Acta Univ. Sapientiae, Alimentaria, **15** (2022) 51–66

DOI: 10.2478/ausal-2022-0005

The role of circular economy in food waste management in fulfilling the United Nations' sustainable development goals

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Abstract. Based on the UNEP Food Waste Index Report 2021, approximately 931 million tons of food waste were generated in 2019, with nearly 570 million tons of that waste occurring in households. Hunger affects more than 800 million people worldwide. Furthermore, the non-consumption of food accounts for 8-10% of global greenhouse gas emissions. Therefore, food waste generation has significant environmental, societal, and economic consequences. The circular economy (CE) is an economic model that seeks to reduce waste and extend resource life. The purpose of this study is to examine and present the connections between the CE, the Sustainable Development Goals (SDGs), and food waste management. Food waste management is commonly regarded as an environmental issue. Still, it also offers vital economic and social benefits for sustainable development. The first section of the research looks at the function of food waste management in the transition to a circular economy. The second part of this study examines the SDGs in food waste management and circular economy. The findings revealed that the most significant connections and synergies between food waste management, circular economy practices, and SDG targets could be found in SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production). Both goals have high scores for direct and indirect contributions.

Keywords and phrases: economic development, responsible consumption and production, global goals, zero hungerwaste hierarchy

1. Introduction

More than 800 million people worldwide suffer from hunger, and the number of hungry people has risen since 2014 (*Kruchten & Eijk*, 2020). Moreover, global food crises will be compounded by the unfolding effects of the COVID-19 pandemic (*Kansiime et al.*, 2021) and with the projection that the global population will reach 8.5 billion people in 2030 (*UN*, 2019).

Food waste is considered a global issue, with roughly one third of all food produced for human consumption being lost or wasted (*Reynolds et al.*, 2020). On a global scale, around 931 million tons of food were wasted in 2019, with nearly 570 million tons of waste occurring at the household level (*UNEP*, 2021). Approximately 88 million tons of food waste are generated annually in the EU, with related costs valued at 143 million euros (*Stenmarck et al.*, 2016). Food waste is responsible for resource losses, greenhouse gas (GHG) emissions, and economic loss (*Niu et al.*, 2022). Apart from the fact that food wastage causes severe financial losses, both for personal consumption and the national economy, it also causes loss of life-supporting nutrition and consumes scarce resources (land, water, and energy) expended for the production, processing, and distribution of food (*Rainer Bräutigam et al.*, 2014). Furthermore, global food loss and waste are responsible for 8-10% of anthropogenic greenhouse gas emissions (*Costa et al.*, 2022).

Circular economy (CE) presents an evolving umbrella concept for closing material loops to improve environmental performance (*Castro et al.*, 2022). The CE concept replaces the linear economy concept to fulfil the need for an alternative approach, which values raw materials differently. Transition to circular economy contributes to utilizing resources' value to the maximum and their retention in use for as long as possible. Materials and products in a CE are meant to reduce waste and are reused, recycled, or recovered (*ISWA*, 2015). As a result, CE is gaining traction worldwide to achieve local, national, and global sustainability goals. Nonetheless, developed countries receive the most of the attention, with developing countries receiving only a tiny portion (*Azizuddin et al.*, 2021).

Transition to a circular economy can be achievable and sustainable if it supports the increased demands of a current growing population while addressing the environmental and resource problems that future generations will face (*Monkelbaan*, 2021). In a circular food economy, waste management aims to produce resources: biofertilizers and biofuels. Biogas is the most valuable product, a non-fossil fuel used for commercial and private vehicles and heating (*Holmberg & Ideland*, 2021).

The 2030 Agenda for Sustainable Development was adopted by the UN General Assembly on 25 Sept 2015. It includes 17 Sustainable Development Goals (SDGs), which set quantitative goals in the social, economic, and environmental dimensions of sustainable development (*UN*, 2015). By 2030, SDGs should be achieved. Even though there are no specific SDGs on waste, several goals and related targets include

direct, moderately direct, and indirect references to waste (*Prokić et al.*, 2016). On the other hand, SDG 2 (Zero Hunger) and SDG 12 (Sustainable Consumption and Production) set targets to deal with food waste with several other SDGs and related targets that are moderately directly and indirectly related to food waste.

This paper provides a framework that establishes detailed interrelationships between food waste management, the CE, and SDGs to direct future sustainable development research, policies, and innovations. Food waste management is generally treated as an environmental challenge, but it also has significant benefits for the economic and social goals of sustainable development.

2. Materials and methods

This study used a desk review methodology to address research objectives (*Bowron & Weber*, 2019). The analysis of scientific literature is developed using the Scopus database of academic publications (*Snyder*, 2019). The research was conducted in two phases. The first phase presents a scientific literature review to examine the link between the CE and food waste. The review highlights how food waste management can contribute to the CE transition and how implementing the CE concept reduces food waste. The second phase of this research analyses the SDGs and related targets in the context of CE and food waste management.

3. Results and discussion

3.1. Contribution of food waste management to the circular economy

Sustainable food waste management is a global issue with a high priority for enhancing food security and conserving natural resources and ecosystems (*Zan et al.*, 2022). Food waste is expected in the early stages of the supply chain in developing and underdeveloped countries where poverty is high. However, waste generation is the largest in the later supply chain stages due to supermarket practices or consumer waste in developed countries (*Joubert & Jokonya*, 2021). On a worldwide scale, food supply chains place a tremendous burden on freshwater resources while also returning excess nitrogen and phosphorus, endangering the health of sensitive ecosystems (*Reynolds et al.*, 2020).

Moreover, food waste management causes more ecological damage, mainly when landfilled, as is a common practice in many countries. In addition, food waste decomposes, creating methane, a potent greenhouse gas in the anaerobic landfill (*Babbitt*, 2017). Therefore, the EU launched European Directive (EU) 2018/851 to avoid waste treatment that locks in resources at the lower levels of the waste

hierarchy. The directive aims to increase preparation for reuse and recycling rates, enable high-quality recycling, and raise the uptake of quality secondary raw materials. The directive is the New Waste Framework Directive (WFD), included in the Circular Economy Package (*EU*, 2018). As of 1 January 2024, the WFD requires that bio-waste, including food waste, be collected separately. Belgium, for instance, has already achieved the 2020 target of 50% recycling rates and has eliminated landfilling biodegradable waste (*Favoino & Giavini*, 2020).

In 2014, the EU adopted a document, *Towards a Circular Economy: A Zero Waste Programme for Europe*, to encourage the transition of the European economy from the linear to the circular model. This document treats waste as a resource, contributing to the circular economy's key concept of "closing the loop". In addition, the EU established an Action Plan for the Circular Economy in 2015, which sets a clear and ambitious EU mission to assist in the transition to a circular economy. Circular economy is regarded as a strategy to safeguard businesses from resource scarcity and price volatility while increasing the EU's competitiveness, creating new economic opportunities, and encouraging more inventive and efficient production processes. The Action Plan is oriented towards the EU. However, it confirms that all stakeholders (Member States, regions, cities, businesses, and individuals) must be engaged in successfully implementing the circular economy. The Action Plan also promotes the Agenda 21 goals, notably SDG 12, which encourages sustainable production and consumption (*UNDP*, 2020).

Conventional waste management practices dispose of or incinerate food waste, contributing to the degradation of the environment while misusing bio-waste, a valuable resource with a great potential for reuse. As a result, decreasing food waste can benefit the environment and society. Furthermore, new business models can arise by using a circular economy strategy to reduce, reuse, and recycle food waste and gain financial benefits from what would otherwise be discarded (*KPMG*, 2020).

CE mainly appears in the literature through three main actions: the 3Rs rule (*Zan et al.*, 2022). Food waste management 3Rs can be presented as follows: Reduce – minimize the amount of material that is thrown away, Reuse – redistribution of excess food, and Recycle – creating new value from inedible by-products and food waste. As shown in *Fig. 1*, the food waste hierarchy is highly associated with CE-based rules. Based on environmental sustainability, a waste hierarchy prioritizes waste treatment actions from the most preferred to the least preferred. The EU WFD can be applied to food waste but should be slightly modified to take account of the particularities of food (*Lombardi & Costantino*, 2021; *EU*, 2018).

In the context of food waste, the first element of CE is food waste prevention (*Zan et al.*, 2022). Preventing food waste generation is possible by using all activities that reduce the amount of waste. It can be achieved by preventing food waste generation in primary production, processing and production, retail and other forms of food distribution, restaurants and food services, and households.

Preventing food waste is the most effective method of waste management; although prevention is a technique that involves the most significant effort when established, it achieves indisputable and best results in terms of sustainability. The second element of CE refers to the more efficient use of generated waste by carrying out various reuse or recycling activities, i.e. converting waste into resources and not ending up in a landfill. Several ways of processing this waste, ranging from the most environmentally and socially desirable, such as donating food to banks or the Red Cross, to processing into animal feed, electricity, and composting.

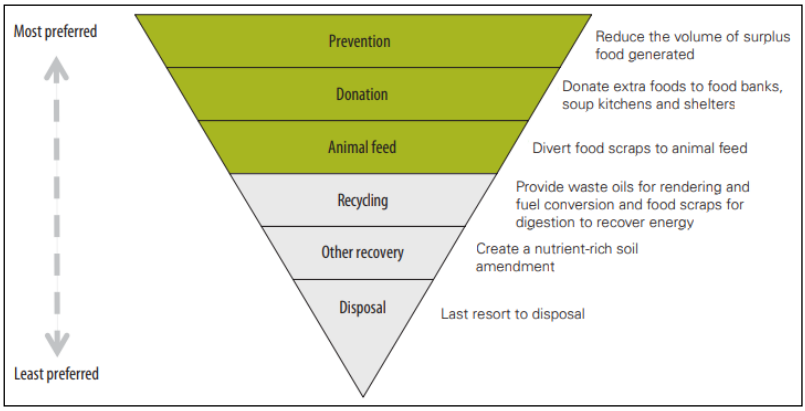


Figure 1. Food waste hierarchy (*EU*, 2018; *KPMG*, 2020)

Throwing food away is the most undesirable solution because it represents a pure economic loss, with severe degradation of the environment. Therefore, waste separation is a necessary condition in achieving a circular economy. The installation and use of appropriate containers to separate this type of waste at its origin is the initial step that must be done to create the conditions for achieving a circular economy (*Favoino & Giavini*, 2020).

Despite environmental policy being a global economic policy, only 8.6% of the world is circular currently, which is a negative trend. A higher degree of circularity can be achieved through transferring global trends to national, regional, and commercial levels. Also, it can be accomplished by establishing implementation models and measures to monitor the transition (such as penalty policies). Additionally, it can be reached by providing accessible education and know-how and involving various stakeholders in forming a global coalition for circular economy (*UNDP*, 2020). Expanded imports of recyclable waste to developing countries can also create new possibilities. For instance, such imports enhance demand for emerging sectors such as repair and recycling, improving domestic waste management. It can also generate a significant number of jobs, as product repair tends to be more labour-intensive than manufacturing from raw materials (*Monkelbaan*, 2021). Furthermore, innovative

business models that contain digital technology can assist in managing food waste at the household and retail levels, which amounts to roughly 88 million tonnes per year in the EU, or 173 kg/person/year (*Stenmarck et al.*, 2016). Globally, food loss and waste are responsible for about 8% of GHG emissions, and all countries have to minimize this figure (*PACE*, 2021).

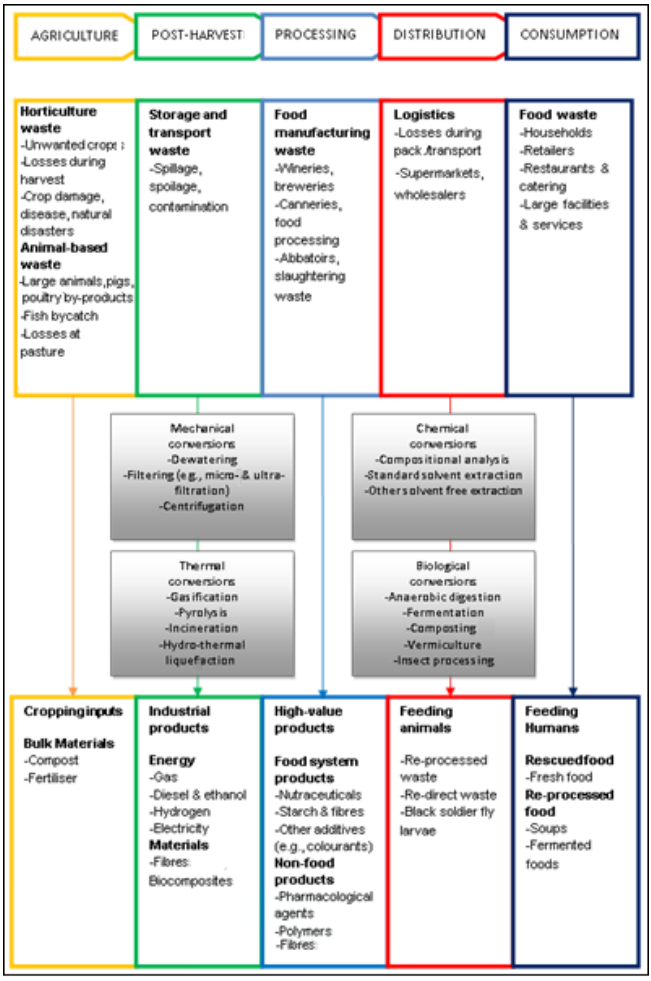
3.2 Reduction of food waste through circular economy practices

Since food waste is generated during primary production, food processing, wholesale and retail trade, food preparation, and consumption (*NALED*, 2019), there are opportunities for waste reduction, reuse, and recycling throughout the supply chain of agri-food products. *Fig. 2* underlines the possibilities of creating value from food waste by applying circular economy principles in the agri-food value chain.

According to *Pour* and *Makkawi* (2021), food waste management methods are classified into two main categories: disposal and recycling. Disposal is a method by which food waste is considered trash or, as of limited value, discarded without processing or pre-treatment. Recycling presents a management method applying collection and processing to upgrade the food waste to a value-added product, for instance, compost or biofuel. The methods of food waste recycling and other recovery, presented in *Fig. 2*, can be classified as follows: mechanical conversation such as dewatering, filtering, and centrifugation; chemical conservation such as transesterification – one of the most promising options for food waste recycling to biodiesel; thermal conservation such as incineration – matured waste treatment technology under the category of thermal or thermochemical conversion; biological conservation such as composting – the transformation of organic compounds to ammonia-nitrogen, carbon dioxide, or complex recalcitrant materials (also known as humic substances) under aerobic conditions; anaerobic digestion – the method used for the generation of methane from organic matter in the absence of oxygen; fermentation – the process that produces ethanol.

Since a large amount of waste is generated by households, we will deal with this type in more detail below. Based on the experiences of other countries and available professional and scientific literature on the management of the system and technological procedures of kitchen waste processing, *Fig. 3* gives a schematic presentation of kitchen waste flows, technological processing processes, and obtained products.

As shown in *Fig. 3*, sorting kitchen waste can be classified as producing biodiesel from edible waste oil, bioethanol, and animal feed from kitchen waste. Unsorted kitchen waste processing operations can be classified as anaerobic digestion, composting of kitchen waste, and thermal treatment, including incineration, pyrolysis, gasification, and hydrothermal carbonization. The final option for kitchen waste treatment is landfilling, the most undesirable option.



Source: reproduced from KPMG, 2020

Figure 2. CE approach to the agri-food value chain

Given the enormous volume of waste, there has been much interest in developing new and novel waste recycling systems with properties like rapid, clean, sustainable, and cost-effective recycling. Therefore, the CE concept should be an obligatory waste management strategy to reach this goal.

In general, composting or biogas production from food waste is reasonably straightforward, with benefits in waste management, soil quality, air emissions, and resource use (*Kruchten & Eijk*, 2020).

Collecting and recovering 1,000 tons of food and organic waste, for example, would generate 60% more GDP and 40% more employment than disposing of it (*Karić et al.*, 2022).

3.3. Food waste as the cross-cutting issue of SDGs through the CE concept

The Post-2015 Development Agenda is built on the Sustainable Development Goals (SDGs), a set of 17 goals and 169 targets that must be met by 2030 (*UN*, 2015). However, the current formulation of SDGs does not recognize the importance of sustainable food waste management as a specific goal. Although there are no specific SDGs on food waste, many goals and related targets include direct, moderately direct, and indirect references to food waste. In addition, food waste is reflected in several goals and targets, such as health, cities, water, oceans, human settlements, and sustainable production and consumption. As a result, proper food waste management is a vital cross-cutting issue that can assist in resolving global and local problems (*Payet*, 2015).

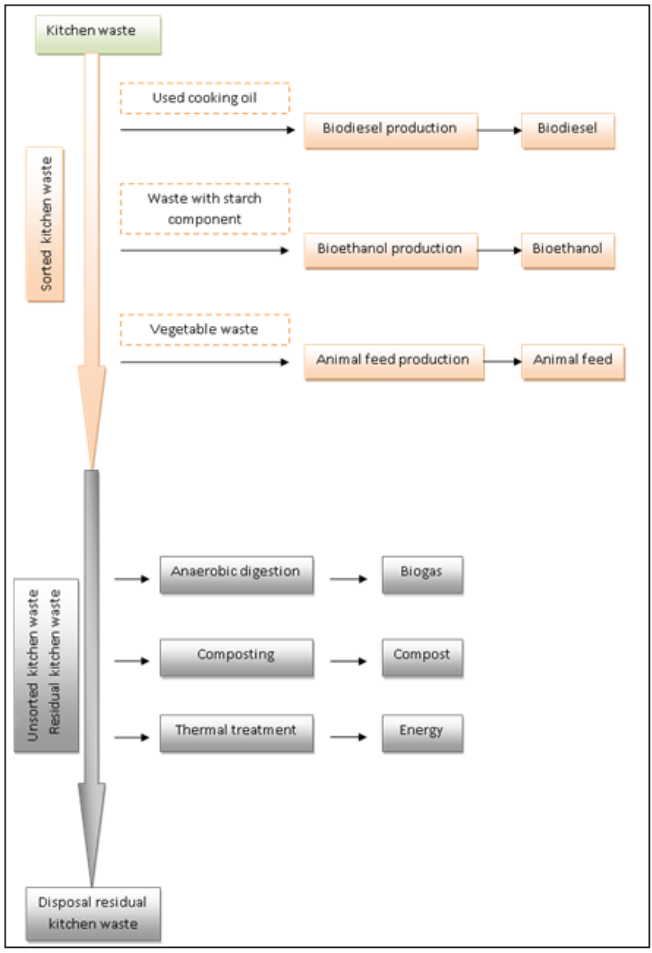


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Figure 3. Flows, processing and products from kitchen waste

SDG 2 "Zero Hunger" emphasizes extreme hunger and malnutrition, as these issues continue to be challenges for long-term development (less productive individuals, more prone to disease, and unable to earn more for improving their livelihoods) (*Kruchten & Eijk*, 2020). In SDG 2, the two targets are directly related to food waste, as presented in *Fig. 4*.

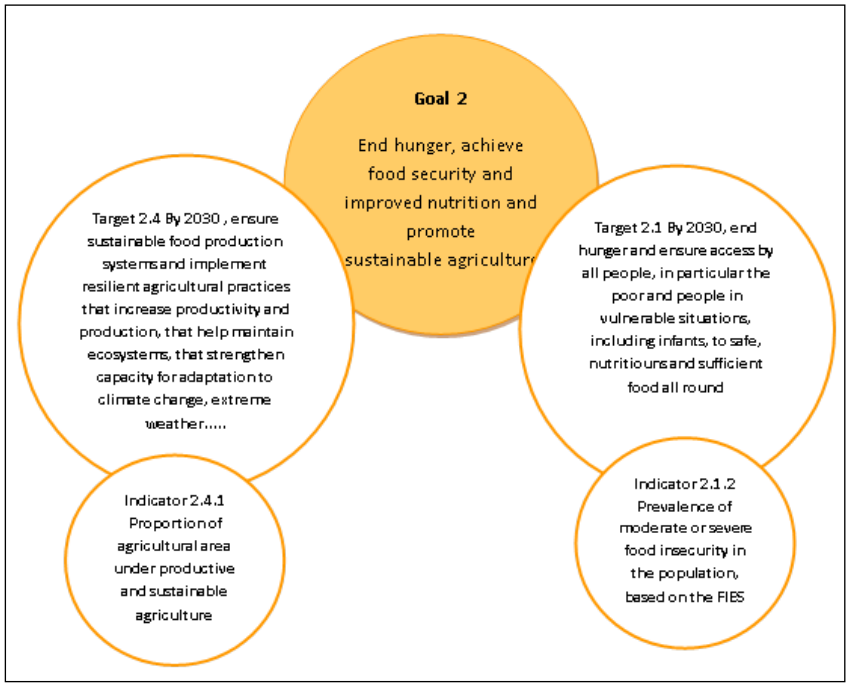

Figure 4. SDG 2 End hunger – directly related to food waste

One way to reach the targets of SDG 2 is by applying circular agriculture, which can help restore and improve soil quality by utilizing techniques, for instance, designing local nutrient loops. Furthermore, biomass from agriculture practice can be crucial for CE. For instance, biomass is a resource for food, animal feed, materials, transport fuel, and energy.

SDG 12, *Ensure Sustainable Consumption and Production Patterns*, aims to reshape consumption and production patterns to reduce resource pressure while promoting human and economic development (*UN*, 2015). On the other hand, unsustainable consumption and production patterns increase waste generation and the pressure on the environment and social and economic aspects of society. Diverse negative environmental impacts are caused by various extractive and processing industries and waste disposal, especially dumping and burning around urban areas.

In SDG 12, Member States also decided to – in target 12.3, "by 2030 [–] halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses". SDG 12, with its 12.3 target, refers specifically to reducing food waste by 50%, which would allow a decrease of 20 to 30% of the total food-sourced GHGs (*Lombardi & Constantino*, 2021). The significant reduction of food loss and waste offers profound benefits, including avoiding environmental impacts generated across the supply chain for food ultimately discarded, often at the landfill, a crucial emitter of potent greenhouse gas, methane. Furthermore, food waste reductions in supply chains generate economic benefits related to efficiency gains. They may grow food availability on the global market (*Prokić et al.*, 2016).

In target 12.5, Member States decided to – "by 2030 [–] substantially reduce waste generation through prevention, reduction, recycling, and reuse". This target intends to reduce waste flows by taking a whole-life approach. It includes lowering overall resource input (addressed by other targets) and raising recycling and reuse rates, which aligns with the 3R method goals (reduce, reuse, and recycle). The target applies to industrial and household waste, including food waste. Therefore, it would help to minimize the quantity of waste landfilled and incinerated. Also, this target should help to reduce overall resource use by replacing primary resource inputs with recycled materials. In addition, establishing a recycling industry and collection system may add new employment (*UN*, 2015).

In SDG 12, the two targets are directly related to food waste, as presented in *Fig. 5*. Many of the circular practices specified in SDG 12 are vital, including water management, waste management, sustainable products and services, sustainable supply chains, and synergies with renewable energy. In addition, circular economy approaches can reduce the industrial pollution of water and soil where the circular 3Rs rule (reduce, reuse, recycle) is crucial to this problem. Food waste management is moderately directly related to SDGs 3, 6, 11, and 14. In SDG 3, target 3.9. covers a wide range of threats to human health. The quality of food waste management services can significantly impact environmental pollution and, subsequently, human contamination. However, the public and political profile of food waste management is often lower than other utility services (*Prokić et al.*, 2016). Unfortunately, statistics linking health outcomes with environmental pollutants from the food waste sector are generally poor (*Weitz et al.*, 2015).

In SDG 6, target 6.3 is a wide-ranging one. Groundwater worldwide is threatened by pollution from agricultural and urban areas, solid waste (including food waste), on-site wastewater treatment, and other industrial sources (SDG). In addition, dumpsites on land can cause pollution of both surface and groundwater (*Prokić et al.*, 2016). A CE can help access to adequate and equitable sanitation and hygiene for all by developing technologies and systems such as biogas systems (*Kruchten & Eijk*, 2020).

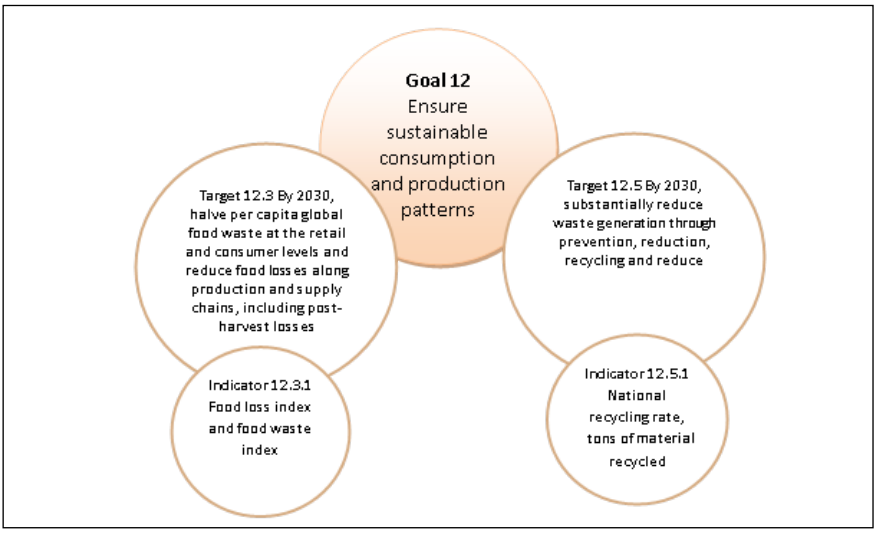

Figure 5. SDG 12 Responsible consumption and production – directly related to food waste

In SDG 11, Member States also decided to – in target 11.6. "by 2030 [–] reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management". A significant percentage of the population affected by pollution and waste lives in densely populated urban or semi-urban areas. Many cities produce more solid waste (including food waste) than they can dispose of properly. Even when municipal budgets are adequate for collection, the safe disposal of collected wastes remains a problem. Dumping and uncollected landfills are sometimes the main disposal methods in many developing countries; sanitary landfills are the norm in only a handful of cities. Solid waste management, including food waste, is essential for cities' sustainability, mainly if it includes: (food) waste reduction, reuse, recycling and composting, incineration, and disposal in landfills (*UN*, 2016). Core elements of circularity in urban areas are embedded within each critical urban system, from water, housing, and infrastructure to food and nutrition. Transition towards a circular city is a complex journey involving collaboration and coordination between the local government, businesses, organizations, technologies, and resources. Local governments are frequently confronted with the same question: what concrete steps can be taken to accelerate transitions towards a more CE? (*Kruchten & Eijk*, 2020). Goal 14 aims to conserve and sustainably utilize oceans, seas, and marine resources for sustainable development. In Goal 14, Member States also decided to – in target 14.1. "by 2025 [–] prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and

nutrient pollution". This goal is especially relevant if we consider the nutrient pollution from food waste.

However, almost every SDG could be linked to food waste management.

For instance, Goal 8, "promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all", is linked to food waste management through recycling and resource recovery, activities that create green jobs and limit consumption of natural resources. Furthermore, Goal 15, "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss", should be related to food waste management, considering that about 6% to 8% of all human-caused greenhouse gas emissions could be reduced if we stopped wasting food. All these facts indicate that food waste management is a cross-cutting issue impacting many aspects of sustainable development, and, considering food waste management issues, it needs to be included in every SDG through different, specific indicators.

4. Conclusions

A circular and sustainable economy is a prospective method for reducing food waste by implementing a production and distribution system in which food waste is reused or valorized into new products while reintegrating into market production channels.

Implementing a CE is a substantial task regardless of CE potential in food waste management. This task requires both macro- and micro-implementation and the vertical and horizontal integration of production and supply chains. Moreover, food waste management is a cross-cutting issue impacting many aspects of society and the economy. Therefore, food waste has strong linkages to SDGs. Although there is no specific SDG on food waste on the Post-2015 Development Agenda, several goals and related targets are directly, moderately directly, and indirectly related to food waste. Further, almost every SDG can be related to waste, considering waste as an environmental and economic and social issue.

The findings revealed that the strongest links and synergies between food waste management, circular economy practices, and SDG targets could be found in SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production). Both goals have high scores for direct and indirect contributions. SDGs cannot be achieved without applying the concept of CE. Therefore, from a food waste perspective, a tremendous potential for the CE application is evident in the SDGs and targets directly related to food waste.

To implement the 2030 Agenda, the UN and other international organizations proposed specific waste management indicators for specific targets. Targets are

aspirational and global, with each government defining its national targets based on the global level of ambition but considering national circumstances. Each government should consider how these aspirational and global targets could be included in national planning processes, policies, and strategies, taking the circular approach into account.

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