Carbon Footprints across the Food Supply Chain: A Microscopic Review on Food Waste-Related Sustainability Assessment

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Abstract

Reducing the carbon footprint along the food supply chain neutralizes the cost of climate change-related impacts on the environment. A third of the food produced globally is wasted along the food value chain. This paper presents a microscopic review covering studies related to carbon footprint analysis across the food industry. The review focuses on the critical aspects of lifecycle-based techniques across the food supply chain, namely, a) calculating the amount of food waste/loss b) evaluating and quantifying the environmental impacts associated with food waste accumulation along the value chain and, c) identifying the stages along the value chain that contribute potentially to the food waste-related emissions and environmental impacts. The results show food waste in terms of mass does not necessarily indicate the food waste-related impact. Although animal-containing products have relatively low waste in terms of mass, they contribute significantly to the food waste-related impact, explicitly affecting global warming potential. This paper's outcomes support food waste-related sustainability assessment and transition to a circular food supply chain.

Keywords: Carbon footprint, climate change, food waste, food supply chain, global warming potential, life cycle, sustainability assessment.

1. Introduction

Over the recent years, sustainability has taken the lead in the food and beverage industry (Kutty and Abdella 2020; Kutty et al., 2020B). Food production plays a significant role in humanity's survival (Bergstrom et al., 2020). With a steady increase in the population, the human need for food has also increased, thus demanding a sustainable slant to the production and consumption patterns (Fróna et al., 2019). The agro-based food supply system would face severe challenges when attempting to feed a population of over 9 billion by 2050 with serious concern on climate change (Rosin et al., 2012). Studies show that a third of the food produced is either lost or accumulated as waste across the food supply chain (FAO, 2014). Agriculture contributes significantly to Greenhouse Gas (GHG), emitting approximately 51 billion tonnes of carbon dioxide (CO_2) annually (FAO, 2017). While, ruminant animals are a primary source of meat and dairy product, livestock's supply chain including their wastes, release harmful emissions such as methane (CH_4), nitrous oxide (N_2O), and CO_2 (Boehm et al., 2018). The livestock supply chain emissions account for nearly 50% CH_4, 24% N_2O, and 26% CO_2 (FAO, 2017) along the value chain.

Despite attempts to achieve a sustainable and secure food supply chain, the current food system has failed to promise food security and mitigate the temperature rise from emissions that contribute to climate change (Bottani et al., 2019). The food industry faces unprecedented challenges while attempting to balance the increasing production and consumption demand and reduce GHG related emissions (Bouzembrak and Marvin, 2019). According to Nicoletta (2019), the livestock sector emissions are relatively equivalent to the total global emissions from cars, trucks, and airplanes. These emissions are not strictly limited to CO_2 alone. Other anthropogenic GHG and ozone-depleting substances also alter the earth's climate. The agro-based industry contributes nearly 13.5% to the total annual anthropometric GHG emissions with a significant contribution of approximately 70% nitrogen dioxide (NO_2), 50% CH_4, and 25% CO_2, as per Nicoletta, (2019)'s study. These anthropogenic GHG emissions are anticipated to increase if no actions are considered to mitigate the negative impact of emissions on the environment. Food loss and waste are coupled with emissions, where all the food waste along the Food Supply Chain (FSC) contributes significantly towards boosting the level of GHG emissions released into the atmosphere (Scholz et al., 2013). Neutralizing the carbon emissions along the value chain remains a concern when addressing food supply chain sustainability (Edwards et al., 2018).

Sustainability is of profound importance (Kucukvar et al., 2016; Kucukvar et al., 2017; Kutty et al., 2020; Kucukvar et al., 2020; Kutty et al., 2020A). Food waste generates around 8% of anthropometric GHG emissions per year (FAO, 2011). Reducing the emissions derived from food waste requires continuous monitoring of GHG emissions along the value chain (Adelodun and Choi, 2020). Understanding the methods and processes involved in carbon footprint related sustainability assessment is essential to carry out research activities to mitigate the ongoing climate change-related impacts. Thus, it is essential to undertake an in-depth review of the critical aspects of lifecycle-based techniques across the food supply chain. This research thus presents a microscopic review on food waste-related sustainability assessment.

The review is organized into four sections starting with an introduction that details the necessity of reducing food waste and associated emissions across the food supply chain. Section 2 attempts to outline the research methodology undertaken for the review process briefly. Section 3 fragments carbon footprint knowledge in food waste sustainability to understand the growing interest in carbon footprint-related studies for food waste management. In the context of food waste, Section 4 aims to quantify the food waste categories across the value chain for several food sustainability-related studies highlighting geographic location's impact when quantifying considerable amounts of food waste along the value chain. The environmental impact of food waste coupled with life cycle assessment tools on several food sustainability-related studies are covered under Section 5. Section 6 identifies the stages along the food supply chain that contribute significantly to food waste accumulation, including primary production, handling, processing, distribution, and consumption stages. Finally, Section 7 provides a conclusion with some recommendation pathways for future research.

2. Method

This paper presents a microscopic review covering studies related to carbon footprint analysis across the food industry. The review focuses on the critical aspects of lifecycle-based techniques across the food supply chain, namely, a) calculating the amount of food waste released and lost b) evaluating and quantifying the environmental impacts associated with food waste accumulation along the value chain and, c) identifying the stages along the value chain that contribute potentially to the food waste-related emissions and environmental impacts. Initially, the research objectives are identified, and the research questions to be addressed are formulated. The scope is then identified, and the area of focus is determined to streamline the study. A keyword-based search is then used in the Science Direct online database, including a combination of keywords such as "Food waste" OR "Food loss" AND Sustainability"; "Food waste" AND "Carbon footprint"; and "Food waste" AND "Supply chain" "for selecting relevant peer-reviewed e-resources to initiate the review process. The authors have chosen mostly peer-reviewed journal articles, book chapters, and book sections from the database. A further search on Google Scholar using the same keywords was conducted to expand scholarly literature search in the English language for dairy food waste related studies. All articles written in foreign languages except English included Spanish, Chinese, French, and German. This search was conducted to review the existing available literature in quantifying food waste, the environmental impact associated with food waste, supply chain analysis of food waste, circular economy for food waste, and applications of carbon footprint models in different food industries.

The literature review attempted to cover relevant publications from 2009 till 2020. The search resulted in a total of 10,969 articles, of which 487 articles were related to the selection criterion; that is, the articles that fall under the publication timeline, language preferences, and articles related to carbon footprint analysis across the food industry. These articles were further examined and checked after skimming through the abstract. The process of further checking the novelty and relevancy of the collected materials led to breaking down the selected articles into 87 documents, which were then cut down to 23 papers to scan in detail. The methodology for searching and sorting the Science Direct database documents is shown in Figure 1. Initially, the search was conducted by identifying the keywords and skimming through the abstract to identify studies most relevant to food waste-related sustainability assessment. The authors then categorized the documents based on the key aspects of lifecycle-based techniques across the food supply chain that formed the basis of the literature review. The results were then documented in a conference paper format.

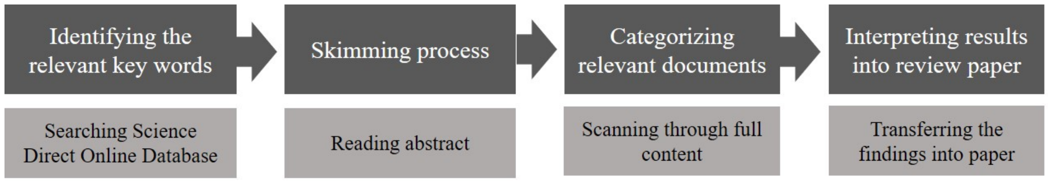

Figure 1. Review method.

3. Knowledge Fragmentation

Over the last decade, many life cycle based carbon footprint related studies have been conducted across the food supply chain. To understand the growing interest in this field of knowledge, particularly the area related to the emissions released from food waste, the authors have sorted the relevant number of publications in the Science Direct online database using the keyword search. Figure 2 shows the distribution of articles based on their type in the selected school of thought as an outcome of the search. Results show that most of the articles were research articles and review articles dealing with life-cycle-based carbon foot printing studies. The highest number of research articles and review articles correspond to the keyword "carbon footprint." Studies on carbon footprint have gained research attention in different fields to implement sustainability and reduce GHG emission related environmental impacts. However, most of the carbon footprint studies focused on reducing the emissions in transportation, electric utilities, industries, commercial, and residential sectors, where few of them only addressed the application of carbon footprint in the agricultural sector, which was too negligible.

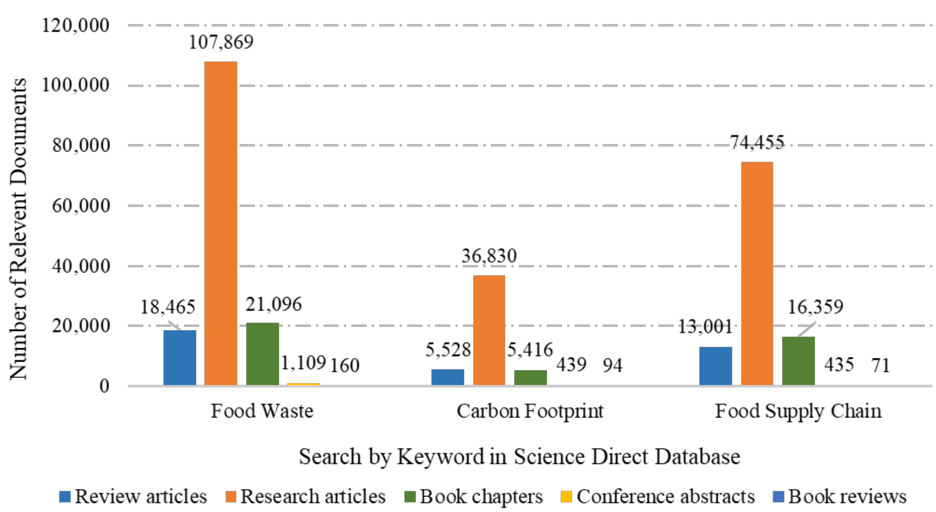

Figure 2. Documents distributions per keyword search.

Due to the importance of awareness of this topic, the authors decided to figure out the distribution of publications under specific keywords. It is evident from Figure 3 that there is an increasing trend in the number of publications from 2009 till 2020, especially in the field of food waste and carbon footprint. Food waste can be categorized into five different groups: dairy waste, protein waste, grain waste, fruit waste, and vegetables and legume waste (FAO, 2019). The authors conducted a deep dive into the ocean of literature to identify the most relevant publications based on the categories of food waste. The search ended up resulting in 114 publications under the dairy food waste category, 57 publications under the protein food waste category, and 38 articles under the grain waste category. While, 69 publications were found under the fruit waste category and 22 publications explicitly focused on the vegetable and legume waste category. Several studies have been conducted in the food supply chain area considering the food supply chain's production and consumption phases since the early 1990s. However, there is a slight increase over time in the publication of articles in the food supply chain area compared to the publication count in the field of carbon footprint and food waste. Therefore, the rationale behind undertaking this review is to find out the contributions made by experts in carbon footprint-related assessments for food waste management. This study acts as a baseline in structuring assessment pathways to shift from a linear food supply chain to a circular food supply chain by understanding the food waste categories and emission-related impacts along the value chain.

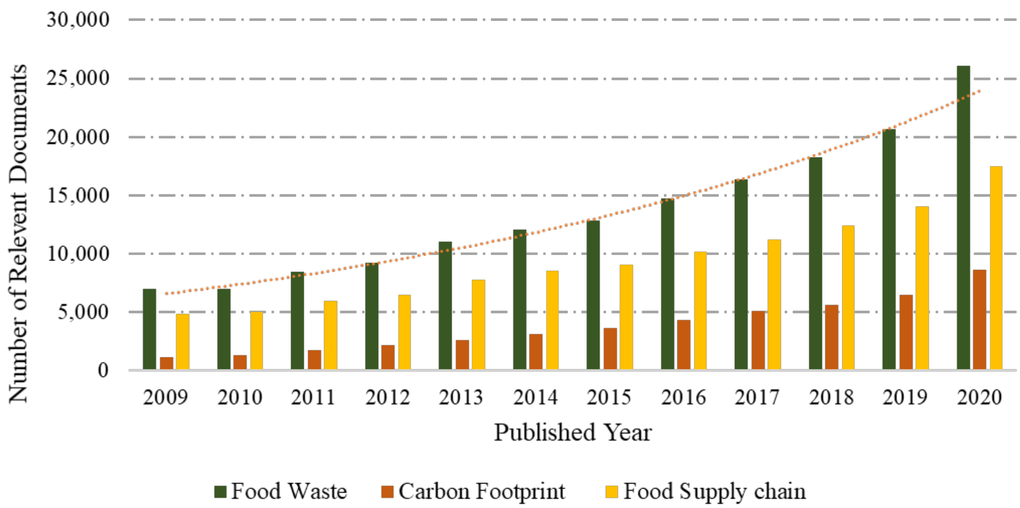

Figure 3. Documents distribution per search keywords from the year 2009 to 2020.

There is a steady increase in the number of publications related to carbon footprinting over the last decade. Thus, it is necessary to further investigate the leading journals that most publish content in the selected research area. Figure 4 shows the distribution of journals that publish studies related to food waste carbon footprinting. The top three journals that publish carbon footprint related studies are "Journal of Cleaner Production," "Science of the Total Environment," and "Resources, Conservation & Recycling" with 1457, 419, and 360 peer-reviewed academic articles, respectively.

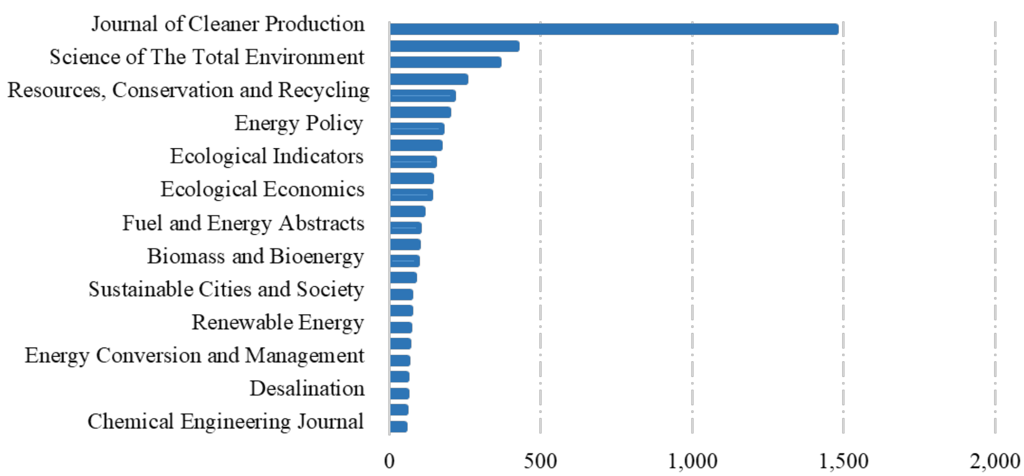

Figure 4. Journal Distribution of Carbon Footprint of Food Waste.

Most of the articles on carbon footprint related studies in food waste management are published in the Journal of Cleaner Production. It mainly focuses on subject areas related closely to cleaner production, environment, sustainability assessment, sustainable development, and carbon footprint related studies. The focus is also extended to areas related to food security, waste minimization, and resource conservation. The other journals that publish studies related to the selected research area are Waste Management, Global Food Security, Resources, Conservation & Recycling, and Science of Total Environment journals.

4. Quantifying Food Waste Along the Value Chain

Calculating the amount of food waste along the value chain has been deemed critical in limiting GHG emissions. Identifying the root cause behind the increasing food waste pattern across the food supply chain can help meet climate action's international targets (Thyberg et al., 2016). This section aims to identify food waste categories along the value chain for several food sustainability-related studies. As per studies conducted by Caldeira et al. (2019), three main categories of food products contribute significantly to the portion of total wasted load along the value chain, namely, cereals, vegetables, and fruits. The cereal waste, including bread, is a significant contributor to food waste's economic cost in terms of mass. The contribution of bread to the total economic cost of food waste stood at 6.7 tons in terms of relative mass annually, followed by fruits and vegetables, adding 6.4 tons in the supermarket food waste load (Brancoli et al., 2017).

Further studies by Scherhaufer et al. (2018) found that the cereal food waste products, excluding beer, created 24.96 million tonnes of food waste load along the value chain. Besides the cereal waste category, milk excluding butter, and vegetables explicitly potato products, has the second relatively high waste footprint of 11.9 million and 10.6 million tonnes respectively. Identifying fruits and vegetables as one of the most wasted food products among other food waste classification has stimulated several researchers, including Eriksson et al. (2017), to investigate four waste treatment methods for five supermarket fruit and vegetable food waste categories.

The geographic location plays a significant role in quantifying significant amounts of food waste along the food supply chain. Food waste in the dairy industry top the list in the United Kingdom, Netherlands, Austria, and the United States. However, as observed in all the previous studies, fresh fruits and vegetables represent the highest proportion of waste, mainly in Turkey (Parfitt et al., 2010). The quantification of avoidable and unavoidable fruit and vegetable wastes differ from one geographical location to another. According to the recent study published by De Laurentiis et al. (2018), the amount of unavoidable fruit waste equals 10kg/person annually in Germany, followed by Denmark and the United Kingdom (UK), amounting to 9kg and 8kg/person annually in the household food waste category. Although the study conditions do not change, the same category is quantified during the same household phase to obtain different food waste values. Three additional studies have also attempted to quantify the household food waste derived from fruit waste categories, namely; Quested et al. (2011) showed that fruit waste accounts for approximately 0.8 portions/person/day in the UK, while, Scherhaufer et al. (2012) and Edjabou et al., (2016) estimated household fruit waste equals 7.5kg/person in Germany, and 9.1kg per person in Denmark annually.

It is evident from the articles mentioned above that the authors are attentive in calculating the amount of food waste along the food supply chain to achieve food security and circularity goals. If food waste is not quantified, it would not be possible to identify waste footprints and reduce the impact of food waste on climate change and other environmental strains. The growing research interest in food-based carbon foot printing shows a consensus among the research community on the practical significance of quantifying food waste along the value chain. Nevertheless, no studies agreed on a single approach for quantifying food waste. Food quantification methods are related to food waste; as long as the definition of food waste varies across the value chain, no standard guidelines for quantifying the food waste has yet been recommended (Corrado and Sala 2018; Caldeira et al. 2018). Table 1 summarizes the food waste-related categories from the most recent publications in food waste-related carbon foot printing. Depending on the research objectives, boundaries (national, global, regional), and available data, the waste product categories were selected from several studies. Most of the research was conducted selecting the limited amount of food waste-related categories, focusing on Swedish supermarket chains, including studies by Brancoli et al. (2017), Eriksson et al. (2017), and Scholz et al. (2015). Few among them extended their research boundaries to European Union countries. Corrado and Sala (2018) studied food waste-related categories from the global scope. However, the study does not include all the sub-categories of dairy food waste, i.e., cheese, butter, and yogurt. The research has included only milk as one of the global dairy food waste products.

Table 1. Summary of main food waste categories identified within the selected studies

Study	Food waste-related categories								
	Vegetable & Fruits	Cereal	Meat	Milk	Egg	Fish	Oilseed & Pulses	Roots & Tubers	Deli
Brancoli et al. (2017)	√	√	√						
Corrado and Sala (2018)	√	√	√	√	√		√	√	
Eriksson et al. (2017)	√								
Scherhaufer et al. (2018)	√	√	√	√	√	√	√	√	
Caldeira et al. (2019)	√	√	√	√	√	√		√[*]	
Scholz et al. (2015)	√[**]		√	√[***]					√
De Laurentiis et al. (2018)	√								

[*]Sugar Beets; [**]Fruit; [***]Dairy & cheese

5. Evaluating Environmental Impact of Food Waste

Food waste is a major contributor to global GHG emissions and climate change (Alsarayreh et al., 2020). The requirement to feed around 7 billion people worldwide increases the ecological burden on the current food supply chain due to the increased food waste accumulation (FAO, 2019). This section aims to identify the environmental impacts associated with the food waste quantified along the value chain during the carbon footprint assessment for several food sustainability-related studies over the years. The food waste in terms of mass does not necessarily indicate the food waste-related impact (Kutty and Abdella, 2020). Several studies have shown the importance of measuring food waste's environmental impacts instead of just identifying the potential food waste in terms of mass.

Food waste categories have shown a distinct contribution in terms of their effect on the environment. For instance, a study conducted by Brancoli et al. (2017), Caldeira et al. (2019), and Jeswani et al. (2021) revealed the cereal food category, including bread, as a significant contributor to food waste in terms of mass. However, although animal-containing products have relatively low waste in terms of mass, they contribute highly to the food waste-related impacts explicitly in Global Warming Potential (kg CO_2-eq/kg meat) (Brancoli et al. 2017, Jeswani et al., 2021). A pooled research conducted by Scholz et al. (2015) revealed the top three products with the highest wastage carbon footprint. The categories included; deli (20%), cheese (22%), and other dairy products (31%), in which the meat waste accounted for just 3.5% by mass. Despite the low waste by mass value, the total wastage carbon footprint was relatively high, with an estimated value of 29%. Therefore, it is essential to eliminate the animal by-products (ABP) waste to minimize the environmental impact. This result was acknowledged by Scherhaufer et al. (2018), showing animal-containing food products contribute significantly to the environmental impacts, with a 69% Global Warming Potential (GWP), 88% Acidification Potential (AP), and 89% Eutrophication Potential (EP) to the whole food waste-related impact. Different food products have different waste related carbon footprint due to the difference in their life cycle behavior, amount of food waste by mass, and the type of GHG related emissions (FAO, 2011). According to Nicoletta et al. (2019), the livestock sector's emissions approximately equals the total emissions from the transportation sector on a global account. Therefore, it is critical to assess the environmental impacts of food waste and loss across the value chain. This improves the emission intensity and optimizes the resources more efficiently to ensure food security and circularity (Cattaneo et al., 2020).

Life Cycle Assessment (LCA) is a commonly used method to assess the environmental impacts of food waste across the food value chain (Kutty and Abdella, 2020). Brancoli et al. (2017), Ascher et al. (2020), and Omolayo et al. (2021) used LCA to assess the environmental impacts of food waste. Environmental impact assessment of food waste is critical in supporting the transition towards a sustainable agri-food system (Notarnicola et al., 2017). The overall food waste-related impact across Europe was estimated at around 170 metric tons of CO_2 equivalent (European Comission, 2010). The GWP of food waste in Europe was 186 metric ton CO_2 equivalent annually compared to the AP value of 1.7 metric ton Sulphur dioxide equivalent and EP of 0.7 metric ton phosphate-equivalent (Scherhaufer et al., 2018). According to Gao et al. (2017), the ultimate approach in cutting down the ecological load across the agri-food system is by reducing the wastage of food along the various stages of the food life cycle. LCA supports this strategy by determining the optimal combination of technologies to support the decision-making strategies and maximize the environmental benefits along the supply chain (Omolayo et al., 2021).

Nevertheless, recent research has shown that LCA is not the only assessment approach towards monitoring the food waste-related environmental impact. According to a study conducted by Hallström et al. (2015), shifting to a dietary food lifestyle plays a significant role in reducing the environmental potential of food waste and loss up to 50% in terms of GHG emissions and land use demand. Valuing the food and diet pattern is among the most robust measures to prevent food waste accumulation along the food supply chain (Diaz-Ruiz et al., 2019). Replacing a carbon-heavy meat-based diet, including beef and pork, with lean protein substituent can result in an immediate drop in the GHG emissions by 34%; however, dietary food-based adherence does not always mitigate the emissions (Van de Kamp et al., 2018). Dietary shifting and plant-based diet might move the environmental burden of food waste from one life cycle stage to another. Also, from one food waste-related impact category to another (Notarnicola et al., 2017). But, to what extent can these dietary transitions help leave a smaller carbon footprint remains unanswered. Therefore, LCA based carbon footprinting becomes essential in understanding and reducing the food waste-related impacts along the food supply chain.

6. Assessing the Stages of Food Waste and Loss

Achieving sustainability across the food supply chain is of great importance priority (Kucukvar and Samadi, 2015; Park et al., 2016; Egilmez et al., 2014; Egilmez et al., 2013; Kucukvar et al., 2014; Kutty et al., 2020B). Experts identify the need to reduce food waste-related emissions along the value chain (Diaz-Ruiz et al., 2019). Food waste accumulation along the value chain contributes to GHG emissions released into the atmosphere (Scholz et al., 2015), resulting in global warming and climate change. This section reviews the stages along the food supply chain that contribute significantly to GHG emissions released from food waste.

Identifying the stages along the global food value chain where food waste/loss can occur is critical (Sen et al., 2020). Recent publications have attempted to address food waste's impact distribution along the food supply chain. Most of the food in Europe is wasted during the production stage, contributing nearly 73% to the GWP, compared to the 6% during the food processing stage, 7% during the retail and distribution phase, 8% during the food consumption stage, and 6% while the food is being disposed of the post-consumption stage (Scherhaufer et al., 2018). Food waste's environmental impact is exacerbated along the food supply chain when food is wasted in the consumption phase; rather than the production phase (Brancoli et al., 2017). Caldeira et al. (2019) showed that most of the food waste accounts during the consumption phase. Brancoli et al. (2017) claimed that most of the food waste in terms of mass and related environmental impact occurs during the food supply chain's production stage. The food waste generated in the household accounts for nearly 53% of the total food waste generated during the entire life cycle (Stenmarck et al., 2016). Food waste emissions from the household value chain account for nearly 1.62 tons of CO_2-eq, followed by food services amounting to 1.53 tons of CO_2-eq, distribution and retail adding 1.35 tons of CO_2-eq the manufacturing phase accounts from approximately 1.26 tons of CO_2-eq (European Comission, 2010). Besides, the Food and Agriculture Organization (FAO) identifies food waste's carbon footprint as relatively high during vacations, events, weddings, and restaurants due to customer behavior and habits (FAO, 2019). The selection of food waste-related category, functional units, system boundaries, and study objectives are the main reason for obtaining different study results.

Food supply chains are complex systems that mainly depend on fossil fuels and non-renewable resources (Markussen et al., 2014), resulting in resource depletion over time (Holden et al., 2018). The transition towards a sustainable food supply chain is thus essential (Holden et al., 2018). A non-ambiguous supply chain evaluation to enhance the environmental performance along the food supply chain is required (Vidergar et al., 2021). A recent study conducted by reading et al. (2020) shows that the food waste/loss along the supply chain is responsible for most of the United States' environmental emissions. The study further indicates halving food waste along the supply chain can reduce the value chain's environmental burden by nearly 8–10%. Educating in values and diet valuation is considered vital in reducing the food waste volume along the supply chain compared to initiating campaigns to increase customer awareness, which is considered a weak preventive measure (Diaz-Ruiz et al., 2019).

Table 2. Stages of food waste/loss along the food value chain

Study	Stages of food waste/loss					
	Agricultural Production	Storage & handling	Manufacturing & processing	Retail	Distribution	Consumption
Brancoli et al. (2017)						√
Corrado and Sala (2018)	√	√	√[1]		√	√[3]
Scherhaufer et al. (2018)	√		√[2]	√	√	√[3]
Caldeira et al. (2019)	√	√	√	√	√	√[4]
Scholz et al. (2015)				√		
De Laurentiis et al. (2018)						√[3]

[1]Manufacturing; [2]Processing; [3]Household; [4]Household and Food Service.

7. Conclusion

The authors conducted a microscopic review of many carbon footprint studies, focusing on life-cycle based approaches across the food supply chain. The review targeted the critical aspects involved in tackling food waste-related challenges along the value chain, namely; a) calculating the amount of food waste/loss, b) evaluating and quantifying the environmental impacts associated with food waste accumulation and, and c) identifying the stages along the value chain that contribute potentially to the food waste-related emissions and environmental impacts. The review highlights the importance of reducing carbon footprint along the food value chain to support the transition to a sustainable and circular food supply chain.

The authors recommend sustainable alternatives to resolve food waste-related emissions. For future research, the authors suggested extending the literature review scope by introducing circular strategies to mitigate the food waste burden along the supply chain. Instead of wasting food in the disposal facilities, food waste and loss need to be treated and processed to ensure the switch from conventional waste management practices to a circular food system (Santagata et al., 2021). Circular food strategies can play a vital role in developing a sustainable and low carbon environment coupled with conserving the resources and maintaining their values in the economy as long as possible (European Commission, 2015; Kucukvar et al., 2019; Kucukvar et al., 2019A; Kutty and Abdella., 2020). When addressing sustainability concerns in the food industry, a hybrid life cycle assessment (H-LCA) approach is essential to cut down the emissions from food waste and propose alternative waste management strategies (Jepsen et al., 2014). To better understand the applications and steps involved in the H-LCA approach, the authors recommend directing to Kucukvar and Tatari (2012) and Kucukvar et al., 2016A. Paes et al. (2020) developed a tool to reduce the GHG emissions released from municipal food waste in Brazil, which can also be applied globally.

Moreover, reducing the GHG emissions along the food supply chain requires a proper understanding of many food waste-related sustainability assessment tools (Kutty and Abdella 2020; Kutty et al., 2020B; Alsarayreh et al., 2020). Several researchers recently adopt statistical and machine learning techniques to provide integrated insights on food waste management (Abdella et al., 2020; Kutty et al., 2020B). Integrated and holistic frameworks based on machine learning techniques become necessary when addressing the sustainability concerns across the food industry from multiple dimensions (Abdella et al., 2020). Kucukvar et al. (2019) and Shaikh et al., (2017) applied statistical techniques to provide a comprehensive understanding of four sustainability metrics, including carbon footprint, to globally analyze the environmental and socioeconomic impacts of the largest food producers. In the context of statistical techniques, the authors suggest applying time series analysis, factor analysis, correlation, and online control charts for detecting any fluctuations that might occur in sustainability assessment of the food industry over time (Abdella et al., 2017; Kim et al., 2019; Yang et al., 2012). Multiple objective-based best-subset approach adopted by Abdella et al. (2019) can be also used for promoting the accuracy of the sustainability assessment in the food industry. Combining LCA with empirical techniques can support sustainability assessment in a comprehensive manner (Tatari and Kucukvar, 2012; Park et al., 2015; Egilmez et al., 2016; Onat et al., 2017). To better understand several empirical assessment techniques that can widely be applied in the field of sustainability research, the readers can refer to Abdella et al. (2016), Abdur-Rouf et al. (2018), Al-Sheeb et al. (2019), Abdella et al. (2019A), Abdella and Shaaban, (2020), Abdella et al., (2020A). Also, recycling food waste using food recycling machines and converting food waste into fertilizers can reduce food waste-related emissions (Bennbaia et al., 2018). Finally, although the sustainable alternatives for mitigating food waste across the value chain can reduce GHG emissions, it is everyone's responsibility to save food across the value chain and reduce the amount of food waste accumulation across the global food value chain.

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