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Sustainable Consumption by Reducing Food Waste: A Review of the Current State and Directions for Future Research

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Abstract

Almost one third of all food produced in the world currently goes to waste. One of the targets under the 'Responsible consumption and production' sustainable development goal calls for halving the per capita food waste at the consumer level as well as across the supply chain from manufacturing, storage and retail by 2030. While numerous strategies have been recommended and implemented to address this problem, major challenges remain to be overcome. The paper presents an in-depth review of current state-of-art practices in food waste management. The solutions and recommendations presented to reduce food waste at the household, retail, restaurant, manufacturing and supply chain levels are reviewed. Regulations and regional variations in food waste management practices are also examined. The findings are used to identify research gaps and propose a conceptual framework to increase closed-loop material flow for more circular food systems that can reduce food waste. Potential areas for application of engineering and management principles to develop analytical models for food waste reduction are also discussed.

Keywords: Food waste management, circular economy

1. Introduction

There is an obvious and sad paradox between the increasing amount of edible food that is lost over the supply chain or consciously discarded by the consumers and the scarcity of food supplies for a significant part of humanity who still suffers from malnutrition [1]. Over the last few years, the food supply chain has become more complex due to an increase in the variety of foodstuffs and the longer distances between the source and the consumption points as a result of market globalization. Food waste is an ever-increasing global problem that currently represents almost one third of the total food produced for human consumption – equivalent to 1.3 billion tonnes every year – that gets lost or wasted [2]. Moreover, food waste is a major issue that has environmental, economic, as well as social and ethical implications. Firstly, it needlessly consumes resources and landfill capacity, as well as it produces greenhouse gas emissions contributing to global warming and climate change. Secondly, it involves significant costs including the value of the products themselves but also the production, storage, transportation and treatment costs. Thirdly, discarded food can be donated while it is safe for consumption to combat hunger as well as contribute to social equality and food security of an

increasing population. Consequently, there is an impeding need to prevent and reduce the amount of food waste in order to improve the resource efficiency of the supply chain, facilitate access to food and reduce hunger.

Food is wasted along the entire supply chain, from agricultural production to storage and transportation stages, down to final household consumption. As can be seen in Fig. 1, according to the Food and Agricultural Organization of the United Nations (FAO) in medium and high-income countries food is wasted and lost mainly at later stages in the supply chain, thus meaning that it is thrown away irrespective of whether it is still suitable for human consumption. Some reasons for this are the prosperity in those countries and the lower food prices. However, in developing countries food waste and losses mostly occur at early stages of the food value chain mainly due to rigorous quality standards in terms of shape, size or appearance, inappropriate food packaging solutions, inadequate transport infrastructure and improper storage, cooling or market facilities [2].

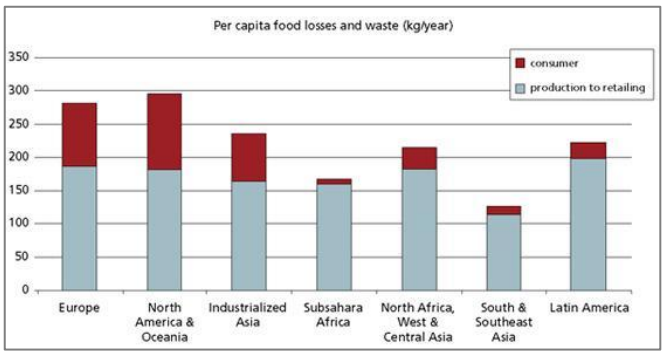

Fig. 1. Per capita food losses and waste, at consumption and pre-consumptions stages in different regions [2].

Annual food waste levels across Europe are estimated to be 88 million tonnes [3] and will rise to approximately 126 million tonnes by 2020 [4]. The most important food groups are cereals, vegetables and fruits, as well as milk and eggs. The two most important sectors contributing to this result are households (53%) and food processing (19%). After them, comes food service (12%), production (11%) and wholesale and retail (5%) [3]. It must, however, be noted that the methods used to collect and calculate data are not standardized, thus making it difficult to establish a baseline for food waste and monitor results.

2. Review of existing regulations on food waste

The food waste problem has made it to the public agenda in different countries in recent years. The issue is expected to gain more attention in the future considering the need to feed a growing population.

According to the hierarchy of waste treatment activities, prevention must be prioritized over re-use, recycle, other recovery e.g. incineration or disposal. Based on it, the EU has defined the food waste hierarchy according to the particularities of food in the following way (see Fig. 2).

At present there is no agreed definition of food waste at either the EU level, or at the FAO. This will be a fundamental step to determine an organic legal reference framework for prevention policies. The EU considers that the top three layers (prevention, donation and animal feed) are actions that can be taken before food becomes waste, prioritizing the two highest levels, i.e. prevention and donation.

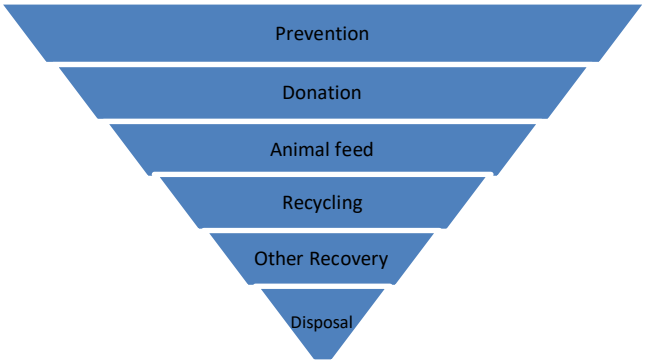

Fig. 2. EU Food waste hierarchy [4].

Table 1 below summarizes the different stages along the supply chain where food waste originates and the situations that give rise to food waste at those stages.

Table 1. Situations causing food waste at the different supply chain stages (adapted from [4]).

Stage	Situations causing food waste
Production	Mortality of animals, discards of products, crops not fully harvested or green-harvested, damages during storage or transportation, interruption of the cold chain, excess stock
Processing	Process losses (peeling, slicing, boiling, spoilages…)
Retail	Date best-of or expiry, poor demand forecasts, unsold products, damages…
Consumers/Restaurants	Date expiry, surplus cooked, food preparation waste, plates scrapings, hygiene rules, poor store management

Legislative actions can play a major role to reach the goal of preventing or reducing food waste by inducing corporate involvement [5]. At the European level, there is no EU policy that specifically tackles the problem of food waste. It is embedded in the EU Waste Framework Directive (Directive 2008/98 EC of 19 November 2008), which means that it is addressed from the environmental point of view, disregarding social or ethical perspectives. This directive sets the basic concepts related to waste management and aims to prevent or reduce the generation of waste [6]. However, the EU can affect the amount of food waste generated through the different policies it has put into place, such as the Common Agricultural Policy, the Common Fisheries Policy, the Food Safety Policy, the Circular Economy Package or the above-mentioned Waste Framework Directive. Concerning food safety, legal requirements to prevent health problems may conflict with the goal to reduce food waste [7]. Besides, the Member States can decide how they enact EU provisions sometimes launching

their own initiatives. As a matter of fact, Member States have started setting targets in order to reduce food waste in line with the provisions of the United Nations (UN). The UN indicated in its agenda for sustainable development to 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 by 2030 (goal 12.3) [8]. For example, in France a law was enacted in 2016 that requires supermarkets to donate food that would otherwise be wasted.

An EU platform on 'Food Losses and Food Waste' is available providing information on EU actions to tackle food waste, a repository of good practices in food waste prevention, communications materials to help raise awareness and a food waste resources library [9]. Besides, the EU offers different instruments that can have an effect on preventing food waste such as labelling, traceability, marketing standards, unfair trading practices and financial stimuli [4].

Despite all these efforts, the Commission's ambition in regard to food waste and the actions taken to date have been fragmented and intermittent. Therefore, strategies to combat food waste must be strengthened and better coordinated [4]. In addition, some authors propose the introduction of mandatory waste reduction targets, the revision of EU legislation on food safety and marketing standards and legally limiting the liability of food donors [7]. Others suggest the need to define a common strategy at the global level with uniform quantification methods, targets, actions to be taken and methods for monitoring the results over the long-term [1].

3. Review of regional practices

Practices and methodologies used for food waste management vary across the different regions in the world. The Food and Agriculture Organization (FAO) data shows the variation of food waste across the different regions and the sources of food waste [10]. As shown in Fig. 3, this data confirms that the majority of food waste in developed countries occurs during the consumption stage whereas in developing/less-developed countries it occurs during production as well as handling and distribution.

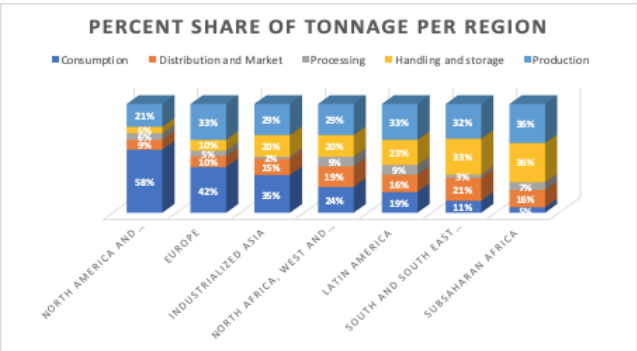

Fig 3. Percent share of tonnage per region [10].

Further assessment of the data from different sources allows a closer examination of sources and distribution of food waste in the European region. As seen in Fig. 4, it is evident that the majority of the food waste occurs during the consumption stage. The Foodspill studies described in [11], however, reveal a higher percentage of food waste occurring during the retail stage. The main reason of the difference between studies is the diversity of definitions and methodologies used in each analysis. For instance, the result for retail sector varies from 9% in the case of FAO study to 32% for the Foodspill study.

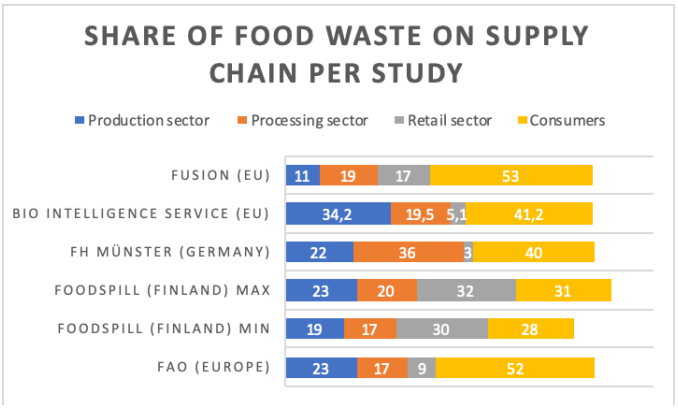

Fig. 4. Share of food waste at the different stages of the supply chain (in %) according to different studies [11].

A study presented in [12] shows the estimate of food waste levels in Europe. Sectors such as primary production, processing, wholesale and logistics combined with retail and markets, food service and household were studied in detail. This study shows that the cost associated with food waste for EU-28 in 2012 are estimated around 143 billion euros. Then all possibilities of food waste reduction are tested: food redistribution through social innovation, animal feed, etc.

In Europe, food waste prevention strategies include:

- *Reducing food waste generation* at each stage of the food supply chain: primary production, processing, manufacturing, retail, other food distribution, restaurant and food services, household for progress towards SDG 12.3;
- *Monitoring and reporting food waste levels* regularly based on common EU methodology.

The European Food Banks Federation (FEBA) focuses on redistribution of food. FEBA estimates that 411,000 tons of food were redistributed in 2014 via their members [3, 12]. In 2018, FEBA recovered surplus food to prevent food waste and reduce food insecurity. It corresponds to 781,000 tons of food equivalent to 4.3 million meals each day, 45700 charitable organizations, and 9.3 million deprived people. The FUSION (Food Use for Social Innovation by Optimizing Waste Prevention Strategies) project has elaborated estimates of European food waste levels and has defined different methods of food waste treatments: charity redistribution, animal feed, composting (central composting at official sites), Home composting, Anaerobic digestion, wastewater treatment plant (intended as well as unintentional waste down the drain, if data are known), incineration with energy recovery, landfilling, other/unknown as explained in [3].

Several European countries have successfully managed to reduce food waste by enforcing policies, increasing public

awareness and participation, and using innovative technological solutions available today [13]. For example, countries like Denmark, Norway, France and Sweden have mandated all surplus food from restaurants, hotels and departmental stores to be redistributed for human consumption rather than disposing of as waste [14]. Some countries have developed mobile applications that alert customers of food products nearing their expiration dates, which can be purchased at reduced prices [15].

One well-known initiative is the so-called 'Stop Wasting Food' in Denmark which provides guidance for consumers on how to avoid wasting food by shopping according to daily needs of households, and promotes better household planning and shopping patterns in order to encourage a movement away from impulsive to rational food shopping and consumption patterns [10]. In the UK, the Waste Reduction Action Plan (WRAP) urges leading brand owners, retailers, and their supply chains to define collaborative approaches towards reducing the amount of food and packaging waste that ends up in landfill [10].

Several reports focus on the severity of consumer food wastage in the USA; according to some studies the per capita food waste is reported to be 132 kg, including from both households and food-service entities [16, 17]. Clearly, reducing food wastage represents an opportunity of significant magnitude, serving food security and the achievement of sustainability goals. The USA stands out among the developed countries producing 766 million metrics tonnes (MMT) of food which is more than France, Germany, Canada, Japan, and Australia combined (595 MMT) or about 89% of EU-27. This variation of food production between the USA and other countries is illustrated in Fig. 5 and the same variation on food supply chain is illustrated in Fig. 6

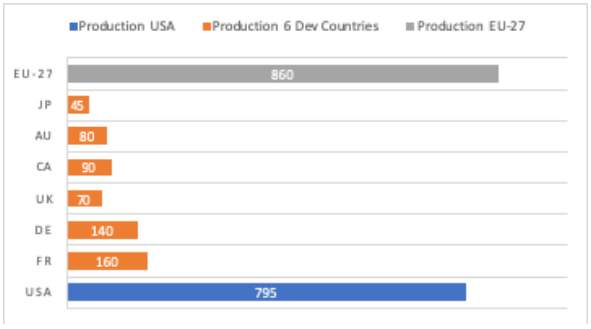

Fig. 5. Comparison of annual food production

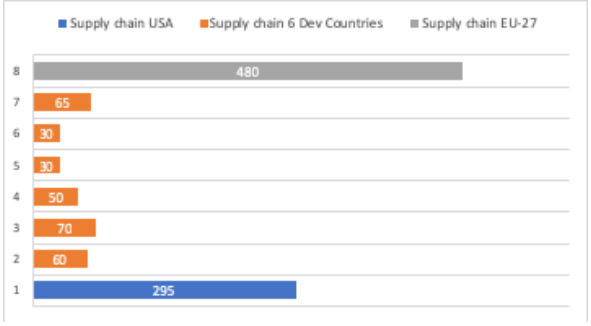

Fig. 6. Comparison of domestic food supply

For instance, in [27], author reports that the amount recovered for human or any other beneficial use, out of the 41 MMT food waste generated by American consumers, is negligibly small. Current food recovery for human consumption approximates 1 MMT (based on BSR and Feeding America reports), which includes 320,000 - 360,000 tons for industry donation, 300,000 - 410,000 tons for wholesale-retail donation, and roughly 250,000 tons fresh produce presumably from gleaning efforts. Thus, the amount recovered is less than 2%. Success stories exist in the USA as well. One example is the Food-Too-Good-To-Waste program, whereby 50-60% reduction of kitchen food discards has been realized among participating households.

Another study reports that each year between 125 and 160 billion pounds of food, amounting up to 40% of the supply, are not consumed in the USA [19]. This waste occurs throughout the food supply chain: farms, processing, distribution, storage, retails stores, food service operations, and households. In Fig. 7, the distribution of the USA food waste at different stages the supply chain is presented.

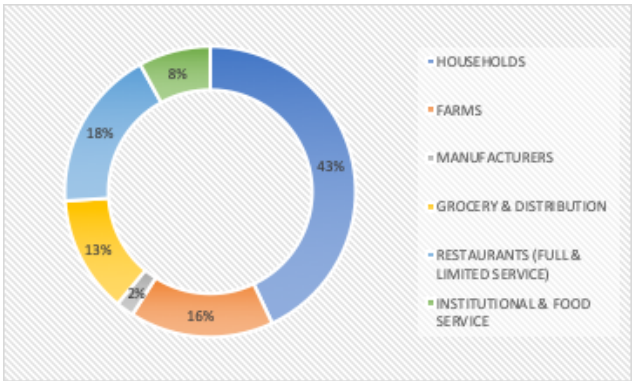

Fig. 7. Food waste generation by supply chain stage in USA [19].

In [20], authors focused on food waste and losses in Asia. Nine indicators are defined for categorizing food waste: edibility, state, origin, complexity, presence of animal products, treatment, packaging, packaging biodegradability, and the supply chain stage [21]. The total quantity of food waste in Asia is evaluated to be around 278 million tonnes (compared to 1.3 billion tonnes in the world). The distribution of this food waste and losses in various geographical regions in Asia is shown in Fig. 8.

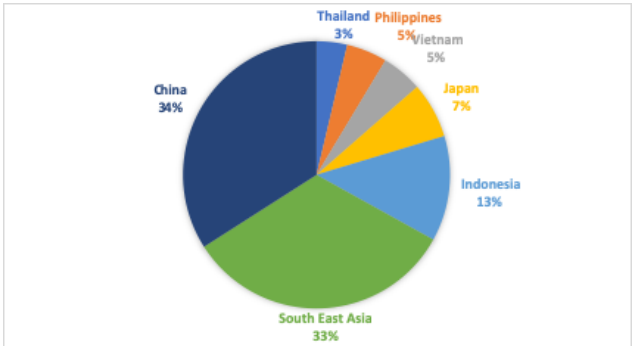

Fig. 8. Quantity of food products wasted in various geographical spectra [22].

The social reasons for food waste generation include lack of awareness or concern, acceptance of wasting food as a social norm, poor planning, personal preferences for certain food, improper and unsystematic storage practices, and over preparation of food.

For standardizing definitions, concepts, methodologies and tools in this domain, UNEP-FAO has elaborated a guide in which four modules are described [23]:

- *Mapping and measuring food and drink waste* (quantifying waste at national or regional level, from the supply of food and drink, and from households)
- Options for *developing national or regional policies and measures* for food and drink waste prevention and reduction (options for motivational strategies, voluntary collective action programs, consumer engagement campaign)
- Developing and implementing *programs to prevent and reduce household food and drink waste* (with five steps as follows where Step 1: Plan and develop a strategy for a consumer engagement program, Step 2: Establish a baseline and set a target, Step 3: Develop evidence-based guidance, Step 4: Take action to prevent food waste, Step 5: Measure, monitor and report progress)
- *Preventing and reducing food waste in the food and drink business supply chain* (retail and manufacturing, and hospitality, and food service): guidance for individual business (corporate strategy, baseline and targets, taking action, guidance with tools and examples, measurement and reporting progress towards targets); guidance for developing voluntary collective action programs (with five steps as follows where Step 1: Plan and develop a strategy for a voluntary collective action program, Step 2: Establish a baseline and set a target, Step 3: Develop evidence-based guidance, Step 4: Take action to prevent food waste, Step 5: Measure, monitor and report progress)).

4. Current research in food waste management

The past decade has seen a significant increase in the amount of food waste-related scientific research that has been carried out. For better representation of the current state of research, as well as to understand the research gaps and future work necessary, we use the total lifecycle-based view of food products. The total lifecycle of a consumer product can be divided into four broad stages of pre-manufacturing, manufacturing, use and post-use [24]. We adapt this perspective for food products as follows. Crop production and preparation, including storage, can be considered as 'pre-manufacturing' for food products. Processing and/or packaging of the crops can be considered the manufacturing stage. The use stage involves consumption of the food products by individual consumers as well as food service organizations such as restaurants. Post-use is generally more prominent for non-consumable products. However, for food products, their handling after consumers have utilized them can be considered the post-use stage and will hereafter be termed the post-consumption stage. Transportation and distribution activities will encompass all these four lifecycle stages. Fig. 9 below summarizes the lifecycle view of food products emphasizing the different sources of food waste and related aspects studied in extant literature that is further discussed in the following paragraphs.

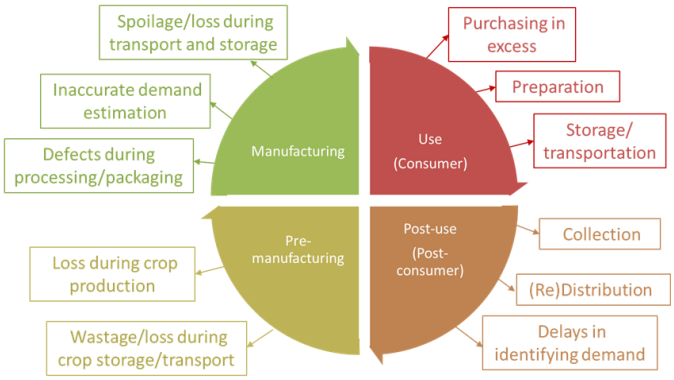

Fig. 9. Lifecycle view of food products and wastes

The emphasis of food waste-related research can generally be grouped into those focusing on measurement or assessment, prevention or reduction, and collection or management. A precursor to eliminating food waste is an understanding and accurate quantification of the food waste that is generated at different points in the lifecycle of food products. A majority of the existing studies have indirectly measured food waste [25]. This is one reason for the disparity in the data about food waste discussed in the previous sections. Thus, while indirect methods are easier to use they may not provide accurate quantification of the total food waste. Hence, it is important to use direct methods to accurately quantify the waste at different points in the food lifecycle or the supply chain.

One of the most impactful methods is avoiding unnecessary food production to prevent downstream food waste reduction [26]. Studies have emphasized the food waste that can occur in the early stages of pre-manufacturing and manufacturing due ineffective demand forecasting [27] or defective raw materials and mistakes/errors during manufacturing [28]. Waste occurring at these early stages during storage, for example due to contamination, as well as transportation has also been emphasized. The application of lean principles to classify the food waste that occurs across the lifecycle into different types of 'lean' wastes is presented in [27]. This approach to food waste classification provides a different perspective to examine continuous improvement efforts to eliminate such wastes. They also provide a systematic review of studies that apply value stream mapping (VSM) as a first step to identify opportunities to eliminate waste across the food lifecycle.

Numerous studies have undertaken quantifying the impact of food waste across the different lifecycle stages, or in other words, the food supply chain. Some more recent studies include those examining impacts due to household and retail food waste [29, 30, 31, 32, 33], impacts of waste during and due to food packing [30, 34], and impacts during food transport [29]. Reviews of studies focusing on environmental assessments of food waste prevention and management strategies have also been presented [26]. Another emerging issue related to the

environmental perspective is the further development of green logistics for food waste collection and distribution in cities as well as shorter and simpler food supply chains in order to reduce food miles [35].

Losses during transportation between and within the different lifecycle stages account for a significant portion of the food waste. A vast amount of literature has focused on managing the collection and processing of food wasted at different points in the lifecycle. A comprehensive review of studies that apply Lifecycle Assessment (LCA) tools to evaluate food waste management systems is presented in [30]. Based on twenty-five studies they point to the wide variation in the results found and emphasize the need for more detailed guidelines for how LCAs should be used when evaluating food waste management systems. A more extensive review of 147 papers focusing on food waste management is presented in [36]. The authors report the most studied prevention strategies were policy solutions, better methods for packaging and labelling food, techniques to improve the transportation and distribution as well as changing consumer behaviour, and methods focusing on reuse/redistribution of waste food. Based on a survey of literature [37] report that Geographic Information Systems (GIS), optimization, multi-criteria decision making and heuristics are among the most common methods used in literature to study solid waste (including food) management systems.

With the developments in wireless networking technologies and the Internet of Things (IoT), the potential to use advanced technologies for waste management in smart cities and smart supply chains has been investigated. A review of literature that discusses opportunities and challenges to waste management in IoT-enabled smart cities is presented in [38]. The authors of [38] elaborate on the potential to increase efficiency of waste collection through intelligent transportation networks. Another study [38] also reviewed existing studies on IoT-enabled waste management for smart cities and offers a conceptual framework to achieve zero waste. While the focus of the reviews by both [38, 40] is solid waste in general, the IoT-enabled methods investigated, and the frameworks proposed, are likely to be equally applicable to food waste management in future smart supply chains and smart cities.

5. Research gaps and directions for future work

While an extensive amount of research has been conducted on the measurement, prevention and management of food waste across various domains, there are still major shortcomings to be addressed. Food waste is widespread across the lifecycle stages. It is imperative that accurate and direct methods are used to quantify food waste at all levels [25]. While measurement allows quantifying the food waste from a historic perspective, comprehensive analytical models are also necessary for forecasting future food waste [40] in order to develop scalable methods for their prevention and management.

The total lifecycle perspective to food (and other) products was introduced earlier in this paper. Adopting a total lifecycle approach will emphasize prevention and elimination of food waste from not just one lifecycle stage but across the entire lifecycle. The lifecycle perspective is also promoted by the Circular Economy concepts that is targeted at moving from a linear economy to a more regenerative and restorative economy. However, through a systematic review of literature authors of [41] posit that most studies on food waste inadequately focus only on some or a few of the stages of this lifecycle. Therefore, further research to examine the food waste problem from a more holistic perspective is needed. This insight is also supported by a study on food in cities carried out by the European Commission [35].

Food waste along the supply chain is examined in [42] considering a previously presented framework for sustainable supply chain management. The authors emphasize how each process and link in the supply chain could contribute to reducing, or potentially preventing, food waste. They also emphasize the importance of integration and synchronization of efforts across the supply chain, similar to the approach required for a Circular Economy or closed-loop material flow. Another school of thought has examined the concept of zero waste used in the context of industrial production that can be applicable to food production. As per [43], this approach also emphasizes adopting a more holistic view to implement systemic measures to eliminate waste rather than merely implementing corrective actions after food is wasted, similar to the Circular Economy approach. Such a holistic view will enable addressing a major aspect of the food waste problem that occurs in the early lifecycle stages of pre-manufacturing and manufacturing due to poor forecasting and overproduction [43].

A variety of studies explore the application of optimization, multi-criteria decision making and other analytical tools for food waste management. However, there is still a need to investigate more about the use of analytical tools and ICT methods for waste management, particularly for recycling, reverse logistics and to support environmental regulations [37]. Solid waste management studies have also mostly focused on economic and environmental aspects without much emphasis on social aspects.

The potential to use IoT-enabled technologies to improve capabilities for measurement, prevention and management of food waste has been highlighted in recent literature. Industry 4.0 technologies, including IoT, artificial intelligence, data mining, machine learning, etc. can help increase capability for demand forecasting, supply chain partner collaboration as well as monitoring and assessing point-of-occurrence of food waste. They can increase capability to make the food supply chain and food waste management more intelligent and agile [44]. The benefits of using collaborative forecasting [42] where partners from across the supply chain come together to identify the demand for food collaboratively to minimize overproduction has been pointed out. IoT-enabled technologies can be an enabler for providing real-time access to data and facilitating the use of capabilities such as collaborative forecasting. Another important aspect that IoT technologies can facilitate is shelf-life monitoring and the possibility of informing consumers of food products reaching their expiration date and attracting them by setting lower prices. Moreover, from the consumer perspective, ‘smart’ fridges can help consumers to purchase in quantities more commensurate with needs, rather

than shopping large quantities in advance. Such features could contribute to addressing high food waste generated by households in rich countries.

Integrating the total lifecycle-based approach essential to promoting Circularity for minimizing food waste and to address the various research gaps discussed above, we propose the framework presented in Fig. 10. The integrated framework is described in the following sections.

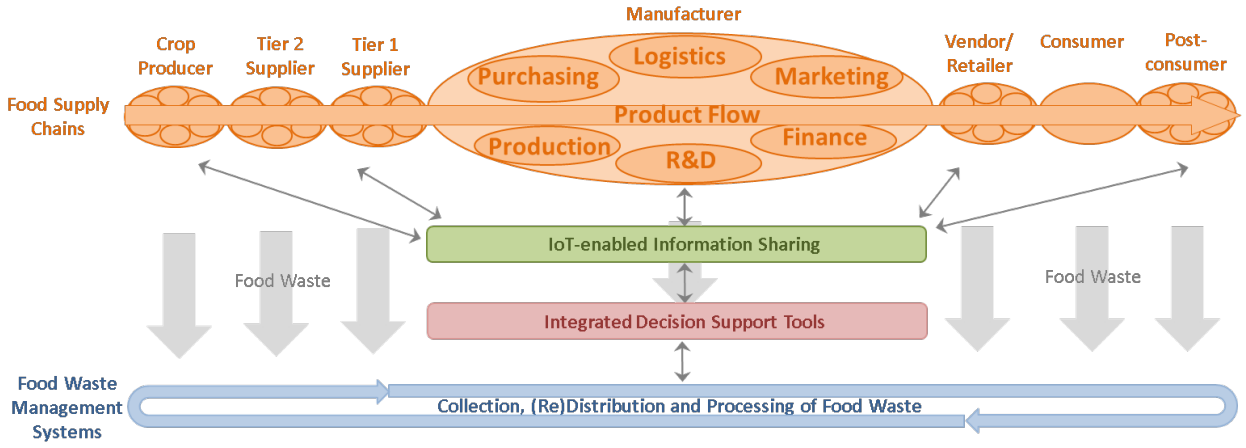

Fig. 10. Integrated Framework for Food Waste Prevention and Management

Most existing research often focus only on the food waste occurring in one part of the supply chain, either at the manufacturer, distribution, retail/wholesale, consumer (households, food service, etc.) or at the post-consumer level. Using an integrated and lifecycle-based framework such as presented in Fig. 10. will enable considering multiple segments of the food supply chain and different stakeholders simultaneously. The upper section of the framework illustrates the holistic consideration of the end-to-end food supply chain to prevent food overproduction and minimize food waste. While zero waste in the food supply chain [41] may be an idealistic target, the proposed integrated framework can enable minimizing food waste to approach the zero-waste target.

It is imperative that different functions of the food manufacturers and their upstream suppliers, including crop producers, are educated and engaged in the processes required to mitigate food waste at their respective stages in the food lifecycle as well as the downstream stages. For example, if the food manufacturer is considered, coordinated decision making by the marketing, production and purchasing units will be necessary to ensure accurate demand planning, material sourcing and food production. The illustration of various functions within the manufacturer (and other supply chain players) in the figure draws emphasis to this requirement.

Effective and timely decision making to mitigate food waste at pre-manufacturing, manufacturing, use and post- consumer stages depends on access to accurate information and advanced tools for selecting the appropriate course of action. This is illustrated in the middle section of the proposed integrated framework (Fig. 10) where IoT-enabled capabilities can allow for information sharing between different parties. This information sharing can lead to more intelligent and agile supply chains [44] as the information can be used in integrated multi-criteria decision-making tools to minimize food overproduction, for waste minimization and management

of post-consumer food waste. The proposed framework can be used to identify information needs and clearly define information that must be shared between each link/partner and among the links/partners in the supply chain [43].

Extensive research will be necessary to develop and deploy a food waste prevention and management system similar to that outlined in Fig. 10. Effective and timely coordination among supply chain is the hallmark of the framework to address supply and demand disparity in food supply chains. While Collaborative Planning, Forecasting and Replenishment (CPFR), a trademark of the Voluntary Interindustry Commerce Standards (VICS) in GS1 US, to cooperatively manage supply chain inventory exist, it is not widely adopted due to the effort required. Further research is necessary to examine how to better facilitate CPFR for collaborative forecasting using IoT and other Industry 4.0 technologies. Research must also be undertaken to develop comprehensive analytical models and integrated decision support tools that will use digitally available information from different partners to reduce the demand and supply disparity. Further studies are also necessary to examine the design and management of systems to collect, (re)distribute and process food waste to increase circularity in material flow.

6. Conclusions

Food waste is a major cause for concern that is gradually attracting more attention of the research community, as well as of the public and private sectors. In the coming years this problem is expected to become even more serious due to an increasing population with significant impacts on the three-bottom line aspects i.e. considering not only economic but also social, ethical and environmental dimensions.

Legislative actions, which can help the private sector to get involved in the fight against food waste, are still scarce and specific food waste legislation is absent. Global strategies providing a common food waste definition alongside unambiguous quantification methods and waste reduction

targets in accordance with the propositions of the UN could be an essential first step towards the solution of this issue.

This paper proposes the use of an integrated and lifecycle-based framework in order to enable the cooperation of all stakeholders to implement a successful Circular Economy-based approach. Such an approach can help address the gap in current research which lacks a holistic perspective to address the food waste challenge. The use of digital technologies such as IoT is likely to improve food monitoring and prevent losses across the supply chain. Moreover, the use of comprehensive analytical models can potentially improve capabilities for forecasting food demand and food waste as well as better coordination for food waste management.

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