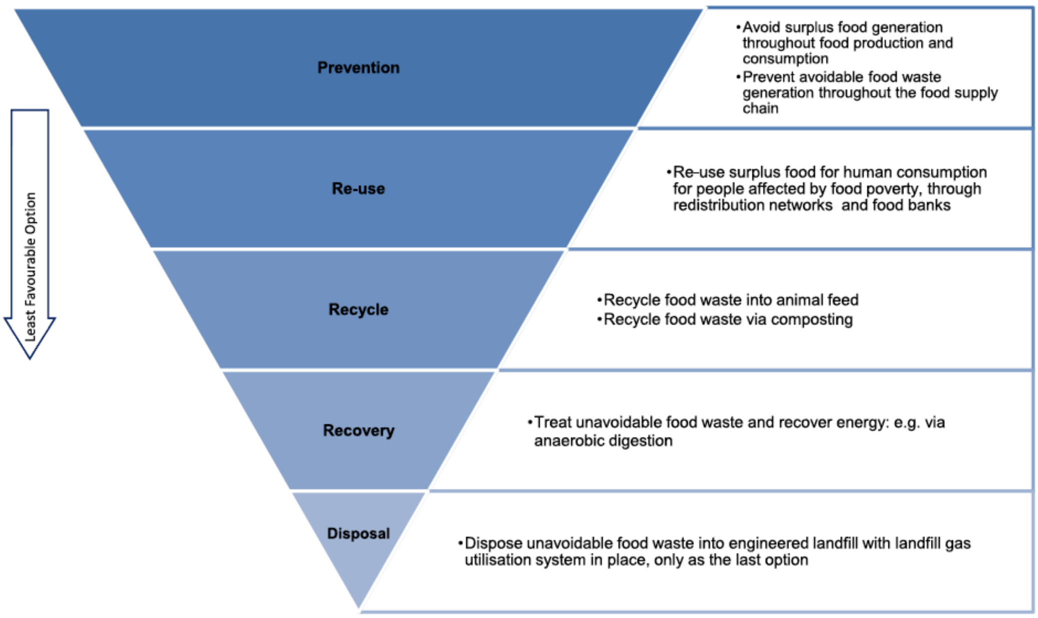


Fig. 5. The food waste hierarchy.

Source: Papargyropoulou et al., 2014

The framework starts by tackling overproduction and excess stock across the food supply chain in order to avoid food surplus. This entails generating just what is required to fulfill global nutritional demands while also addressing unsustainable consumption practices. It is advocated that excess food that has not been eaten be redistributed to organizations in need, if food safety can be maintained. When excess food is no longer appropriate for human use and becomes food waste, the framework differentiates between avoidable (food that was previously edible) and unavoidable (animal bones and fruit peel) food waste. Furthermore, the framework recommends recycling unnecessary food waste into animal feed, with composting as a backup alternative if recycling isn't possible; if this isn't an option, energy recovery is the next best choice.

Finally, after all other choices have been explored, disposal in landfills is regarded as the least desirable option for handling the remaining percentage of unavoidable food waste (Papargyropoulou et al., 2014).

Pham et al. (2015) and Kiran et al. (2014) investigated food waste energy recovery strategies to create biofuels such as biogas, bioethanol, and biohydrogen. The process of producing biogas is known as anaerobic digestion. The latter is a popular biological technique that produces methane and carbon dioxide by decomposing organic waste such as food scraps in the absence of oxygen. Food waste may be converted into useful products such as nutrient-rich digestates for soil development, providing advantages such as renewable energy generation, nutrient recycling, and waste volume reduction. However, there are some drawbacks to this method; it is a lengthy process that may last up to 40 days, and if not controlled correctly, it might produce dangerous gases. Furthermore, excessive quantities of ammonia in food waste may impair methane-producing microbes.

Bioethanol production from food waste includes the use of sugar-rich food waste sources such as banana peels, sugar beet pulp, and citrus waste. Fermentation is the method by which ethanol is produced: a kind of yeast is put into a combination of food waste, giving birth to the chemical reaction that will generate bioethanol. This procedure, in conjunction with anaerobic digestion, is an efficient method of converting food waste into energy. Despite favorable advantages such as reduced food waste and carbon footprint, its economic sustainability needs more research to minimize manufacturing costs.

Finally, hydrogen generation from food waste is promising thanks to its high energy output, but numerous aspects such as food waste composition (it must be rich in carbs), pre-treatment procedures, and process design impact its process. According to the scientists, the bioconversion yield for food waste to hydrogen generation remains low, and investigating the commercial potential of organic acids is critical for economic feasibility. Furthermore, integrating hydrogen generation with operations that produce methane, organic acids, or ethanol may improve overall efficiency. However, issues relating to purification, storage, distribution, and economic feasibility must be overcome before biohydrogen can be widely used as a green energy source.

The production of biofuels from food waste is not the only available option, as food waste finds application also in the production of functional food and in the pharmaceutical and cosmetic industries.

Fruits and Vegetables: Tomatoes, olives, and exotic fruits are rich in a variety of healthful chemicals. They are all high in carotenoids and phenolic chemicals, which act as natural antioxidants and improve food shelf life. Tomato peels may be utilized in functional foods since they are abundant in dietary fiber and macronutrients. Exotic fruit waste, such as mango peels, improves the nutritional content of food, while byproducts from the coconut production generate useful goods such as coconut protein powder. Moreover, papaya waste acts as a substrate for yeast development and shrimp feed (Mirabella et al., 2014). The byproduct of apple processing, apple pomace, includes dietary fiber, pectin, and phenolic chemicals. Additionally, it may produce chemicals such as phlorizin, which has the potential to be an oral diabetes treatment (Helkar et al., 2016).

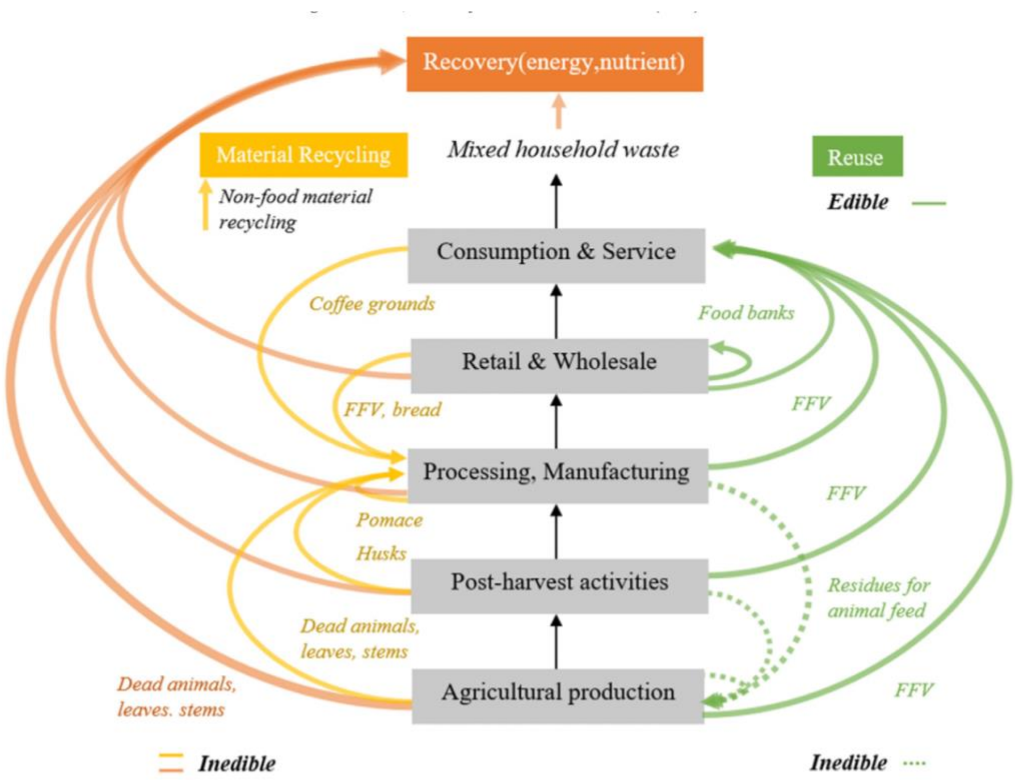
Meat: The byproducts of livestock production, such as bones, epidermis, blood, and collagen, have multiple uses. For example, gelatin derived from collagen is extensively used in the food industry for gelification, whereas hydrolysates (collagen-derived proteins) generate peptides that are beneficial for osteoarthritis treatment. In addition, certain combinations of these proteins and hyaluronic acid are commercially available to improve joint performance and alleviate ache. Pork skins are used to treat ulcers and wounds, and organs are a source of melatonin, heparin, and insulin. Lastly, fat have several applications in the cosmetic industry for body moisturizers and bath products. (Toldrà et al., 2020)

Fish: After processing the exoskeletons, chitin, a polysaccharide, can be extracted from the residues of shrimp, crab, lobster, and krill shells. Chitin and its derivatives, chitosan and chitooligosaccharides, offer a vast array of biological activities, such as antioxidant and antimicrobial effects, making them valuable to numerous industries. In the food industry, for instance, they can be used to improve food safety, quality, and shelf life as food preservatives and consumable packaging materials that prevent microbial decomposition. Chitin, chitosan, and their derivatives are utilized in the pharmaceutical industry for drug encapsulation, controlled release, and coating to effectively deliver various pharmaceutical constituents. In addition, the combination of chitin and antioxidants is used in cosmetics because it protects the epidermis from solar radiation. (Hamed et al., 2016)

The many food waste applications listed here demonstrate how food waste may be utilized for circular practices both inside and outside the food supply chain. According to an OECD assessment (2019b), resource recovery business models minimize landfilling and incineration, hence minimizing related environmental consequences. By boosting the availability of secondary materials, these models lessen the demand for primary resources, lowering the environmental effect of extraction. Furthermore, making products from waste uses less energy and produces fewer greenhouse emissions than producing materials from virgin resources (OECD, 2019b). This not only allows for the reduction of food waste in a sustainable manner, but also for the creation of shared value for multiple businesses operating in the same or distinct supply chains (Genovese et al., 2017).

However, Teigiserova et al. (2020) suggest that in order to prevent a rebound effect, it is essential to prioritize those categories of food waste that demand the most resource consumption and have the most environmental impact.

Figure 9: Circular framework for food waste and loss in the food supply chain



Source: Teigiserova et al., 2020

3.3 Challenges for a Circular Economy in the food industry

Despite the potential benefits of a Circular Economy in the food business, its implementation faces several challenges. Mehmood et al. (2021) identified many challenges to the implementation of circular methods in the food supply chain:

Financial and economic restrictions appear as major hurdles to CE projects in the food industry, since stakeholders often perceive significant initial costs associated with CE implementation, such as agricultural waste collection and treatment, which adds to their operating expenditures. Furthermore, the seasonality of agricultural output poses extra financial risks, influencing price stability and product and service availability.

Public policy and institutional constraints also play an important role in impeding the transition to a circular economy. For example, weak and ineffective CE legislation, as well as a lack of established mechanisms for measuring rule efficacy, all contribute to this difficulty. Furthermore, insufficient governmental backing, technical ability, and a lack of encouraging policies impede the transition to circular practices.

Logistical and infrastructure hurdles take many forms, including uncertainty about the return of commodities, such as amount, quality, timeliness, and location. Indeed, food waste collection rates remain low, and insufficient waste treatment facilities increase these issues. Issues regarding waste collection time and location impede the realization of economies of scale in CE procedures.

Knowledge and skill obstacles are defined by players in the agricultural sector's lack of knowledge and comprehension of CE's implications and principles. While the notion of "circular economy" is well-known, its meaning is often ambiguous. Furthermore, the lack of technical skills and training capacities creates substantial barriers to the efficient implementation of CE programs (Gontard et al., 2018).

To summarize, the move to a circular economy in the food supply chain is faced with financial, regulatory, logistical, and knowledge problems. To overcome these obstacles, stakeholders, governments, and enterprises must work together to build an enabling environment for the circular economy.

CONCLUSION

It is reasonable to infer from the study provided here how there are objective effects, proved by the existence of data, at the environmental, economic, and social levels caused by the intense use of planetary resources, particularly food waste.

The circular economy, which is still in its infancy, may prove to be a helpful resource for reversing this tendency. China's and the European Union's measures to facilitate the transition to a circular economy are examples of how international action is being done. Indeed, adopting circularity as enormous advantages both for economies as a whole as well as for businesses. As the EU legislative framework demonstrated there is the potential for new job opportunities. Moreover, adopting the circular economy would contribute to a decreased dependency on already scare resources and so a lower environmental impact, operational efficiency and tremendous economic growth potential.

Furthermore, the use of circular approaches in food waste management seems promising. The waste hierarchy system serves as a road map for proper food waste management, which includes reducing overproduction, redistribution, and recycling. The several researches conducted to investigate the possibilities of food waste in energy recovery, biofuel generation, and its use in diverse sectors such as cosmetics and pharmaceuticals, have demonstrated its adaptability.

Tonelli and Cristoni's four circular business models demonstrated the diversity and creative potential, providing solutions to meet the needs of various sectors and consumers. The Product Residual Value business model, in particular, together with industrial symbiosis, may be feasible options for the adoption of circular practices in the food supply chain. For example, an Eco-Industrial Park may be built, incorporating various companies, where waste generated by food supply chains could be utilized to make cosmetics, biogas, or reintegrated into the production of other foods.

However, there are also concerns about the circular economy, foremost among them the absence of a globally acknowledged concept and rules. Despite the fact that the concepts of sustainability and circular economy are often used interchangeably, it is still unclear how much the latter contributes, particularly to the development of social elements. Moreover, practices such as the extension of life of some products may result in altered flows on material and have rebound effects.

The high costs required for reuse and particularly recycling of food waste may prevent different actors in the food supply chains to adopt circular practices. For this reason, a broader framework of incentives by governments may be helpful to adopt circularity to a large extent. Additionally, the lack of a clear communication, essential for a successful implementation of the circular economy, among the different actors in the food supply chain could be solved by the use of technology such as data and IoT.

For what concerns sustainability, adopting a circular economy in the food industry seems to decrease the production of food waste and the consequent impact on the environment. However, it is not actually known how much food waste reduction might actually contribute to the decrease of global hunger, and so have a positive impact on the social aspect of sustainability.

In general, implementing circular practices in the food supply chain seems to be a viable way to reducing food waste and loss, but more study and research are required to better understand its limits and potentials.

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