QATAR UNIVERSITY

COLLEGE OF ENGINEERING

CARBON FOOTPRINT ANALYSIS OF DAIRY FOOD WASTE: FARM-TO-FORK LIFE CYCLE BASED ASSESSMENT ALONG DAIRY VALUE CHAIN.

BY

MUNA A. AL-OBADI

A Thesis Submitted to
the College of Engineering
in Partial Fulfillment of the Requirements for the Degree of
Masters of Science in Engineering Management

June 2021

COMMITTEE PAGE

The members of the Committee approve the Thesis of
Muna Al-Obadi defended on 18/04/2021.

Galal Abdella
Thesis/Dissertation Supervisor

Murat Kucukvar
Thesis/Dissertation Co-Supervisor

Approved:

Khalid Kamal Naji, Dean, College of Engineering

ABSTRACT

AL-OBADI, MUNA, Masters: June: 2021. Master of Sciences in Engineering Management.

Title: Carbon Footprint Analysis of Dairy Food Waste: A Farm-to-Fork Life Cycle Based Assessment Along Dairy Value Chain.

Supervisor of Thesis: Galal Abdella and Murat Kucukvar.

Reducing the agricultural industry's carbon footprint is a severe challenge, as around a third of the produced food is wasted along the supply chain globally. Despite attempts to reduce carbon emissions from the agri-food system, agriculture contributes significantly to Greenhouse Gas (GHG) emissions, with approximately 51 billion tons of carbon dioxide equivalent globally. Although ruminant animals are a primary source of meat and dairy products, livestock's supply chain, including their wastes, releases a considerable greenhouse gas such as methane, nitrous oxide, and carbon dioxide. The presented paper starts with bringing up a mini literature review on several methods for quantifying food waste, assessing the environmental impact of food waste, identifying the potential stages along the food supply chain, and providing circular food economy findings for reducing the emissions released from the food waste globally. The study has emphasized that food waste in mass does not necessarily indicate the food waste-related impact. Although animal-containing products have relatively low waste in terms of mass, they have a significant food waste-related impact explicitly in global warming potential (Kg C02 eq). The results reveal that milk is the top dairy product responsible for the wastage of dairy products in terms of mass and wastage Carbon Footprint (CF). The consumption stage accounted for nearly 50% of dairy food waste in terms of mass.

The primary production stage is responsible for most of the dairy sector's carbon intensity from farm-to-fork life cycle assessment. The study explains the reason why animal-containing food waste carbon intensity gets exacerbated in the primary production chain. Although the wastage carbon footprinting varies among different geographical locations, the United States dominated the top wastage dairy emissions, followed by United Kingdom, Turkey, Slovak Republic, and Germany. Further policy recommendations have been suggested to mitigate the impact of dairy food waste emissions eventually. The paper attempts to support strategic decision-making towards the transition to a sustainable food supply chain in the dairy sector to mitigate food waste challenges ultimately.

DEDICATION

Dedicated to my family, friends, and university instructors.

ACKNOWLEDGMENTS

I would like to express my thanks and gratitude to God for providing me the strength, commitment, and knowledge to undertake this research study. I would also like to thank Qatar University for giving me the opportunity to complete my master's degree. Great thanks and gratitude to the thesis supervisors Dr. Galal Abdella and Dr. Murat Kucukvar, for their valuable guidance and support throughout this journey. Many thanks to Eng. Adeeb Kutty for his kind and continuous support for assessing me to complete the research work. Finally, the acknowledgment will not be done without expressing my thanks to my strength, my family. I want to thank them for their patience, not only on this research work but throughout my entire life. This research work will not be achieved without their tremendous support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS.

1. GHG: Greenhouse Gases.
2. FAO: Food and Agriculture Organization for the United Nations.
3. OECD: Organization for Economic Co-operation and Development.
4. CF: Carbon Footprint.
5. CO2e: Carbon dioxide equivalents.
6. FSC: Food Supply Chain.
7. GWP: Global Warming Potential.
8. FLW: Food Loss and Waste.
9. IPCC: Intergovernmental Panel on Climate Change.
10. UCSUSA: United Nation Framework Convention on Climate Change.
11. LPS: Livestock Production System.
12. LCA: Life Cycle Assessment.
13. LCSA: Life Cycle Sustainability Assessment.
14. SIANI: Swedish International Agriculture Network Initiative.
15. UNECE: United Nations Economic Commission for Europe.
16. IUCN: International Union for Conservation of Nature.
17. FAOSTAT: FAO Statistical Databases.

CHAPTER 1: INTRODUCTION

The livestock sector has gained extensive attention from different researchers for the potential contribution of livestock to boost emissions and other environmental aspects (Steinfeld et al., 2006). Discarded edible food originates food waste causing the loss of many valuable natural resources exposed to scarcity, including waste, land, and fuel for electricity and transportation (Depta, 2018). Approximately 4.4 gigatonnes of greenhouse gas emissions are released annually from natural resources for producing food that is ultimately wasted along the food supply chain (Rezaei & Liu, 2017). The tremendous loss of natural resources along the value chain is an emerging critical global issue (Hegnsholt et al., 2018). Although some food waste elements are inevitable, reducing food waste volume will significantly impact global food security and sustainable agricultural development (Brett, 2013). Therefore, tackling food waste in an integrated sustainable manner should always be treated as the right chance to feed people globally and optimize natural and financial resources simultaneously (Rezaei & Liu, 2017).

Rotted discarded foods are kept in the landfills generating methane, a potent GHG with a GWP 25 more than carbon dioxide (Depta, 2018). The carbon footprint released from the food waste, including dairy food waste, is approximately 3.3 billion tonnes of carbon dioxide equivalent annually (FAO, 2013). The same report has shown that the anthropometric methane emissions released from landfills food waste deemed one of the largest significant sources of GHG emissions. According to the UNECE report, approximately 60% of global methane emissions are raised by human activities (UNECE, n.d.). The report shows that the agricultural industry, including the livestock dairy sector, is one of the primary contributors to anthropogenic methane emissions. According to FAO (2013), the Agricultural sector is in charge of most plant threats and the animal species threats tracked by IUCN. Reduction in atmospheric Greenhouse Gases plays a significant role in achieving a healthy environment and making our planet more inhabitable (Scholz, 2013). The world has witnessed the impact of GHG through global warming, rising sea levels, and climate change.

1.1 Background.

In the past years, due to the dramatic and rapid development of industrialization and globalization, natural resources, including resources used for the production of dairy products, have peaked, leading to the concentration of atmospheric greenhouse gases, including carbon dioxide (Steinfeld et al., 2006; United Nations, 2015). Consequently, the seriousness and riskiness of climate change phenomena have gained a great deal of attention from the research and the public. The dairy sector is facing substantial challenges due to the need to increase the production of dairy products to cope up with the world population growth need, while at the same time reducing the number of emissions to respect the global target of not exceeding a temperature of 2°C (Grossi et al., 2019; Masson-Delmotte et al., 2019). The production of dairy products will increase to reach 177 tons by 2050; simultaneously, the consumption rate per capita per year for dairy products also expected to increase by 0.8% and 1.7% in the developed countries comparing to a 0.5% and 1.1% increase in developed economies (FAO, 2016).

Livestock activities significantly influence several aspects of the environment. Almost all environmental elements, including air, water, land, climate change, and biodiversity, are significantly affected by the livestock sector activities (Steinfeld et al., 2006). The livestock production system of dairy products is continuously contributing to influence not only the water, land, biodiversity resources but also climate change and polluting gases (FAO, 2010b, 2016, 2017b). Animals and their wastes contribute directly and indirectly through grazing or feed crop production to climate change (Steinfeld et al., 2006). Unsurprisingly the livestock sector is sharing around 18% of GHG anthropometric emissions measured in carbon dioxide equivalent (Steinfeld et al., 2006). The livestock sector shares a considerable amount of greenhouse gases, e.g., producing 15 % methane, 17% nitrous oxide, and 44% ammonia (FAO, 2016; Grossi et al., 2019; Steinfeld et al., 2006). The warming potential of nitrous oxide, one of the greenhouse gases produced by the livestock sector, is approximately 296 times greater than the warming potential of carbon dioxide (FAO Livestock Policy Brief, n.d.).

A recent research study by the United Nations Panel on Climate Change (International Monetary Fund. Communications, 2019a) shows that the way food is produced and how nations are eating the food has a more outstanding contribution to climate change and human health burning fuel. Globalization has boosted greenhouse gas emissions from half of the total atmospheric emissions by 2050 compared to only a quarter of the total emissions in 2019, according to a special report in IPCC on climate change (Masson-Delmotte et al., 2019). Dairy food waste is acting as a complementary factor for raising the carbon footprint. Around one-third of the food produced for human consumption is either lost or wasted from the early stage of food production until the consumer stage (FAO, 2014b), as shown in Figure 1. All food production stages along the Food Supply Chain (FSC) contribute towards boosting the level of greenhouse gas emissions released into the atmosphere (Scholz, 2013). Approximately 1.3 billion tons of edible food per year are not reaching the nations as it is lost during food production stages and causes emissions (FAO, 2014b). The effect of food waste extends to starvation. (FAO, 2017a) roughly estimates that out of 7.6 billion people worldwide, almost 815 million people suffer from hunger and unbalanced nourishment. Under the current distressful circumstances, there is an imperative need to adopt sustainability development and monitor the number of greenhouse gases released to the atmosphere from food waste, including dairy waste.

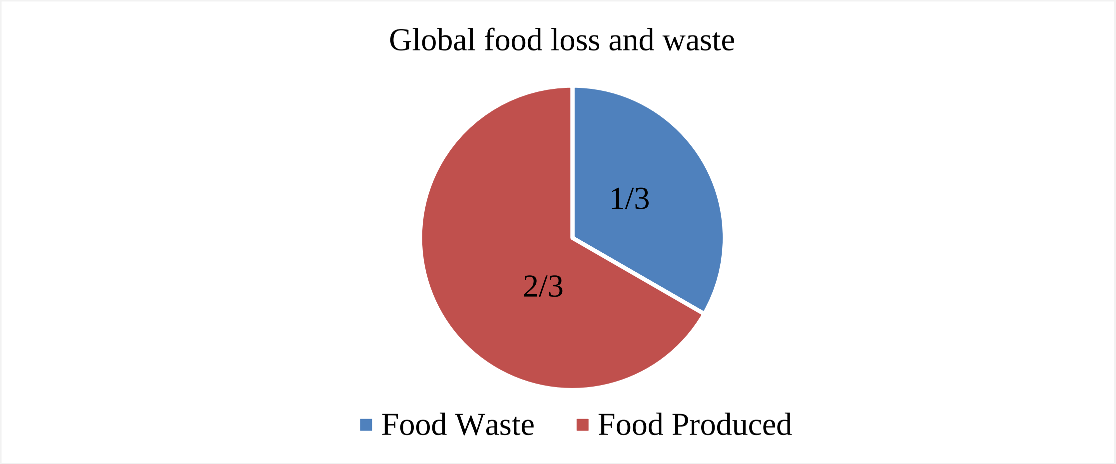

Figure 1. The position of food loss and waste from the total food production.

Food and Agriculture Organization (FAO, 2014a) has defined sustainable development (SD) as the management of natural resources and the orientation of multiple technological and institutional changes to maintain and satisfy the human's need for present and next generations. In other words, sustainable development ensures that current human needs are fulfilled without compromising future generations' needs. Addressing sustainability in the food industry and monitoring atmospheric greenhouse gas emissions becomes essential for humans to meet their demand for food and maintain a green and healthy environment. Food is one of the basic needs of human beings to survive. Livestock products, such as milk, meat, and eggs, are the critical factors for food security, providing 34% of the proteins, fats, and other nourishing elements necessary to grow up, build, function, and repair the body (FAO, 2017b). Without the livestock sector's valuable food sources, human body function will start to atrophy, affecting internal body organs' health conditions. (Staniškis, 2012) claimed that human's need for food is increasing dramatically in the last 50 years, in which human food consumption is 30% more than the actual capacity. There is a proportional relation between the amount of food produced/consumed and atmospheric greenhouse gas emissions. As food waste and loss increase along food production stages, the number of emissions released from that waste increases. Therefore, reducing food waste and loss (FWL) will tremendously influence the atmosphere. Growth in prosperity, quick urbanization and population growth are factors that contribute to rising carbon emissions. The world population is anticipated to increase significantly in the next 15 years by approximately one billion people to reach around 8.5 billion people in 2030 (United Nations, 2015). The report has also shown that population growth will continue to rise further to get 9.7 and 11.2 billion people in 2050 and 2100, respectively. As a result, population growth is predicted to increase even more over time. Such a boost will increase the need to ensure and secure a green and healthy environment by reducing anthropometric carbon emissions.

1.2 Problem Statement.

Reducing dairy food waste has been a growing area of interest in the agricultural research industry (Raak et al., 2017). Several initiatives, studies, and projects aim to increase food waste issues, raise people’s awareness, and foster collaboration across the food supply chain to reduce food waste and corresponding emissions (SIANI, 2017). However, research on food waste is still an emerging field as there is a lack of knowledge about food supply chain function, the amount of food being wasted along the value chain, and the corresponding causes of food waste globally (SIANI, 2017). Ruminant animals are a significant source of meat and dairy products; however, livestock's supply chain, including their wastes, releases a considerable greenhouse gas such as methane, nitrous oxide, and carbon dioxide (FAO, 2017b); (B. Kim et al., 2015). The livestock supply chain emissions account for approximately 50% methane, 24% nitrous oxide, and 26% carbon dioxide (FAO, 2010b). According to the International Monetary Fund Communications (2019b), the emissions released from the livestock sector are equivalents to all the world's emissions from cars, trucks, airplanes. Recent studies have shown that animal-containing food waste, including dairy food waste products, is increasingly seen as a potential factor affecting the environment. Despite its relatively low waste in terms of mass, animal-containing food waste has the majority share of emissions related to climate change category (Brancoli et al., 2017). These results are acknowledged by Jeswani et al. (2021) and Scherhaufer et al. (2018), showing that although livestock food waste, including dairy products, represents only 10% of the total food waste, the significant contributors of food waste-related emissions. FAO showed that dairy food waste mainly occurs during the consumption stage, especially in Europe, America, and Asia, as shown in Figure 2. Pocketbook (2013) has shown most dairy waste in the UK occurs in the consumption stage.

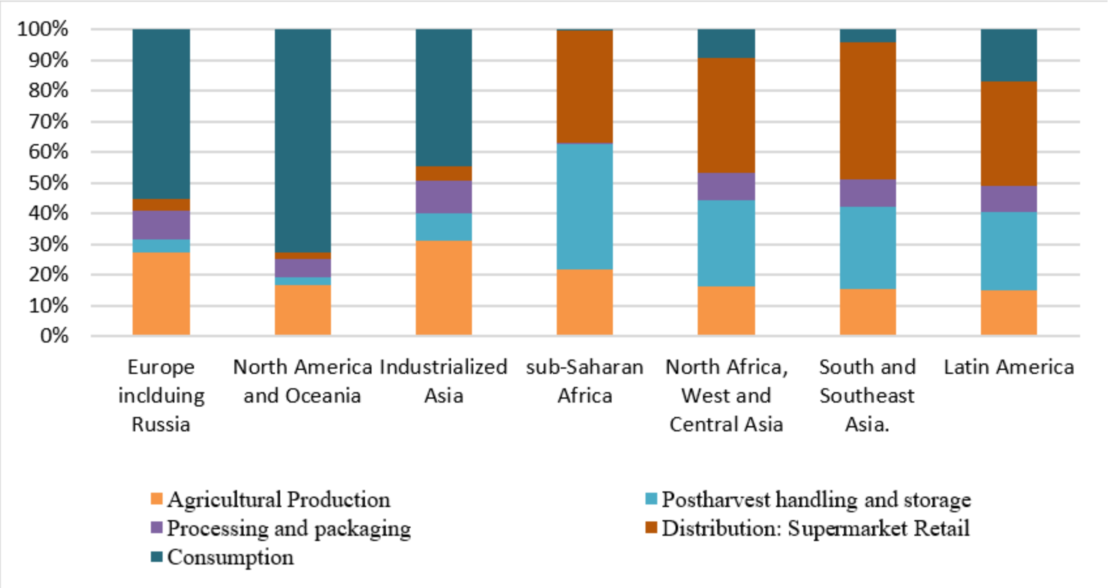

Figure 2. Percentage of dairy food waste, including milk, along the food supply chain stages at different regions.

The current food system failed to promise to secure daily food products for humanity and respect the maximum rise temperature from emissions (Loboguerrero et al., 2020). As mentioned earlier, the dairy sector faces a real challenge between increasing production to meet population growth demand and reducing polluting emissions. The emissions are not strictly limited to carbon dioxide, one of the leading chemical gases contributing significantly to the greenhouse effect. According to Montzka et al. (2011), carbon dioxide is not the only contributor to greenhouse gases. Other anthropogenic emission gasses, methane, oxide, nitrous, and ozone-depleting substances, also alter the earth's climate. According to the same study, several sectors studied their emissions of $\text{non}-\text{CO}_2$ gases and their contribution to the total anthropogenic emissions; these sectors are agriculture, energy-related, landfills, biomass burning, and other sectors. Unsurprisingly, the agriculture sector contributes to 13.5% of total annual anthropometric greenhouse gas emissions with a significant contribution of approximately 70% nitrogen dioxide, 50% methane, and 25% carbon dioxide. Multiple factors drive greenhouse gas emissions. One of the best contributors to increasing the emissions released to the atmosphere is the agricultural sector; therefore, the impact of climate changes and global warming has risen to its doubled original amount (Muthu., 2014). According to (Montzka et al., 2011), agriculture is the largest participant with a significant fingerprint to anthropogenic greenhouse gas emissions. The Sustainability Development (SD) has been defined by Commission on Environment (1987) as "Meeting the needs of the present without compromising the abilities of future generation to meet their own needs." There is a must to mitigate emissions released to the atmosphere by developing a carbon footprint model for food waste. The anthropometric greenhouse gas emissions are anticipated to increase more if there are no actions considered to mitigate the negative impact of emissions on the environment and nations.

Several researchers classified the types of environmental footprint to confine and quantify food waste's ecological impact globally. Čuček et al. (2012) have categorized various kinds of scientific indicators for environmental footprint, including Carbon Footprint (CF), Water Footprint (WF), Energy Footprint (ENF), Emission Footprint (EMF), Nitrogen Footprint (NF), Land Footprint (LF), Biodiversity Footprint (BF), and other footprints such as Phosphorus Footprint (PF). Humans in different demographics are taking advantage of natural resources' existence without a precise quantification measurement of environmental impact. Therefore, the classification of environmental footprints raises the opportunity to quantify the ecological impact on a local and global scale (Nairobi, 2016). Recently, Carbon Footprint (CF) has become one of the main pillars of sustainable environmental indicators. Čuček et al. (2012) has clarified the carbon footprint definition from different researcher's perspectives. For instance, according to Galli et al. (2012), the carbon footprint is defined as a quantitative measurement used to measure the number of greenhouse gas emissions, whether they are caused by activities or accumulated over the product's or service life stages directly or indirectly. These activities could include human activities or activities caused by individuals, organizations, companies, industry sectors, or any other type of activities that could be used to measure greenhouse gas emissions. However, Solé et al. (2018) have defined Carbon Footprint (CF) as the total amount of carbon emissions released to the atmosphere; these emissions could be direct or indirect emissions released from an activity or accumulated over time for the life stage of a product. The Carbon Footprint of dairy waste products comprises emissions such as methane, carbon dioxide, and nitrous oxide along the value chain, including production, distribution, processing, transportation, retail, consumption. According to Čuček et al. (2012), there are different terms used to represent greenhouse gas emissions, such as climate footprint, CO_2 footprint, footprint, methane footprint, and Global Warming Potential (GWP) footprint.

The research questions that are going to be addressed in this research are the following:

1. What are the most significant dairy waste categories responsible for contributing potentially to carbon footprint-related emissions along the dairy value chain?
2. What do dairy value chain stages account for most dairy waste in terms of mass and wastage CF derived from the dairy sector?

Although some studies have addressed the quantification assessment of food waste-related impact along the supply chain, almost no scientific research has been conducted for dairy food-waste carbon footprint along the food supply chain. Recent investigations have worked on carbon modeling in different sectors other than dairy food waste, such as developing a comprehensive model for determining the carbon footprint for fossil fuel electricity, the modeling carbon footprint of textile products, and creating a model of success of reducing the organization's carbon footprint.

1.3 Objectives.

The key objectives of the research study can be summarized as the following:

- Quantify food waste by determining the amount of dairy food waste at each food supply chain stage based on the available data. This helps in identifying the stages along the value chain that contribute potentially to the dairy food waste.
- Analyze the quantitative assessment of environmental impact, explicitly carbon emissions, related to dairy food waste along the food supply chain. This helps develop visualization dashboards for the dairy food waste vs. supply chain and dairy food waste vs. emission intensity for different countries.
- Recommend practical policies that support strategic decision-making towards the transition to a sustainable food supply chain in the dairy sector to mitigate food waste challenges ultimately.

1.4 Scope.

The study's scope has been tightened to comprises the emissions released for the dairy food waste only, excluding the emissions released from dairy food and ruminant animals' production. Although sustainability has three main pillars: economic, environmental, and social, in this research, the focus will be on assessing the wastage carbon footprint of dairy food waste throughout a well-defined life cycle, mainly from farm to fork. The assessment comprises the wastage derived from milk and milk products. Several indicators are classified under the agri-environmental hands: fertilizer indicators, land use indicators, land cover, livestock patterns, livestock manure, pesticide indicators, emissions shares, emissions intensities, and temperature changes.

However, due to this research's nature, indicators related to dairy emissions will be addressed only for the carbon footprint of dairy food waste across the supply chain to support managers and decision-makers for making better-informed decisions towards the transition of sustainable and circular food economy system. Even though the livestock sector consumes natural resources and contributes significantly to global greenhouse gas emissions, the focus will be only on the carbon emissions released from dairy food waste. The emissions released from ruminant animals used for milk production, such as enteric fermentation and manure storage, are excluded. Grossi et al. (2019) have shown that the livestock sector releases emissions estimated by 7.1 gigatons of carbon dioxide equivalents from different sources. Direct livestock emissions come from enteric fermentation (39%), manure excreted and applied to the soil, and manure storage (10%) of total emissions. Indirect sources processing & transportation (6%), transportation, feed processing agricultural operation, fertilizers and chemicals, and land-use change are indirect emissions from feed production, contributing to 45% of the total emissions.

1.5 Study Outline.

In this study, five chapters are included to assess the carbon footprint modeling for dairy food waste across the value chain from farm-to-fork for four dairy waste product categories. In chapter 1, a brief introduction is used to provide a comprehensive picture showing the livestock sector's contribution to global emissions and the need to develop a detect the wastage carbon footprint to mitigate the environmental impact of GHG emissions derived from the dairy sector. The same chapter has also highlighted the research objective, scope, and problem statement. A microscopic review of the current research studies (literature) for quantifying food waste, identifying the environmental impact related to food waste along the value chain, assessing the stages of food supply chain which contributes potentially to food waste, suggesting circular food economy techniques for mitigating food waste in the agriculture sector, is shown in chapter 2. Thus, the literature chapter aims to review the history of food waste, including dairy waste, and the corresponding emissions along the supply chain.

Chapter 3 is used to describe the research methodology for quantifying dairy food waste, calculating the greenhouse gas emissions at the different food supply chains, and assessing the wastage carbon footprint derived from the dairy food waste sector. Indeed, chapter 3 demonstrates the method of collecting the data, structuring the research process flow chart, assessing the CF of dairy waste, and visualizing the results. The illustration and discussion of the acquired results after analyzing the data are discussed in chapter 4. The chapter also indicates the data visualization results obtained from chapter 3 and the wastage carbon footprint. Although the research investigates the emissions of dairy waste products across the value chain associated with the wastage carbon footprint, some limitations have to be mentioned to be addressed in future work, as discussed in chapter 5. Besides, chapter 5 aims to summarize and conclude the main findings obtained in this valuable study.

CHAPTER 2: LITERATURE REVIEW.

Globally, the agricultural sector plays a substantial role in the survival of humans. Today, with the population growth, the human's need for food is increasing drastically in the last 50 years, in which human's food consumption is 30% more than the actual capacity (Staniškis, 2012). The agri-food system faces a severe challenge feeding around nine billion by the twentieth century with climate change (Stock et al., 2012). Agriculture contributes significantly to Greenhouse Gas (GHG) emissions, with approximately 51 billion tons of carbon dioxide equivalent globally (FAO, 2018). 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 2.1 attempts to outline the research methodology undertaken for the review process briefly. Section 2.2 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 2.3 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 2.4. Section 2.5 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 2.6 presents the circular food economy findings towards reducing the food waste emissions and food waste related impacts along the value chain. Section 2.7 summarizes the review of the presented chapter with some recommendation pathways for future research.

2.1 Review Method.

This paper presents a comprehensive review of the literature on dairy food waste related to the environmental impact assessment of dairy waste along the supply chain to address the research objectives. In the early stages, the paper shows the research objectives and identifies the research questions to be addressed. Then, the paper restricts the study's boundary by identifying the scope and defining the study focus.

A keyword-based search in Science Direct online database including a combination of words such as "dairy products," "waste," "carbon footprint," "supply chain," "waste minimization," etc. for selecting relevant peer-reviewed journals, articles, book chapters, and open access content. The authors have chosen mostly peer-reviewed articles, few published books, and book sections on the Science Direct online database. Further search on Google Scholar using the same keywords has been widely searched for scholarly literature in the English language's dairy food waste area. All articles written in a language different from English are excluded: Spanish, Chinese, French, and German. This search was conducted to review the existing available literature in the calculation of food waste, environmental impact assessment of food waste, supply chain analysis of food waste, circular economy for food waste, and applications of carbon footprint models in different industries.

The scope of the literature review to cover relevant publications during the timeline between 2009 to 2020. The total number of articles coming from the combination of the research keywords are around 3593 reviewed articles, of which 351 articles were related to the selection criterion; that is, the publications timeline, English language, and articles related to environmental impact assessment of dairy food waste. These articles were further examined and checked after skimming through the paper's abstract. The process of further checking the novelty and relevancy of the collected materials led to the breaking down the selected articles into 73 documents.

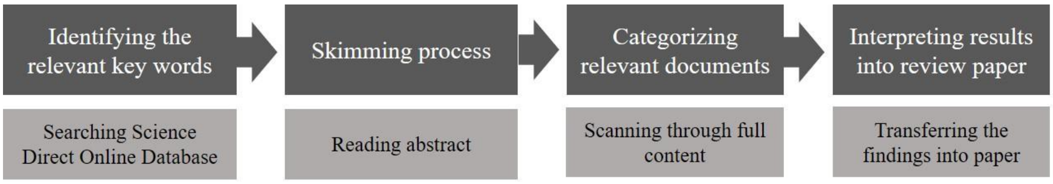

Figure 2. Review Method.

As mentioned earlier in chapter 1, sustainability has three main pillars: environmental indicators go under sustainability assessment indicators. Environmental indicators (EIs) are used to measure the goods and services burdens on the environment. Carbon footprint is an ecological indicator of greenhouse gas emissions. The metric measure of carbon footprint is carbon dioxide equivalent. CO_2 equivalent is a standard scale used to compare various greenhouse gas emissions with different impacts and contributions to global warming into a single metric of emissions (Babiker et al., n.d.); (Ritchie & Roser, 2020).

2.2 Knowledge Fragmentation.

In the last decades, many studies have elaborated on the environmental impact of food waste, greenhouse gas emissions on the environment, and the food waste supply chain. To investigate the researchers' interest in this field, particularly the area related to emissions released from food waste, the authors have sorted the relevant number of publications in the Science Direct online database by keywords. Figure 1 shows that most of the research keyword documents are from the research articles and review articles. The highest number of research articles and review articles are corresponding to the carbon footprint keyword. The carbon footprint area has gained various researchers' attention in different fields to implement sustainability and reduce greenhouse gas emissions on the environment. However, most of the carbon footprint applications are focused on reducing the emissions in the transportation, electricity, industries, commercial, and residential, where few of them only address the application of carbon footprint in the agricultural sector to some extent.

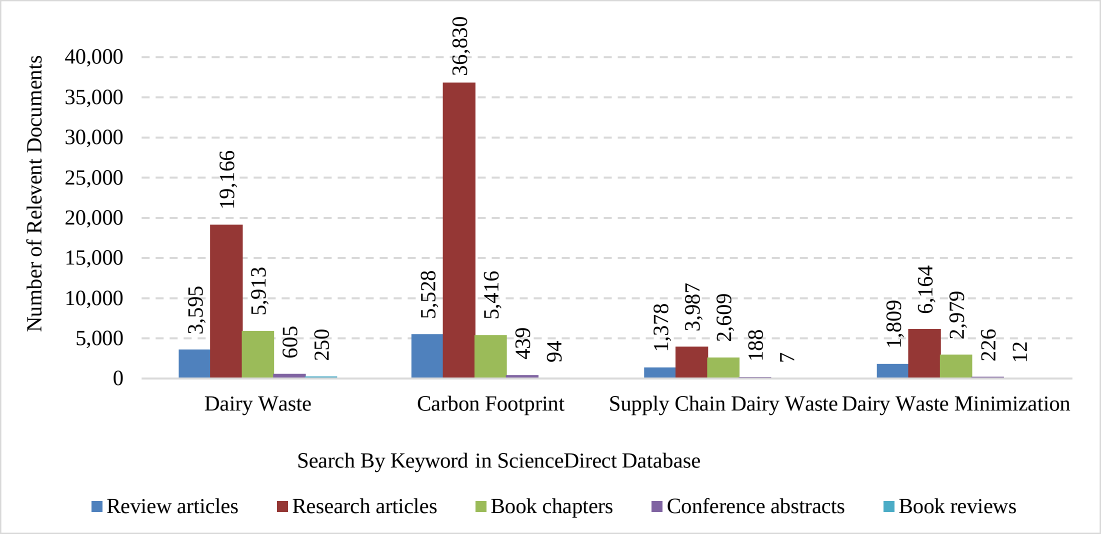

Figure 3 Number of relevant documents per keyword search.

Due to the importance of sustainability and increasing its awareness by the researchers. Authors have decided to figure out the distribution of publications in carbon footprint, dairy waste minimization, and supply chain analysis of dairy food waste overtime in the last decade. It is evident from Figure 3 that the number of published papers is rising over the specified timeline mentioned in the previous section (2009 – 2020), especially in the carbon footprint field. Different studies have been done in the food supply chain field's production and consumption phases in the early 1990s. Therefore, it is no longer a new field and tends to become relatively conventional.

However, the distribution of dairy waste and dairy waste minimization keywords increases overtime slightly compared to the dramatic rising carbon footprint field. Therefore, the purpose of the study's literature review to find the combination of relevant carbon footprint and dairy waste minimization papers to find out the research gap and extent of the published research in the context of carbon footprint analysis in dairy food waste.

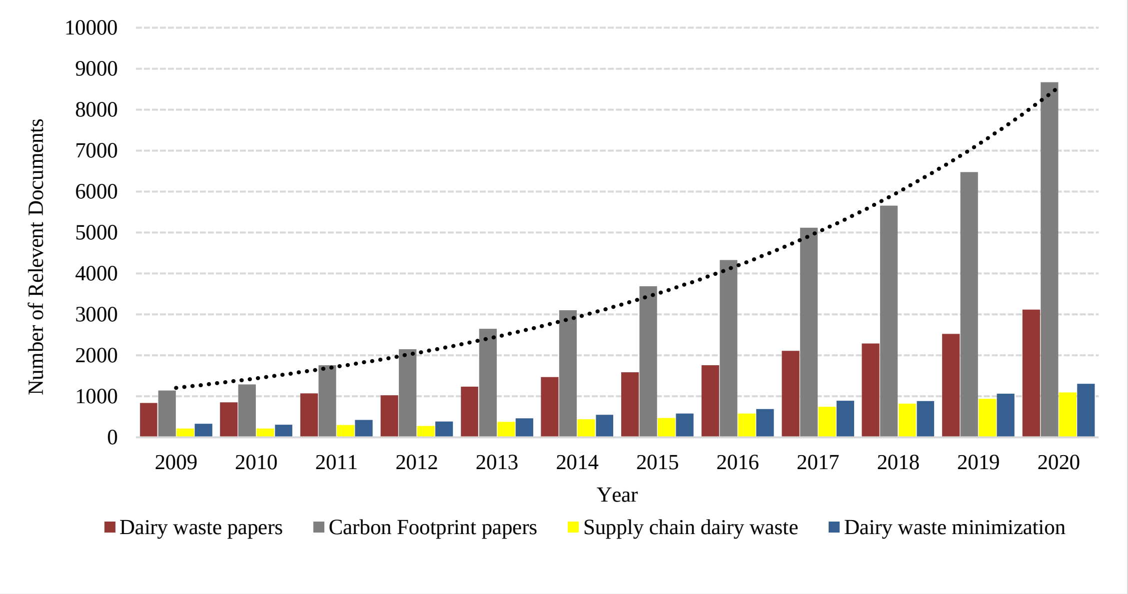

Figure 4 Number of relevant documents per search keywords (2009 – 2020).

There is a steady increase in the number of publications related to carbon footprint over the last decade. Thus, it is necessary to conduct further investigation of the top journals that most publish the food waste selected area. Figure 4 illustrates a comprehensive picture of the publishing journal distribution of carbon footprint in food waste areas. The top three journals that contributed towards publishing articles in the carbon footprint area are Journal of Cleaner Production, Science of The Total

Environment and Resources, Conservation & Recycling with 1457, 419, and 360 peer-reviewed academic articles, respectively. Unsurprisingly, most of the published articles on the carbon footprint of food waste are dominated by the Journal of Cleaner Production. It mainly focuses on subject areas related closely to cleaner production, environmental, sustainability assessment, sustainable development, and sustainability in which carbon footprint falls under the sustainability assessment of food waste subject area. It is not necessarily all the collected documents for reviewing the peer-reviewed academic articles related to the carbon footprint of dairy food waste that will be selected from the Journal of Cleaner Production. The presented study relies heavily on other journals related to food security, waste minimization, and resource conservation. Most of these keywords are primarily covered in Waste Management, Global Food Security, Resources, Conservation & Recycling, and Science of Total Environment journals.

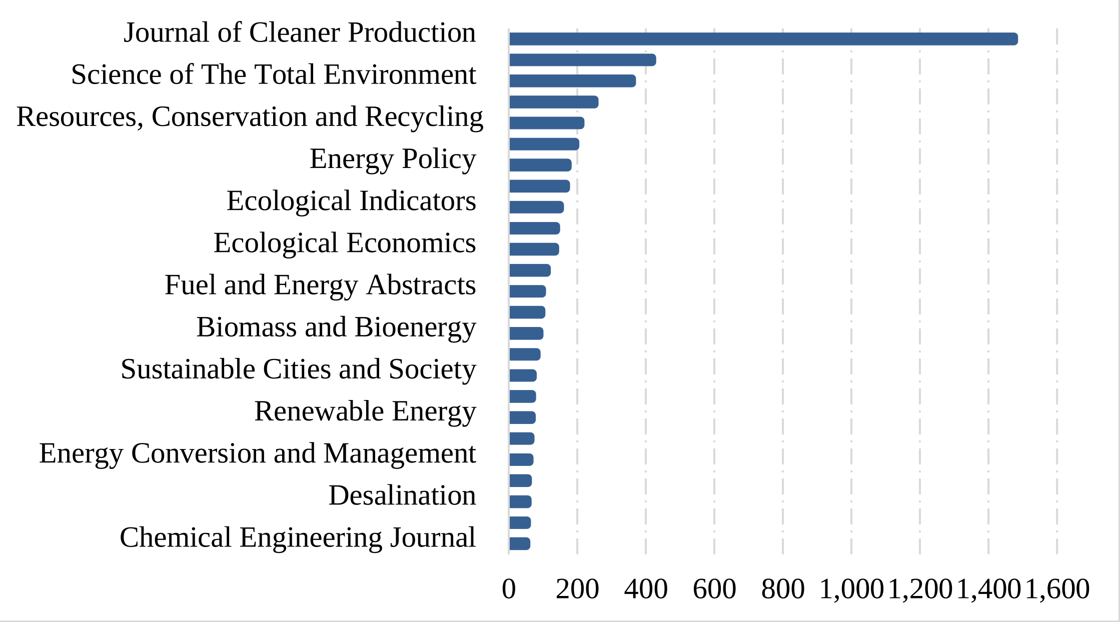

Figure 5 Journal Distribution of Carbon Footprint Food Subject Area.

2.3 Quantifying Food Waste.

Quantifying food waste helps in reducing the impact of food waste along the value chain. Several research types have taken the initiative to quantify food waste along the supply chain globally, regionally, and locally. The quantification of food waste in the Agri-food system is essential for strategic decision-makers to identify the root causes behind the increasing food waste pattern and settle well-planned waste management policies (Thyberg & Tonjes, 2016). Thus, this section aims to identify food waste categories along the value chain for several food sustainability-related studies.

Addressing the quantification of food waste categories along the value chain accelerates the sustainable food system's assessment. Eighty-nine metric tons of food waste is generated annually in Europe, where fresh cheese, potato, and sugar from sugar beets during production are quantified as the top three food products with 85-90%, 80%, 86% of waste, respectively (European Commission, 2010). The research published by (Caldeira et al., 2019) claimed that three main food categories are responsible for the most considerable proportion of food waste along the supply chain: cereals, vegetables, and fruits. Attempts to investigate and quantify the food waste categories corresponding to the highest percentage of mass waste are still under development. The cereal food waste category, including bread, is seen as the dominant food waste factor in terms of mass. Bread has the highest portion of food waste with a relative mass of around 6.7 tons annually, followed by fruits and vegetables corresponding jointly to 6.4 tons in the supermarket food waste (Brancoli et al., 2017). This result is acknowledged by (Scherhaufer et al., 2018), emphasizing the cereal food waste products, excluding beer, which has the highest portion of mass waste with 24,962 measured in 1000 tons of respected waste. Besides the cereal waste category, milk, excluding butter, and vegetables explicitly potato products, has the second relatively high waste of 11,999 and 10,592 measured in 1000 tons. Fruits and vegetables are the most categories wasted along the supply chain, accounting for 45% (FAO, 2019). The repetition of identifying the fruits and vegetable categories as one of the most wasted food groups among other food waste classification has stimulated several researchers. (Eriksson & Spångberg, 2017) has investigated four waste treatment methods for five types of supermarket fruit and vegetables.

Highlighting the geographical location when addressing food waste quantification along the supply chain becomes necessary to account for the highest food waste proportion. Unusually dairy products are considered the top waste products representing a high portion of waste in the United Kingdom, Netherlands, Austria, and the United States. However, again 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 differs from one geographical location to another. Recent research published by (De Laurentiis et al., 2018) shows that the highest inevitable (unavoidable) fruit waste corresponds to Germany is 10 Kg per person annually, followed by Denmark and the United Kingdom, representing 9 and 8 Kg per person per year in the household supply chain. Although the study conditions do not change, the same category is quantified during the same household phase, different food waste values are obtained. Three additional studies have quantified household food waste derived from fruit waste categories: (Quested, 2009) showed that 8.8 in the United Kingdom (G. Hafner, J. Barabosz, F. Schneider, Dr. S. Lebersorger, S. Scherhaufer, H. Schuller, 2012) 7.5 in Germany, while (Edjabou et al., 2016) has estimated household fruit waste as 9.1 in Denmark all measured in Kg per person annually.

It is evident from the articles mentioned above that the authors are attentive in quantifying food waste along the supply chain. If food waste is not quantified or confined, it would not be possible to identify waste causes and reduce its related impact. The growing recent publications attempting to quantify food waste acknowledge researchers' focused efforts in the food waste field and the importance of food waste quantification. Researchers have a consensus 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 guideline for quantifying food waste is recommended (Caldeira et al., 2017).

Food waste-related categories are comparatively acquired by the recent studies adopted within the last five years. Table 1 summarizes the most recent studies conducted in the food waste-related categories field. Depending on the study aim, boundary (national, global, regional), and available data, the studies have selected their product basket. Most of the researches is conducted in Swedish supermarkets with a limited selection of food waste-related categories, including (Brancoli et al., 2017); (Eriksson & Spångberg, 2017); (Scholz et al., 2015a). Few of them have extended their research boundaries to European Union countries. Only one study (Corrado & Sala, 2018) has included some food waste-related categories' global scope. However, the study does not include all sub-categories of dairy food waste, i.e., cheese, butter, yogurt, cheese. The research has included only milk as one of the global dairy food waste products.

Table 1. Reports the leading food waste-related main categories adopted within the selected studies. The symbol (√) means that the element is considered in the study.

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

*Sugar Beets; ** Fruit; ***Dairy & cheese.

2.4 Environmental Assessment of Food Waste.

Food waste addresses one of the essential environmental contributors to greenhouse gas emissions globally. The requirement to feed around seven billion people worldwide increases the ecological burdens. The more food is produced and wasted along the food-related supply chain, the more environmental and economic costs. This section aims to identify food waste's environmental impact on several food sustainability-related studies along the value chain.

The food waste in terms of mass does not necessarily indicate the food waste-related impact. Several studies have shown the importance of measuring food waste's environmental impact instead of emphasizing only 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 Caldeira et al. (2019), Brancoli et al. (2017), and Jeswani et al. (2021) reveal that the cereal food category, including bread, responsible for the highest amount of food waste in terms of mass. However, although animal-containing products have relatively low waste in terms of mass, they have a significant food waste-related impact contribution explicitly in Global Warming Potential (Kg C02 eq) (Brancoli et al., 2017); (Jeswani et al., 2021). A supportive study presented by Scholz et al. (2015a) reveals that top three products with the highest wastage carbon footprint: deli 20%, cheese 22%, and dairy department 31% among all the food waste categories in which meat wasted mass accounted for 3.5%, but its total wastage carbon footprint is relatively high estimated by 29%. Therefore, animal product waste show be reduced to minimize the environmental impact of waste carbon footprint. This result is acknowledged by Scherhaufer et al. (2018) showing that animal-containing food products share most of the food waste environmental impact, accounting for 69% Global Warming Potential, 88% Acidification Potential, and 89% Eutrophication Potential of whole food waste-related impact. Livestock supply chain emissions account for approximately 50% methane, 24% nitrous oxide, and 26% carbon dioxide (FAO, 2010b). According to International Monetary Fund Communications (2019b), the emissions released from the livestock sector are equivalents to all the world's emissions from cars, trucks, and airplanes. Therefore, it is critical to assess the food wastage's environmental impact to improve emission intensity and use the resources more efficiently (Cattaneo et al., 2020).

Life Cycle Assessment is commonly used to assess the food industry's environmental impact. A diversity of studies adopted by Brancoli et al. (2017), Omolayo et al. (2021), and Ascher et al. (2020) have used life cycle assessment to assess the environmental impact of food waste. Environmental impact assessment of food waste, including life cycle assessment, is increasingly seen as a critical factor towards the transition in supporting sustainable agri-food systems (Notarnicola, et al., 2017a). The overall food waste-related impact in Europe is estimated at around 170 metric tons of carbon dioxide equivalent (European Commission, 2010). The global warming potential of food waste in Europe is evaluated by 186 metric ton carbon dioxide equivalent annually compared to acidification 1.7 metric ton Sulphur dioxide equivalent and eutrophication potential of 0.7 metric ton phosphate-equivalent (Scherhaufer et al., 2018). Although the ultimate way of reducing the agri-food system's ecological load is through saving food (Gao et al., 2017), life cycle assessment is still used as a methodological approach to determine the optimal combination of technologies towards supporting decision-maker strategies and maximizing environmental benefits along the supply chain (Omolayo et al., 2021).

Nevertheless, recent research has shown that life cycle assessment is not the only assessment approach towards assessing food waste environmental impact and minimizing food waste-related impact. According to a study conducted by Hallström et al. (2015), shifting to a dietary food lifestyle plays a powerful way in reducing the environmental potential of food waste and loss up to 50% in terms of greenhouse gas emissions and land use demand. Valuing food and diet is among the most robust prevention measures to prevent food waste volume along the food supply chain (Diaz-Ruiz et al., 2019). Meat replacement in dietary food-based can reduce greenhouse gas emissions by 34%; however, dietary food-based adherence does not always mitigate the emissions (van de Kamp et al., 2018). Dietary shifting might move the environmental burden of food waste from one life cycle stage to another or from one food waste-related impact category to another (Notarnicola et al., 2017a). Therefore, life cycle assessment becomes essential towards assessing and reducing food waste-related impact along the supply chain.

2.5 Supply Chain Analysis of Food Waste.

The food supply chain is increasingly seen as a critical key to ensuring a sustainable food system. There is a considerable consensus emphasizing the need to reduce the food waste-related chain (Diaz-Ruiz et al., 2019). Several organizations, particularly the food and agriculture organization, have estimated that around one-third of the food produced for human consumption is lost or wasted along the food supply chain (FAO, 2014b). All food production stages along the food supply chain contribute to boosting greenhouse gas emissions released into the atmosphere (Scholz, 2013). Therefore, this section aims to identify the food supply chain stages contributing mostly to food waste emissions and environmental impact.

Many researchers have continuously wanted to spot out which food waste-related chain is responsible for the most outstanding food waste and loss. Recent publications have addressed the impact distribution of food waste along the supply chain. Most of the food is being wasted in its production stage, in which the production phase's contribution to global warming potential is 73%, compared to food processing 6%, retail and distribution 7%, food consumption 8%, and food disposal 6% within the European context's food waste (Scherhaufer et al., 2018). The food waste's environmental impact is exacerbated along the supply chain when food is wasted in the consumption phase; rather than the production phase (Brancoli et al., 2017). Although recent studies consensus mainly on highlighting that the other food is wasted along the supply chain, the more related food waste-related occurred, significant discrepancies occurred when comparing the food waste-related chain results among different studies. For instance, Caldeira et al. (2019) showed that most food waste is mainly derived from the food waste supply. While (Brancoli et al., 2017) claimed that most of the food waste in terms of mass and related environmental impact is deriving from the production supply stage. Prominently food waste is generated in the household accounted for 53% of total food waste grouped by the supply chain stage (Stenmarck et al., 2016). Food waste emissions are mostly developed in the household value chain representing 1.62 tons C02-eq followed by food services, 1.53 tons of C02-eq, distribution and retail of 1.35 C02-eq, and manufacturing of 1.26 tons C02-eq (European Commission, 2010). Complementary, food and agriculture organization has shown that food waste is mainly generated 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, study aims, and objectives is the main reason for obtaining different study results.

Food supply chains are complex systems, and their substantial impact is broadly seen on the environment. The existing chains mainly depend on fossil fuels and non-renewable resources (Markussen et al., 2014), and their contribution is causing resource depletion (Holden et al., 2018). Thus, the transition towards sustainable food-related supply chains becomes essential (Holden et al., 2018). A non-ambiguous supply chain evaluation to enhance the food supply chain's environmental performance towards achieving a sustainable food system is clearly needed (Vidergar et al., 2021). A recent study conducted by Read et al. (2020) shows that food waste and loss along the supply chain are responsible for most of the United States' environmental emissions. The article further indicates halving food waste and loss along the supply chain can reduce the value chain's environmental burden by 8 – 10%. Educating in values and diet valuation is considered a vital prevention measure to reduce food waste volume along the supply chain compared to initiating campaigns to increase customer awareness, treated as a weak prevention measure (Diaz-Ruiz et al., 2019). Table 2 summarizes food waste supply chains for recent studies conducted in the last five years. Some internal chains like transportation are neglected to simplify food supply chains tables.

Table 2. Summary of the leading food waste-related supply chains adopted within the selected studies. √ means that the supply chain stage is considered in the study.

Study	Food waste-related supply chains				
	Agricultural Production	Storage & handling	Manufacturing & processing	Distrubution & Retail	Consumption
(Brancoli et al., 2017)					√
(Corrado & Sala, 2018)	√	√	√1	√	√3
(Scherhaufer et al., 2018)	√		√2	√	√3
(Caldeira et al., 2019)	√	√	√	√	√4
(Scholz et al., 2015a)				√	
(De Laurentiis et al., 2018)					√3

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

2.6 Circular Economy of Food Waste.

The transition towards a sustainable circular economy in the food supply chain becomes increasingly substantial. Instead of wasting food in the disposal facilities, food waste and loss should be treated and processed to ensure the switch from conventional to circular food economy (Santagata et al., 2021). Circular economy targeting the environmental burden by handling waste and extracting the maximum value of the resources wasting along the food supply chain. Consequently, a circular economy constitutes a compulsory reference for a food waste-related management framework (Ciccullo et al., 2021).

Food waste treatment methods are recommended to transition towards a circular food economy properly. There is a sequence of waste treatment technologies used for handling food waste, including anaerobic digestion, in-vessel composting (heat-moisture reaction), landfilling, and incineration (Gao et al., 2017). However, food waste treatment methods' impact differs in reducing environmental load and economic costs. On average anaerobic digestion, among the other waste management treatments, has the lowest environmental impact of food waste in terms of global warming potential (Gao et al., 2017); (de Sadeleer et al., 2020); (Slorach et al., 2019); (Tonini et al., 2020); (Paritosh et al., 2017). In contrast, according to de Sadeleer et al. (2020), the incineration waste process has relatively high energy efficiency compared to anaerobic digestion. Landfill waste treatment has a significant impact on climate change; it is one of the highest contributors among other treatment processes to global warming potential. According to Slorach et al. (2019), in-vessel composting is the worst waste treatment option with the highest environmental impact among the other methods. Although the ultimate way of reducing the agri-food system's ecological load is through saving food (Gao et al., 2017), circular food economy treatments, explicitly anaerobic digestion, play a sustainable alternative in reducing environmental and economic costs.

Food waste definitions and frameworks are required in establishing an efficient circular food economy. Surplus, food loss, edible and inedible waste are different types of food waste that must be categorized towards improving food waste quantification methods. Researchers have distinguished between different kinds of food waste along the supply chain to identify food waste root causes and propose sustainable alternatives. Jurgilevich et al. (2016) has summarized the food system's circular economy phases as shown in Figure 6. A recent study conducted by Teigiserova et al. (2020) shows that unclear food definition can minimize food waste quantification methods' efficiency. Therefore, the study has distinguished six different food categories for measuring food surplus, waste, and less efficiency. A circular economy framework developed for food surplus, waste, and loss is suggested to prioritize the knowledge of unavoidable or edible waste at each stage of the food supply chain (Teigiserova et al., 2020).

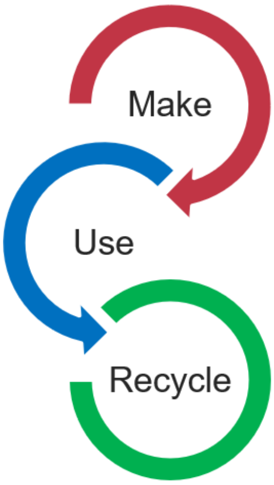

Figure 6. Three stages of the food system in a circular economy

Tackling food waste and loss by introducing a circular economy is seen as a critical factor towards the transition to Europe's circular economy. The prevention of food waste through a circular economy model is rationally a new concept that should be addressed in future studies. There is a necessity to develop a holistic, interdisciplinary, and integrated circular economy model to address and tackle food waste availability. Before 2015, there was no clear policy for the circular economy concept's applicability in the Agri-food system in Europe (Dora et al., 2020). Lately, the European Commission has initiated remarkable actions toward a circular economy system to conserve the resources and maintain their values in the economy as long as possible. The commission has also shown that the transitions towards a circular economy are essential in developing a sustainable competitive economy with low carbon emissions (European Commission, 2015).

2.7 Conclusion.

The agricultural sector plays a substantial character in human survival. The dairy food supply chain is an indispensable sector of the entire agricultural system because ruminant animals represent meat and dairy products' primary source. However, livestock's supply chain, including their wastes, releases a considerable greenhouse gas such as methane, nitrous oxide, and carbon dioxide. Generally speaking, the current agri-food system contributes to (GHG) emissions, with approximately 51 billion tons of carbon dioxide equivalent globally. Furthermore, population growth is burdening and challenging the current food system. The human's need for food is increasing dramatically in the last 50 years, in which human's food consumption is 30% more than the actual capacity. To adapt to the speed jump in population, the agri-food system is facing a real challenge between increasing production to meet population growth demand and reducing food-waste polluting emissions.

Creating a balance between increasing production to meet population growth demand and reducing the polluting emissions of food waste remains a concern when addressing a sustainable food system. Throughout this study, a mini-scale literature review is presented to confine carbon emissions of dairy food waste covering three main sections: calculating food waste, environmental impact assessment of food waste, and supply chain analysis of food waste. The literature review scope covers relevant publications related to food waste minimization and the carbon footprint of dairy waste during the last decade, between 2009 to 2020. The total number of articles coming from the research keywords' combination is approximately 3593 reviewed articles. Although most of the articles are related to carbon footprint, the carbon footprint model's applicability was mostly focused on reducing transportation, electricity, industries, commercial, and residential sectors. A few of the current articles address the global relevance of carbon footprint in the agricultural sector.

CHAPTER 3: METHODOLOGY.

The methodology of collecting the dairy food waste data, conducting a research flow chart to illustrate the process from quantifying dairy food waste to visualizing the dashboard of dairy waste and the corresponding carbon emissions will be discussed in this chapter. Throughout this study and before drilling down into the dairy waste and their related emissions, the dairy food categories are classified based on Food and Agriculture organization definitions to harmonize dairy food waste. Moreover, the dairy value chain, including the milk supply chain, has been defined to partition the dairy food supply chain into different activities. Farm-to-fork life cycle assessment is considered for the dairy food-waste carbon footprint. The method of calculating the dairy food-waste carbon emissions is based on the existing literature factor of carbon footprint expressed in kg CO2e per kg product for different dairy products. Finally, three visualization dashboards have been generated to illustrate the position of dairy food waste among other waste categories, identify dairy food waste per product along the dairy value chain, and assess carbon emissions per dairy waste product compared to the dairy food waste along the food supply chain.

3.1 Research Flow Chart.

A research flow chart showing the paper's flow progress from quantifying the dairy food waste to eventually generating the three visualization dashboards of dairy waste and their corresponding related emissions is shown in Figure 7. The research flow chart acts as a visual map illustrating the overall steps of quantifying dairy food waste, identifying waste along the supply chain, formulating and calculating the carbon footprint of dairy food waste, and eventually visualizing the dairy waste data to interpret the results for the three dairy waste and waste-related emissions dashboards namely, a) developing a comprehensive picture of food loss and waste globally to identify the position of dairy waste among other food waste categories b) quantifying dairy food waste accumulation along the value chain for the four dairy waste categories and, c) evaluating the environmental impact of dairy waste, explicitly carbon emissions, and identifying the stages along the value chain that contribute potentially to the food waste-related emissions and ecological impacts.

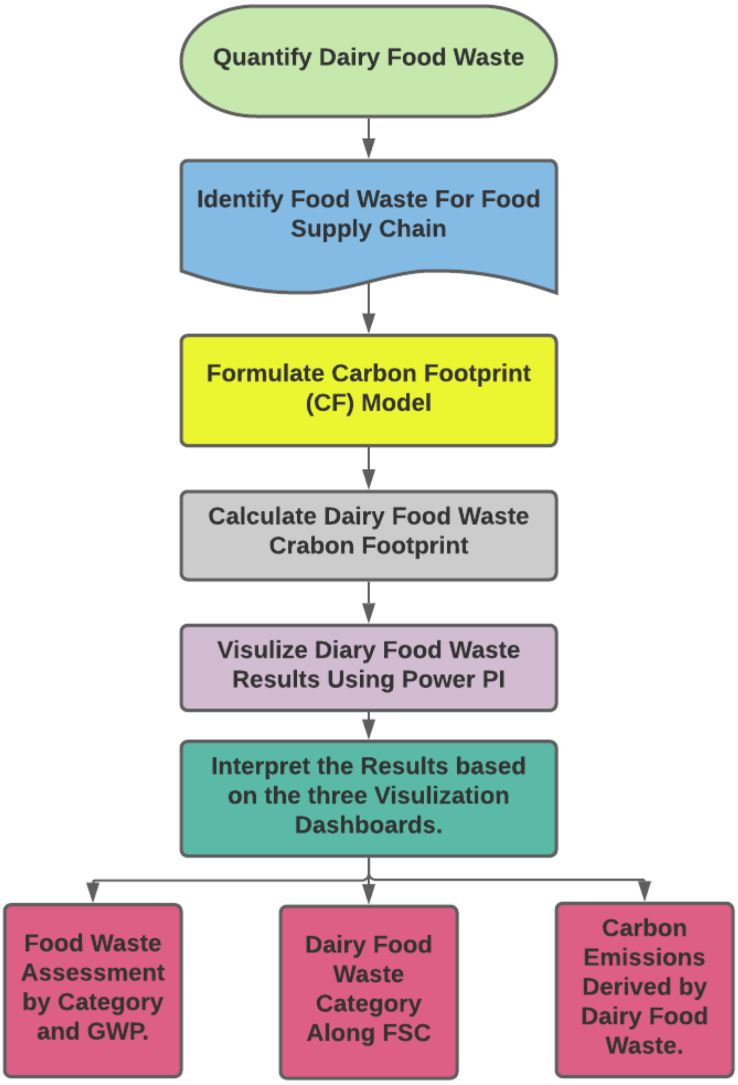

Figure 7 Research flow chart.

3.2 Dairy Food Waste Data Collection.

In this study, the data used for dairy food waste and dairy wasted-related emissions along the food supply chain are mixed between collected data and generated data. Dairy food waste data is collected mainly from the FAOSTAT & OECD database; however, wastage carbon footprint data is calculated based on the collected dairy waste data. The wastage carbon footprint was calculated for different dairy food products wasted along the dairy supply chain. The availability of the collected data differs substantially over the years and among analytical parameters. The FAOSTAT & OECD database provides accurate, integrated, and detailed statistics for FWL, mainly supported by scientific publications, technical reports, and governmental statistics. These databases use several sources such as academic research, analytical reports derived from public or private sectors, international organizations, governmental statistic institutes, delegations, private industry or governmental analytical reports, and many other related sources to support their statistics. Multiple resources have been used to provide a holistic, integrated view about when, where, and why dairy food waste is being wasted along the dairy value chain for different countries. Dairy food waste derived from United States, United Kingdom, Turkey, Slovak Republic, and Germany in 2013 is considered in this study. Although the period covered in the database differ across a range of different countries depending on the availability of data, usually between 1993 to 2013 for OECD and 2000 – 2018 for FAO, the authors have tight the scope for one year only to avoid misleading and provide consistency for the study's result.

Even though FAOSTAT (Food and Agriculture Organization of the United Nations) provides a global database for food waste, including dairy food waste per product such as milk, yogurt, and other products, it does not provide detailed statistics, where food loss takes place in the food supply chain. Most of the dairy food waste data shown in the FAOSTAT database indicates that food is wasted in the entire supply chain. A complementary database, such as OECD, and other relevant peer-reviewed journals and reports for dairy food waste data are needed to provide holistic and integrated data for quantifying dairy food waste, assessing the environmental impact of the dairy waste, and identifying the stages along the value chain that contribute potentially to the dairy waste-related emissions. The study's primary data sources include the following:

- Food and Agriculture Organization for United Nations (FAO) database.
- Organization for Economic Co-operation and Development (OECD) food waste database.
- Environmental impacts of food waste in Europe (Scherhaufer et al., 2018).
- Atlas Food Waste Database for Dairy Food Waste.
- Greenhouse Gas Emissions from the Dairy Sector A Life Cycle Assessment (FAO, 2010a)
- Global Food Losses and Food Waste (Gustavsson et al., 2011)
- Food Wastage Footprint & Climate Change (FAO, n.d.-b)
- Peer-reviewed journals.

The available data for food waste – food loss category across different databases and reports are expressed in different units (tons, kg/capita, kg/household, Million Kg, kg, and percentage) for the dairy food waste category. Dairy food waste in terms of kg/household and percentage of the waste is excluded from the study analysis. The reference unit used food for all dairy products food-waste categories is either tons or kg to harmonies the dairy food waste results.

3.3 Dairy Food Waste Carbon Footprint.

In this study, dairy food is classified into four main categories and the dairy value chain definition before drilling into calculating the wastage CF of the dairy food waste. This section is divided into three sub-sections, namely, 3.3.1) milk classification categories, 3.3.2) milk supply chain: the dairy value chain, 3.3.3) dairy food-waste carbon footprint calculation.

3.3.1 Classifying Dairy Food Category.

Several organizations and research have classified food categories for the seek of harmonizing the food industry. In this study, dairy food classification, including milk and milk products, is based on (FAO, n.d.-a). Food and Agriculture organizations have grouped the food categories into 18 food classification groups in which the dairy products are classified (milk and milk products) category. Milk and milk product categories are split into four subcategories: milk, fragmented milk product, cream, and cheese, as shown in Table 3. Milk is the first sub-category that falls under the milk and milk products. Milk includes only fresh and processed milk, where fermented milk products such whey, cheese, and other milk products are excluded. Fermented milk products are the second sub-category, including fermented milk products such as flavored and non-flavored yogurts, sour and fermented milk. The four dairy categories corresponding to their definitions are shown in Table 3. The use of a standard food classification and description system from different countries, covering different ages, contributes to harmonizing food data globally and reaching coordinated and consistent results.

Table 3. Milk and milk product categories are classified based on FAO definitions.

Dairy Categories	Definition
Milk	Fresh and processed milk are considered where processed fermented milk products including, yogurt, cream, whey, butter, cheese, and other milk products, are eliminated in the milk category. The milk considered in this category is derived from cattle, and other mammals or ruminant animals, including additional items and products derived from the milk. This sub-category includes evaporated milk as well as condensed and dried milk protein. It also comprises processed milk products such as healthy dairy snacks and flavored milk by either reducing the amount of water or increasing the sugar content. All fragmented milk products are not considered under this category.
Fermented milk products	Fermented milk products, including yogurts, kephir, kumis, and fermented milk, flavored and non-flavored manufactured commodities derived from mammal’s milk, are falling under the fermented milk products category.
Cream	Any cream, whey, and sour cream derived from the mammal’s milk, including cow’s milk, sheep’s milk, and goat’s milk, is considered under the cream category. It also includes creamy powdery products such as dried whey/cream and powder sour cream. The cream category comprises manufactured items such as flavored and non-flavored whey, cream, and sour cream produced from mammal's milk. Fermented milk commodities and several kinds of cheese are excluded from the cream.

Dairy Categories	Definition
	category. As one of the leading milk products, the cream is obtained by segregating its different components such as cream, whey, and other milk products by isolating the milk's fats.
Cheese	All types of cheese produced from mammal’s milk, including cow, sheep, and goat milk, fall under the cheese category. Various kinds of cheese such as cured/uncured cheese, pickled cheese, soft and hard ripened cheese are included. Rind and spreads (processed cheese) are also considered under the cheese category.

3.3.2 Defining Milk Supply Chain: The Dairy Value Chain.

Several studies have clearly defined the food supply chain stages of different food categories. A non-ambiguous food supply chain is required harmonizing food to reduce waste and thus mitigate carbon emissions derived from the food waste sector. Food and Agriculture Organization has defined the general value chain stages where food loss and waste take place. Food loss and waste occur along the value chains, namely a) production and harvest, b) transportation, c) processing, d) packing, e) retail, f) export, and g) consumption (FAO, 2019). In the milk supply chain context, (Rodríguez-Enríquez et al., 2015) have defined eight stages for the milk along the supply chain to understand the full supply chain cycle Figure 8. The definition of each milk supply chain stage can be explained as the following:

1. Production of feed for cows: Dairy value chain, including the milk supply chain, starts with growing crops and grass. Cows mainly feed on corn, hay, and

soybeans to produce milk. The production of cow’s feed falls under the pre-farm stage, before ruminant animals' milking process.

2. Milk production: Dairy cows and cattle are grazed, housed, fed, and milked on an intensive specialized dairy farm. The production of milk on dairy farms is considered the primary production phase of milk at the farm.
3. Milk transportation: After the milk production stage is completed, milk is transported from the dairy farms where the cows are milked to an insulated tanker temperature-controlled trucks to conserve the transported milk's freshness.
4. Processing: After the milk is produced and transported, the milk is further processed in the processing factories to transform fresh and processed milk into cheese, whey, yogurt, ice cream, powdered milk, butter, and other products.
5. Packaging: Dairy processors packed the processed dairy products into paperboard or plastic containers in different sizes designed to keep the products healthy, fresh, and clean.
6. Distribution: Dairy products are typically distributed by the distribution companies that transfer milk and milk products from the processing factories to retailers, restaurants, schools, hospital services, and other outlets in refrigerated temperature-controlled trucks.
7. Retail: Dairy products are now available at retail outlets to be accessed by the consumers offering all shapes and sizes of milk and milk products.
8. Consumer: Milk and milk products, including cheese, yogurt, cream, are delivered to customers. Products derived from milk contain nine essential nutrients to consumers.

Figure 8. Milk supply chain: the dairy value chain (Rodríguez-Enríquez et al., 2015).

In this study, the stages are simplified and grouped into the four main categories from farm-to-fork life cycle to evaluate and quantify the dairy waste along the food supply chain. The groups are: 1) primary production at the farm level (milk production, mainly milking the cows), 2) processing (transforming raw milk to yogurt, cheese, and cream) and packaging milk and milk products, 3) Distribution and retail where dairy products are distributed into different retails and 4) consumption, including household only. Food waste that occurs in food services is excluded. Dairy value chain stages, including the production of feed for cows, milk transportation, milk disposal, and milk waste management, are not considered in this study.

Life cycle assessment is a commonly used methodology for assessing a process or product's environmental impact through its life cycle (Roy et al., 2009). Several different life cycle assessments, including cradle-to-grave and cradle-to-cradle, are implemented for assessing the environmental impact for all the stages of the products from the early stages of extracting the raw materials until disposal treatments (Muralikrishna & Manickam, 2017). Cradle-to-gate and gate-to-grave life cycle assessment approaches are also used to assess the impact, explicitly ecological impact, of the product's life in particular stages. In this study, farm-to-fork life cycle assessment is used within the dairy value chain context, comprising dairy production, processing and packaging, retail and distribution, and consumption. Figure 10 shows the system boundary of dairy food waste and waste-related carbon emissions from farm-to-fork life cycle assessment. Waste and emissions derived from the diary food waste are considered. However, emissions released from the production of dairy products and emissions from waste treatment management are excluded from the study.

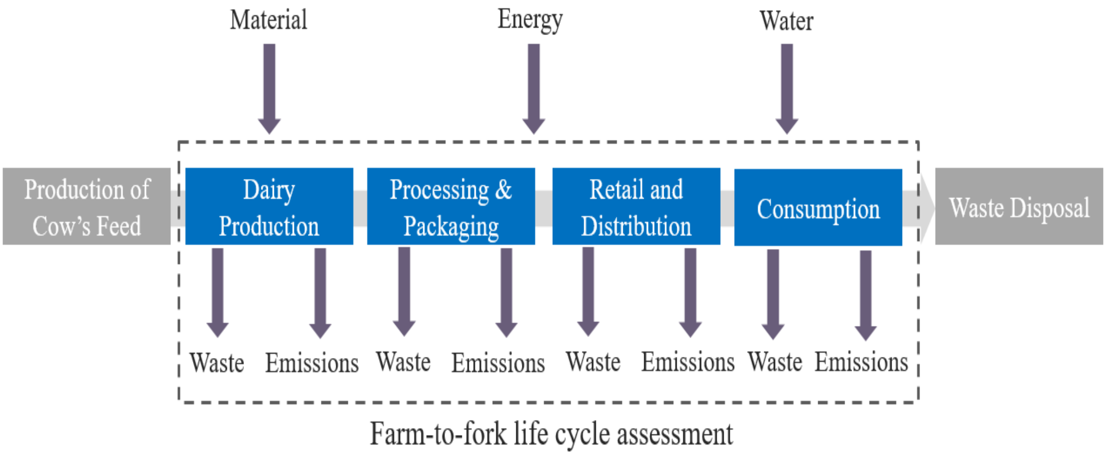

Figure 9. The system boundary of dairy food waste and waste-related emissions.

3.3.3 Assessing Dairy Food Waste Carbon Footprint.

Assessing the environmental aspects of food waste-related impacts becomes necessary to achieve a sustainable agricultural system (Scholz et al., 2015a). Several studies have quantified dairy food waste along the supply chain using different life cycle assessment approaches. Researchers have assessed and calculated the environmental impact of dairy products under various activities and circumstances for several other production systems in the past decades. Nevertheless, scarce studies have studied the effects of different dairy products and the carbon footprint derived from the dairy waste sector. Flysjö (2012) has calculated various dairy products' carbon footprints, including milk, cheese, yogurt, and cream produced at Arla dairy company. In this research, dairy products' carbon footprint values per Kg are obtained from the existing literature of Life Cycle Assessment (LCA) of dairy food waste based on the study conducted by Flysjö (2012). Table 4 shows the primary four dairy products carbon footprint expressed in kg CO2e per kg product along the dairy supply chain considering the milk production at the farm stage up to the consumption phase. Flysjö (2012) has defined different products under each dairy waste category. For instance, whole milk, semi-skimmed milk, and skimmed milk fall under the milk category and similarly for cheese, yogurt, and cream. This study will calculate the carbon footprint derived from whole milk, yogurt, cream, and yellow cheese. In this study, the discrepancies between dairy food waste quantities, mass, and wastage carbon footprint derived from dairy food products wasted will be analyzed. The carbon footprint is expressed in terms of carbon dioxide equivalent ($\mathrm{C0_2e}$) common standard unit. Gasses such as carbon dioxide ($\mathrm{C0_2}$), nitrous oxide ($\mathrm{N_2O}$), methane ($\mathrm{CH_4}$) are included in which the global warming potential of nitrous oxide and methane gasses is expressed relative to carbon dioxide based on IPCC report (Solomon et al., 2007).

Table 4. Carbon footprint (kg CO2e per kg product) of different dairy products partitioned into farm-to-fork activities. All numbers are excluding emissions from land-use change (Flysjö, 2012).

Dairy Products	Dairy food waste-related chains (kg CO2e per kg)				Total
	Farm	Processing	Packaging	Retail & Consumption	
Milk – Whole milk (1 liter)	1.00	0.05	0.04	0.23	1.32
Yogurt - Yoghurt (1 Liter)	1.06	0.10	0.04	0.25	1.45
Cream – Cream (0.5 liter)	5.07	0.05	0.03	0.24	5.39
Cheese - Yellow cheese (800 g)	8.71	0.76	0.03	0.30	9.8

As mentioned earlier, farm-to-fork life cycle assessment considering the four main dairy value chains is considered in the dairy value chain. The carbon footprint factor values initiated by Flysjö (2012) show the emission factor of other dairy food waste along the supply chain in different activities. The retail and consumption stage's carbon footprint factor is combined as a single value for different dairy waste products, as shown in Table 3. Food wastage footprint & climate change report by FAO (n.d.-b) has been used to distinguish the carbon factor for each stage separately as defined in this study previously. The report shows that 15% of food waste's carbon footprint corresponds to retails and distribution while 35% corresponds to the consumption phase. Therefore, retail and distribution factor of carbon footprint for whole milk 0.23*0.15 = 0.0345 compared to 0.23*0.35 = 0.0805 for consumption. Similarly, for the other three dairy food waste products, including yogurt, cream, and cheese.

In order to calculate the wastage CF of dairy food waste, the specific CF factor of the dairy waste product acquired from the existing literature, comprising emissions related to the primary production of milk at the farm stage up to delivery to the consumers, multiplied by the total mass of the wasted respective product. Equation (1) is used for calculating the sum of milk waste-related impact ($\mathrm{I_{MW}}$), explicitly, carbon footprint along the dairy value chain, including primary production ($\mathrm{I_{MW/PP}}$), processing ($\mathrm{I_{FW/FP}}$), distribution and retail ($\mathrm{I_{FW/RD}}$), and consumption ($\mathrm{I_{FW/FC}}$).

$$\sum \mathrm{I_{MW}} = \sum \mathrm{I}_{\frac{\mathrm{MW}}{\mathrm{PP}}} * \mathrm{m}_{\frac{\mathrm{MW}}{\mathrm{PP}}} + \sum \mathrm{I}_{\frac{\mathrm{FW}}{\mathrm{FP}}} * \mathrm{m}_{\frac{\mathrm{MW}}{\mathrm{FP}}} + \sum \mathrm{I}_{\frac{\mathrm{FW}}{\mathrm{RD}}} * \mathrm{m}_{\frac{\mathrm{MW}}{\mathrm{RD}}} + \sum \mathrm{I}_{\frac{\mathrm{FW}}{\mathrm{FC}}} * \mathrm{m}_{\frac{\mathrm{MW}}{\mathrm{FC}}} \qquad (1)$$

A holistic, integrated view of food waste and their related emissions to identify the position of dairy waste among other food categories has been developed using the approach and data adopted by Scherhaufer et al. (2018). The more food wasted occurs along the food supply chain, the more significant environmental impact occurred. The total food waste-related impacts ($\mathrm{I_{FW}}$) along the food supply chain is calculated at each stage of the value chain to determine the environmental impact of food waste-related emissions. In this study, the impact will be calculated at each step in the value chain, including production, processing, distribution, and consumption for different products. Equation (2) shows a sample to calculate the environmental impact of food waste-related emissions initiated only by the primary production stage. Similarly, it will be applied for the other three stages of the food waste-related chains.

$$\sum \mathrm{I_{FW/PP}} = \mathrm{I_{PP1-9}} * \mathrm{m_{FW1-9/PP}} + \mathrm{I_{PP1-9}} * \mathrm{m_{FW1-9/FP}} + \ldots. + \mathrm{I_{PP1-9}} * \mathrm{m_{FW1-9/FC}} \qquad (2)$$

Alternatively, Equation (3) used to calculate the environmental impact of food waste by multiplying the sum of the specific product’s impact by the corresponding food waste mass along the food supply chain generated from the primary production stage ($\mathrm{I_{MILK}}$). In this equation, the primary production stage is taken as an example because all the food waste is initially produced in the primary production chain.

Similarly, the same procedure will be applied for calculating FW in the processing, retailing, and consumption dairy value chains.

$$\sum \mathrm{I}_{\mathrm{MILK/PP}} = \mathrm{I}_{\mathrm{PP/MILK}} * [\mathrm{m}_{\mathrm{MILK/PP}}+\mathrm{m}_{\mathrm{MILK/FP}}+\mathrm{m}_{\mathrm{MILK/RD}}+\mathrm{m}_{\mathrm{MILK/FC}}] \quad (3)$$

The same process will be applied to the other stages and categories along the value chain. Eq. (4) used to calculate the sum of the total food waste-related generated throughout the entire food supply chain stage.

$$\sum \mathrm{I}_{\mathrm{FW}} = \sum \mathrm{I}_{\mathrm{FW/PP}} + \sum \mathrm{I}_{\mathrm{FW/FP}} + \sum \mathrm{I}_{\mathrm{FW/RD}} + \sum \mathrm{I}_{\mathrm{FW/FC}} \quad (4)$$

3.4 Dairy Waste Visualization Dashboards.

Data visualization is the graphical representation transforming unstructured and scattered data into meaningful and understandable information fitting the human visual mind (Aparicio & Costa, 2014). Visualization tools generate elements like charts, graphs, and maps to provide a reachable and convenient way to observe, understand, and analyze data trends and patterns. (Few, 2007). In this study, Microsoft Power PI and Microsoft Excel were used to provide insights for dairy food waste as an attempt to translate raw dairy data into useful and visible information to assess the decision-making processes for better decisions, detect relevant information, and find out relationships among dairy waste categories and their associated emissions. Data visualization tools provide quick, clear, and informative data that synthesize large volumes of data into understandable and coherent dashboards (Few, 2007). Several studies have shown that translating the raw data into meaningful information to support the decision-makers represents a real challenge (Vellido et al., 2011). Data has to be classified, cleansed, and organized before jumping to visualization to avoid ignored, misunderstood, and ineffective use of the presented data (Few, 2007). Unfortunately, according to Midway (2020), many figures incorrectly demonstrate information across scientific disciplines or, when not incorrect, still use suboptimal data visualization practices. In this study, to avoid misleading or inaccurate visualization results, the dairy food waste data collected from multiple resources have been categorized, cleaned, and filtered based on the study's need. The data is then retrieved into Microsoft Power BI to be visualized and interpret the results eventually found on the constructed dashboards. Figure 10 shows the process from collecting the data to categorizing and cleaning data to provide a visualization dashboard ultimately. Microsoft Power BI can visualize data from multiples sources into visual figures, graphs, and charts that are easy to understand and draw insights with the ability to share multiple dashboards (Becker & Gould, 2019).

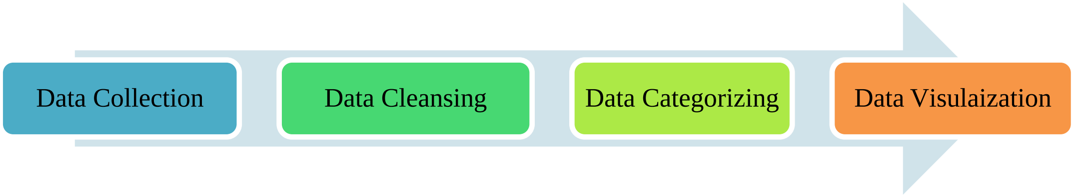

Figure 10 Steps for Data Visualization.

Today, data visualization is increasingly taking its rightful place as an essential data-driven business intelligence tool (Few, 2007); (Morabito, 2016); (Kumar et al., 2018). It has been applied in different industries globally due to the pictures' strength for effortless recognizing and processing than words to recall due to ancient human nature (Dewan, 2015). Bragas & Abundez (2016) have applied data visualization to improve the fire safety system by creating useful dashboards to visualize fire incident hotspots and high response-time areas for statistical measurements allowing the industrial specialists to shape better-informed decisions for achieving a safer world. Ejaz et al. (2012) has generated 3D visual interactional data cubes for high dimensional analytical processing data analysis of social network data using cloud computing. In comparison, Rübel et al. (2010) presented an integrated visualization framework and an analytical model for encouraging and guiding data clustering users to examine new complex data groups.

Studies implementing visualization in the food waste industry are relatively small compared to other sectors. In this study, three visualization dashboards are initiated to dive from the top base dashboard representing the total food waste and their related emissions to eventually visualizing the carbon emissions related to dairy food waste. Figure 11 shows the pyramid structure of visualizing dairy food waste dashboards split into three parts for the three visualization dashboards. The base of the pyramid represents the top idea of dashboard #1 to provide a comprehensive full picture for food waste categories to identify the position of dairy food waste. In the middle, dashboard #2 is used to drill down to find the waste for dairy food waste categories, including milk, cheese, yogurt, and the dairy value chain. Finally, the last dashboard representing the pyramid peak shows the dairy waste carbon footprint in different food waste activities.

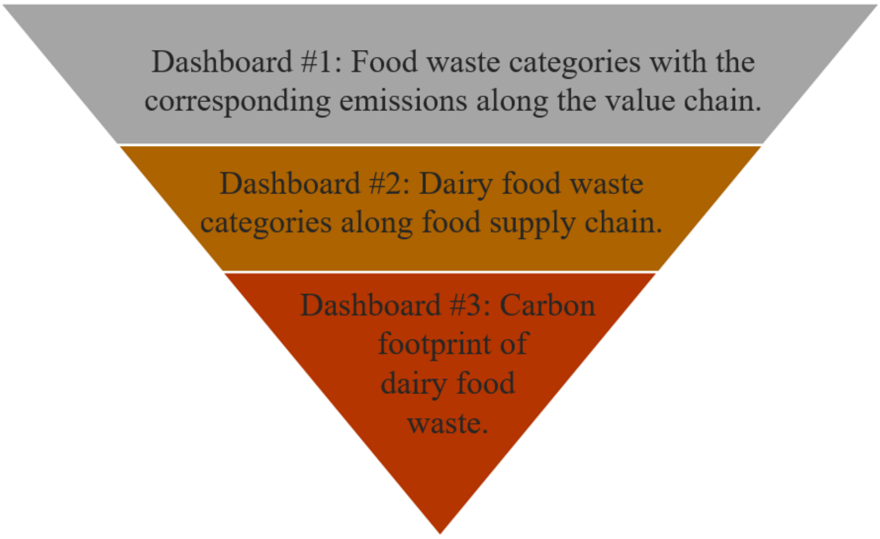

Figure 11. Dairy food waste visualization dashboards pyramid.

CHAPTER 4: RESULTS AND DISCUSSION.

The data analysis and discussion of the acquired results are discussed in the following sections. The results of this study are mainly divided into three significant subsections, namely, a) developing a broad overview picture of food loss and waste impact assessment in Europe to identify the position of dairy waste among other food waste categories b) quantifying dairy food waste accumulation along the value chain for the four dairy waste categories and, c) evaluating the corresponding carbon emissions related to dairy food waste concerning the stages along the value chain that contribute potentially to the dairy food waste-related emissions. This chapter compares and discusses the carbon footprint associated with different categories of dairy food waste and the corresponding supply chains responsible for accumulating food waste. Discussion about the results' findings by giving some practical policy recommendations, including prioritizing the food supply stages accountable for the potential waste associated with the most extensive dairy food waste product, will be partially discussed in this chapter, explained in detail by the preceding chapter.

4.1 Food Waste Related Impact Assessment.

Assessing the environmental impact of food waste is increasingly seen as a critical factor due to its significant contribution to greenhouse gas emissions and global warming potential (Al-Rumaihi et al., 2020). The first interactive dashboard provides a big view, a comprehensive picture, for showing dairy food waste, mainly milk, among other food waste categories. The food waste categories and the environmental impact, global warming potential are being analyzed, calculated, and visualized. Animal-containing food wastes, including milk, beef, pork, chicken, and other categories such as bread, tomato, and potato, are considered. Figure 12 shows the first interactive dashboard of food waste categories and their related impact of the four main supply chain stages, production, processing, retailing, and consumption. The dashboard shows the percentage share of dairy waste along the supply chain regarding mass and waste-related environmental impact, explicitly global warming potential. Animal-containing food waste, including milk, is the major contributor to food waste associated with GWP measured in 1000 tons CO_2 equivalent. Milk occupies the 4th most wasted food categories contributing to global warming potential. Food waste in terms of mass does not necessarily indicate the contribution of the corresponding food waste-related impact. Although animal-containing food waste, mainly beef, have relatively low waste in terms of mass, its contribution to the environment is relatively high.

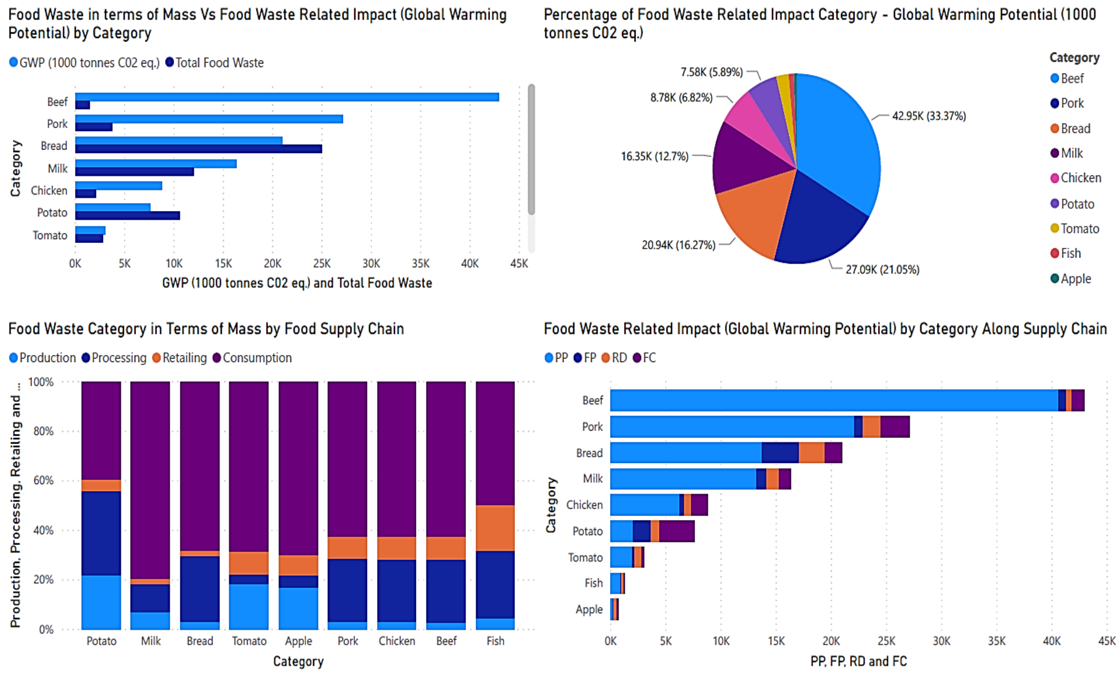

Figure 12. Dashboard 1: Food Waste Related Impact Assessment.

The interactive dashboard shown in Figure 12 is customized and divided into four main visual elements, including charts and graphs. The top-left chart shows the food waste categories mass compared to the corresponding environmental impact; global warming potential measured in 1000 tonnes CO_2 eq. The food waste product categories along the value chain associated with the total waste per product and per stage are shown in Table 4. The top right pie chart in Figure 12 shows the percentage share of food waste global warming impact categories. It illustrates that milk is one of the top four wastage categories generating carbon emissions in the scale of Europe. Most of the food waste categories, including milk food waste, are wasted in the consumption stage, as shown in the bottom left chart. The global warming potential indicator used for calculating food waste for each value stage is shown in Table 5. The environmental impact numerical values of food waste categories related to emissions and global warming potential are shown in Table 6. Notwithstanding, most of the food waste-related impact derived from animal-containing food waste, including milk, occurred in the primary production stage, as shown in the bottom left chart.

Table 4. Food waste product categories along the value chain.

Category	Production	Processing	Retail	Consumption	Total food waste
Apple	363	103	175	1489	2131
Tomato	504	116	245	1891	2755
Potato	2331	3593	496	4172	10592
Bread	832	6577	527	17026	24962
Milk	861	1352	259	9527	11999
Beef	43	367	137	904	1452
Pork	126	948	336	2337	3746
Chicken	66	527	187	1300	2080
Fish	17	98	67	179	361
Indicator total Waste	5143	13681	2429	38825	60078

Table 5. GWP indicator measured in (Kg C02-eq) factors along the value chain.

Indicator categories	Production	Processing	Retailing	Consumption
Apple	0.100	0.025	0.180	0.091
Tomato, field	0.250	0.100	0.330	0.110
Tomato, greenhouse	2.100	0.100	0.150	0.110
Tomato, total	0.720	0.100	0.290	0.110
Potato, fresh	0.150	0.000	0.120	0.690
Potato, frozen	0.250	0.530	0.220	0.920
Potato, chilled	0.440	0.790	0.580	0.290
Potato, total	0.190	0.200	0.160	0.760
Bread	0.550	0.140	0.130	0.091
Milk	1.100	0.083	0.120	0.110
Beef	2800	0.490	0.440	1.300
Pork	5.900	0.200	0.630	1.100
Chicken	3.000	0.210	0.460	1.100
Fish	2.600	0.160	0.930	0.400

Table 6. Environmental impact (GWP) of the nine indicator waste categories.

Indicator	Production	Processing	Retailing	Consumption	Total GWP
Apple	213	44.175	299.52	135.499	692.194
Tomato	1984.32	225.2	619.44	208.01	3036.97
Potato	2012.48	1652.2	746.88	3170.72	7582.28
Bread	13729.1	3378.2	2281.89	1549.366	20938.556
Milk	13198.9	924.454	1174.32	1047.97	16345.644
Beef	40628	689.92	458.04	1175.2	42951.16
Pork	22107.3	724.2	1683.99	2570.7	27086.19
Chicken	6240	422.94	684.02	1430	8776.96
Fish	938.6	55.04	228.78	71.6	1294.02
Total	101051.7	8116.329	8176.88	11359.065	

In terms of wastage mass and wastage carbon footprint, milk and milk products emerge a pressing need to determine the types of diary waste products contributing potentially to waste and emissions by giving some practical policy recommendations. Although dairy food waste products have a low mass fraction compared to other categories, they have a high environmental impact per Kg (Brancoli et al., 2017).

Therefore, dairy food waste-related impact might have a significant contribution to the environmental emissions. According to Parfitt et al. (2016), around 50% of the total waste occurred in meat and dairy products. Dairy food waste products represent approximately 23% of the entire avoidable waste in the United Kingdom (Parfitt et al., 2016). Therefore, drilling to investigate the dairy waste categories accounted for the wastage emissions along the value chain becomes necessary.

4.2 Dairy Waste Quantifications and Categorization.

Several attempts have been initiated to quantify food waste driven by the need to highlight the scale of waste globally (Parfitt et al., 2010). This section discusses and quantifies dairy food waste accumulation along the four dairy waste categories' value chain. The section digs down into dairy food waste categories along the value chain from farm-to-fork, including producing, processing, retailing, and consuming. Figure 13 shows the interactive dashboard for visualizing the dairy waste per product across the dairy value chain. The dashboard is customized and divided into two main sections: the left side illustrates the most wastage of dairy food products and demonstrates a mini online world map showing the top five countries contributing to dairy food waste. Similarly, the right side presents the dairy chain stages responsible for most dairy waste in terms of mass. It also shows the different dairy waste categories at different stages in the food supply chain.

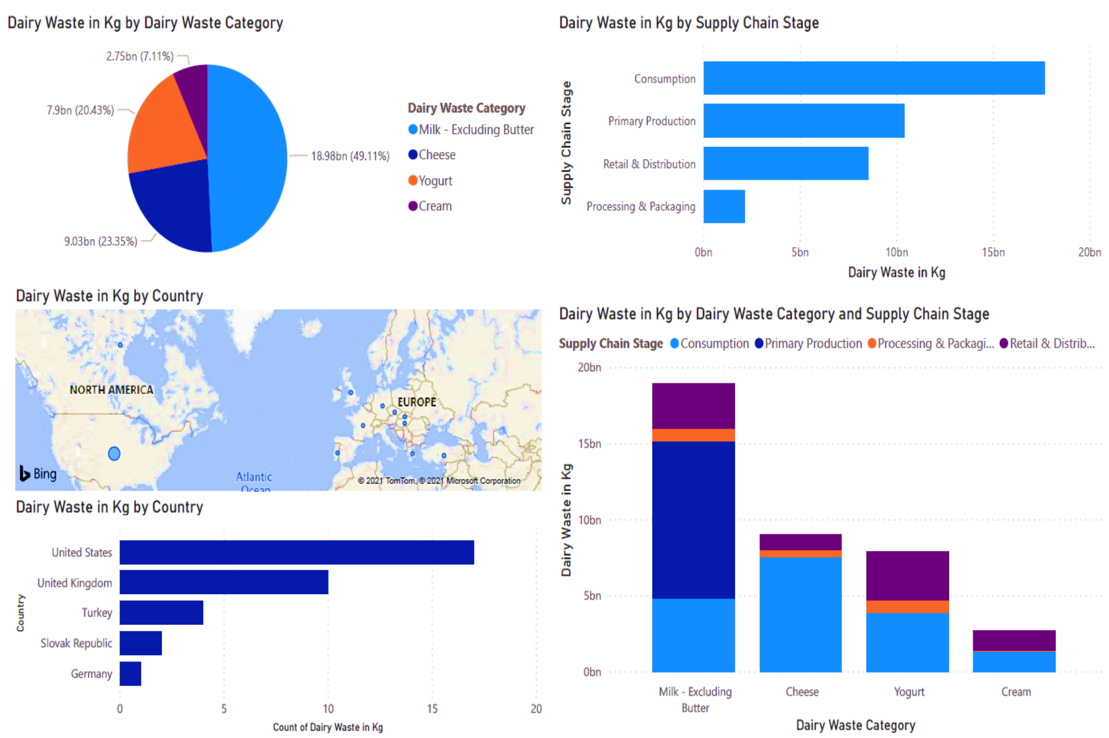

Figure 13. Dashboard 2: Dairy food waste categorized by product across FSC.

The results show that dairy food waste products, including milk, cheese, yogurt, and cream, is mostly wasted at the consumption stage. This study results in consensus with the finding obtained from several studies. (Caldeira et al., 2019) has shown that food waste mostly occurs in the consumption stage. According to the FAO report initiated by (Gustavsson et al., 2011), dairy food waste occurs at the consumption level, making up approximately 40-65% of total food waste in all three industrialized regions, including Europe, North America, and Oceania, and industrialized area as shown in Figure 14. Significant amounts of dairy wastes occur in the consumption stage mostly during vacations, religious holidays, weddings, ceremonies, gatherings, restaurants and hotels (FAO, 2019). According to (Fisher & Whittaker, 2018), the consumption stage is accountable for a significant volume of milk waste, reaching 290,000 tonnes per year in 2012 in the United States, distributed among the following factors:

- Approximately 55,100 tonnes of milk are wasted when the milk is not used within the use-by date and discarded once it is opened and not used for a long time.
- 101,500 tonnes of wastage milk occur because milk and milk products are not used in time, reaching the expiry date before using them.
- Roughly 63,800 tonnes of milk products are being wasted due to over-pouring and excessive serving in restauranters, hotels, and hospitals.
- More or less 43,500 tonnes of milk products are discarded because of people's personal preference.
- Explicitly 26,100 tonnes of milk products are discarded due to leakage or breakage of products packaging.

Although the percentage of dairy waste differs among geographical locations, dairy food wastage mainly occurs in the consumption supply chain stage, followed by production/manufacturing, processing, and retailing. This result is acknowledged by the studies conducted by (Pocketbook, 2013); (Gustavsson et al., 2011), emphasizing that waste at the consumption stage should be tackled and minimized to mitigate food waste-related impact along the value chain.

Milk is the top wastage of dairy products representing almost 50% of dairy food waste along the value chain, followed by cheese 23%, yogurt 20%, and cream 8%. The result is acknowledged by Tonini et al. (2018), showing that milk is the most dairy product wastage representing almost half of the UK's dairy food waste. According to Tonini et al. (2018), milk waste is roughly estimated at 334 kg per one ton of avoidable food waste in processing, retail, and consumption, followed by cheese and yogurt wastes accounts for 90 and 30 kg, as shown in Figure 14.

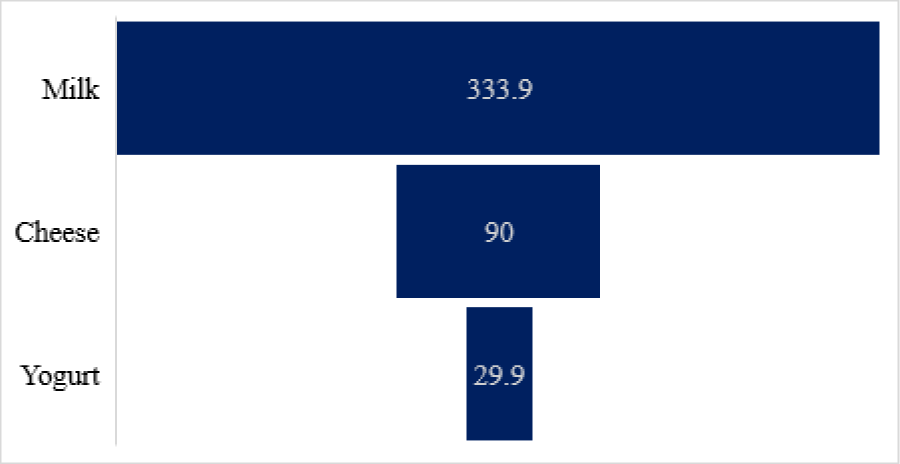

Figure 14. Milk & dairy products avoidable food waste in the UK (Kg per one tonne of waste).

The generation of dairy food waste differs among different geographical locations. Despite geographical variations, food waste's catastrophic impact is still deemed a critical issue for developed and developing countries globally (Kosseva & Webb, 2020). The analysis shows that the United States and the United Kingdom dominate most dairy waste, followed by Turkey, the Slovak Republic, and Germany. (Venkat, 2012) The avoidable food waste in the United States has recently exceeded approximately 55 million tons wastes annually, representing around 29% of total production annually. This result is acknowledged by (Statista, 2017) showing that the United States is the second top country contributing to food waste per capita, followed by Turkey and Germany in 2017.

4.3 Wastage Carbon Footprint of Dairy Products.

Carbon footprinting calculation is the first essential step towards quantifying and thus reducing the carbon emissions released from the food industry (Awanthi & Navaratne, 2018). Recently, several research works have been done in carbon footprinting to identify opportunities for mitigating carbon emissions in the food supply chain (Espinoza-Orias et al., 2011). The wastage carbon footprint should be calculated to assess food waste-related impact as food waste in terms of mass does not necessarily provide sufficient information for the associated environmental impact (Scholz et al., 2015b). The carbon footprint should be considered a useful tool to keep track of waste reduction goals (Scholz et al., 2015b); (Awanthi & Navaratne, 2018). Nearly 95% of food waste, including dairy products, are ended up in the landfills emitting carbon, methane, and other GHG emissions (Melikoglu et al., 2013). Accordingly, this section aims to evaluate the environmental impact of dairy waste, explicitly carbon footprint, and identifying the stages along the value chain that contribute potentially to the dairy food waste-related emissions. This section also discusses the discrepancies between dairy waste in terms of mass and dairy waste emissions.

The wastage dairy and wastage carbon footprint released from the dairy sector per product at different stages along the FSC are shown in Figure 19. The dashboard is mainly divided into two main sections. The left-hand section illustrates the percentage of dairy waste categories compared to wastage carbon footprint for different countries. However, the right-hand demonstrates the pie charts for dairy waste and wastage CF. It also shows the C02- Equivalent emissions accumulated along different stages along the supply chain associated with the dairy waste in terms of mass.

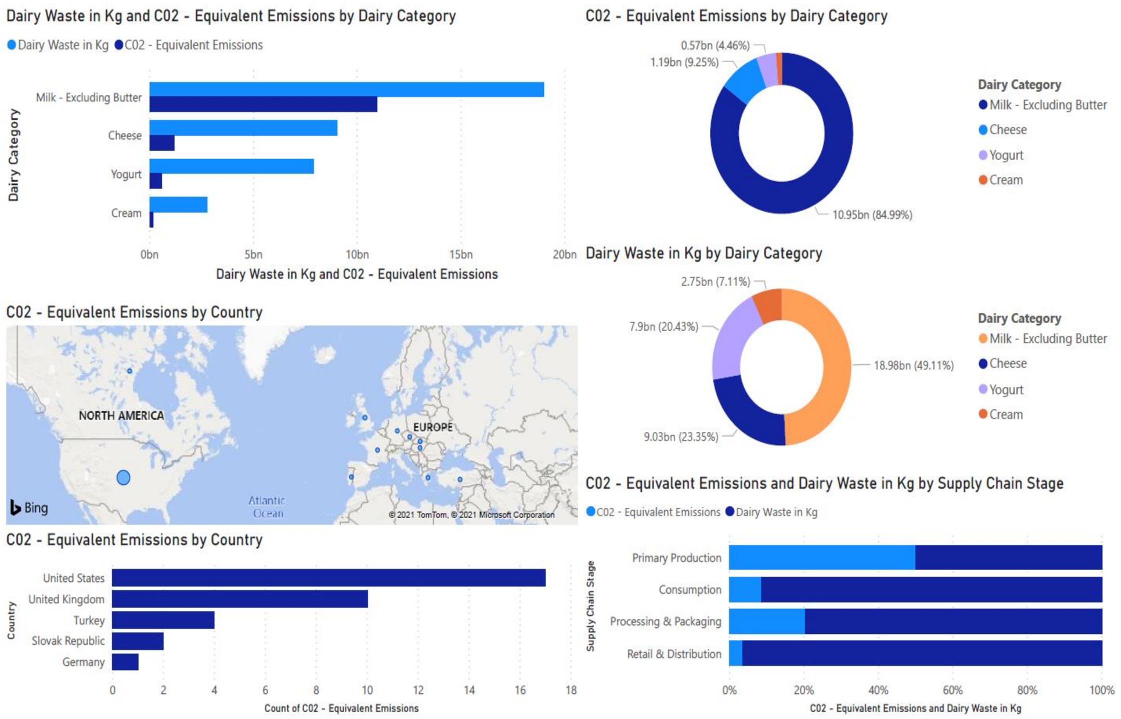

Figure 15. Dashboard 3: The wastage carbon footprint of dairy products.

The results reveal that dairy food waste emissions mainly occur in the primary production followed by the processing, consuming, and retailing stage. Nearly 50% of the wastage carbon footprint are originated from production, followed by processing contributing to 20%, consuming 10%, and retailing 5%, as shown in Figure 12. Although food consumption is among the main environmental impact drivers (Notarnicola et al., 2017b); (Tan et al., 2013); (FAO, n.d.b), the primary production stage is responsible for most of the insensitive carbon emission in the dairy sector. This result is acknowledged by Scherhaufer et al. (2018), confirming that most of the environmental impacts of animal-containing food waste are driven by the GHG emissions from the primary production stage. Besides the wastage CF derived from the dairy food waste at the primary production, methane representing the potent source of GHG emissions, are also generated during the production chain from enteric fermentation (Broucek, 2014); (Moss et al., 2000); (Alemu et al., 2011).

The wastage of dairy products, including milk and milk products, contributes to carbon footprinting. Milk is the top dairy product responsible for the wastage of dairy in terms of mass and wastage emissions representing roughly 50%, followed by cheese 24%, yogurt 20%, and cream 7%, as shown in Figure 21. Table 7 summarizes the carbon dioxide equivalents released from the dairy waste categories measured in 1000 tonnes CO2-eq. FAO (2010a) has been demonstrated that the milk commodity alone is contributing to 1328 GHG emissions (million tonnes CO2-eq) compared to the total production of 553 million tonnes, as shown in Figure 20, driven by the production, processing, and transportation steps of the chain. Emissions from milk production are estimated by 4.6 gigatonnes CO2-eq representing around 30 percent of the livestock sector emissions (Opio et al., 2013).

Table 7. Carbon Footprint of Dairy Waste Categories in 1000 tonnes CO2-eq

Dairy waste category	CO2 – Equivalent Emissions.	Percentage (%)
Milk	10950	84.99 %
Cheese	1190	9.25 %
Yogurt	570	4.46%
Cream	113	1.3%

Carbon intensity highly diverse based on the geographical location depending on their production system and management practices (Opio et al., 2013); (Alamar et al., 2018). Although the wastage CF varies among different countries, as shown in Figure 21, US is still dominating the first place in wastage CF of dairy products. UK occupies second place, followed by Turkey, Slovak Republic, and Germany. The GHG emissions in the US have exceeded 112 million metrics of CO2-eq per year, driven by 55 million metric tonnes of food waste (Venkat, 2012), compared to 23.7 metric tonnes of CO2-eq year in Turkey (Cakar et al., 2020).

CHAPTER 5: SUMMARY AND CONCLUSION.

In conclusion, the wastage CF of dairy products is assessed throughout this research to provide insights into the dairy wastage's environmental impact. This section summarizes the main findings of this research as well as the discussion of the key highlight. Policy recommendations are also discussed in this section, and the recommendation and future work exploring ways to extend this research work.

5.1 Conclusion.

Assessing the carbon footprinting of dairy food waste becomes necessary as animal products tend to have a relatively high impact. Therefore, it is essential to emphasize the prevention of wastage CF (Scholz et al., 2015b). The study aims to confirm that quantifying dairy food waste is insufficient as it does not provide enough information about wastage CF. Throughout this study, three visualization dashboards are generated to provide insights for identifying the position of dairy waste among other food waste categories, quantifying different dairy food waste products accumulated along the supply chain, and finally assessing the wastage CF associated with the wastage of dairy in different geographical locations. The study's results reveal that animal-containing food waste contributes significantly to the environmental impact, explicitly global warming potential, compared to their relatively low quantity.

Further investigation was required for identifying the dairy food waste categories responsible for the emissions intensity. Accordingly, milk shows the highest dairy product contributing to the wastage quantity and wastage CF. Dashboard 2 reveals that the consumption stage mainly drives dairy waste. However, the primary production stage accounts for approximately 50% of carbon footprinting intensity. Although dairy food waste varies mostly across different geographical locations, the United States and the United Kingdom dominated the top countries in wastage quantity and wastage CF.

5.2 Recommendation and Future Work

The ultimate way of reducing food waste is by saving it. However, some dairy food waste elements are inevitable. There is a pressing need for adopting policy recommendations to take appropriate measures towards reducing the food waste burden, including wastage of dairy products (Paritosh et al., 2017). A combination of actions is required to trigger changes rather than focusing on a single solution (Aschemann-Witzel et al., 2015). Policy recommendations for reducing and treating dairy food waste along the supply chain are summarized as the following:

1. The implementation of a circular food economy helps towards mitigating the significant impact of animal-containing emissions. Different waste management techniques are suggested to treat food waste, including anaerobic digestion, in-vessel digestion, and waste composting instead of discarding dairy food waste in landfills emitting around 95% of GHG emissions (Melikoglu et al., 2013); (Gao et al., 2017); (de Sadeleer et al., 2020); (Slorach et al., 2019); (Tonini et al., 2020); (Paritosh et al., 2017).
2. The adoption of blockchain technology along the value chain improve the process of tracking, transporting, and selling food digitally across the food supply chain (Kamilaris et al., 2019). Blockchain provides detailed, transparent, and accurate information about the food items including their batch number, storage temperature, expiry date, and shipping details stored in blocks (Caro et al., 2018). The tracking records of food items are stored in blocks along every stage of the food supply chain allowing food traceability, supply chain transparency and auditability, which ultimately reduces the amount of food being wasted (Kamilaris et al., 2019); (Duan et al., 2020); (Tian, 2017).

3. Innovative food waste treatments should be adopted as the current waste treatment options are not offering an environmentally sustainable solution for food waste management. Ensuring innovative waste treatments that avoid endangering human health without imposing additional costs or harming the environment are urgently required to mitigate wastage food risks (Arvanitoyannis, 2008).
4. Increasing the awareness of daily food waste and loss to the public, e.g., shop smart, save leftovers, and donate. Aschemann-Witzel et al. (2015) has shown that consumers' motivation to avoid food waste should be prioritized as it has an extensive influence on the consumer's food waste behaviors.
5. The development of FLW governmental protocol is increasingly seen as a critical factor in measuring food waste and, therefore, monitoring systemically the wastage food accumulated in the value chain (Lipinski et al., 2013). If food waste is not measured or quantified, there are no possible practical actions that can be implemented to reduce food waste-related burdens.
6. Enteric methane emissions derived from the dairy cows can be reduced by feeding cows an algae meal high in DNA (Moate et al., 2011). Methane emissions originated by the natural process of enteric fermentation in ruminant animals are greatly related to feed intake (Patra, 2016). The existing mitigation strategies changes the nutrient components used for feeding ruminant animal to reduce methane by manipulating ruminant fermentation (Boadi et al., 2004).

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., 2019a); (Kucukvar et al., 2019b); (Kutty & Abdalla, 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 & Tatari, 2012); (Kucukvar et al., 2016). 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 & Abdalla, 2020); (Kutty et al., 2020a); (Alsarayreh et al., 2020); (Elhmoud & Kutty, 2020). Several researchers recently adopt statistical and machine learning techniques to provide integrated insights on food waste management (Abdella & Shaaban, 2020); (Kutty et al., 2020a); (Abdella et al., 2021a). Integrated and holistic frameworks based on machine learning techniques become necessary when addressing sustainability concerns across the food industry from multiple dimensions (Abdella & Shaaban, 2020). Moreover, Shaikh et al. (2017) has applied statistical techniques to comprehensively understand four sustainability metrics, including carbon footprint, to globally analyze the largest food producers' environmental and socioeconomic impacts. 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); (Abdella et al., 2012); (Abdella et al., 2021b). Multiple objective-based best-subset approaches adopted by Abdella et al. (2019b) can also be used for promoting the accuracy of the sustainability assessment in the food industry. Combining LCA with practical techniques can support sustainability assessment in a comprehensive manner (Tatari & Kucukvar, 2012); (Park et al., 2015); (Egilmez et al., 2016); (Onat et al., 2017); (Kutty et al., 2020c). 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 & Shaaban, 2020); (Onat et al., 2021); (Kutty et al., 2020b). 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 play a significant role in mitigating GHG emissions, it is everyone’s responsibility to save and reduce the amount of food waste globally.

REFERENCES

Abdella, G. M., Al-Khalifa, K. N., Kim, S., Jeong, M. K., Elsayed, E. A., & Hamouda, A. M. (2017). Variable Selection-based Multivariate Cumulative Sum Control Chart. *Quality and Reliability Engineering International*, *33*(3), 565–578. https://doi.org/10.1002/qre.2041

Abdella, G. M., Al-Khalifa, K. N., Tayseer, M. A., & Hamouda, A. M. S. (2019a). Modelling trends in road crash frequency in Qatar State. *International Journal of Operational Research*, *34*(4), 507–523. https://doi.org/10.1504/IJOR.2019.099106

Abdella, G. M., Kim, J., Al-Khalifa, K. N., & Hamouda, A. M. (2016). Double EWMA-Based Polynomial Quality Profiles Monitoring. *Quality and Reliability Engineering International*, *32*(8), 2639–2652. https://doi.org/10.1002/qre.2093

Abdella, G. M., Kim, J., Al-Khalifa, K. N., & Hamouda, A. M. (2019b). Penalized Conway-Maxwell-Poisson regression for modelling dispersed discrete data: The case study of motor vehicle crash frequency. *Safety Science*, *120*, 157–163. https://doi.org/10.1016/j.ssci.2019.06.036

Abdella, G. M., Kucukvar, M., Ismail, R., Abdelsalam, A. G., Onat, N. C., & Dawoud, O. (2021a). A mixed model-based Johnson’s relative weights for eco-efficiency assessment: The case for global food consumption. *Environmental Impact Assessment Review*, *89*, 106588. https://doi.org/10.1016/j.eiar.2021.106588

Abdella, G. M., Kucukvar, M., Kutty, A. A., Abdelsalam, A. G., Sen, B., Bulak, M. E., & Onat, N. C. (2021b). A novel approach for developing composite eco-efficiency indicators: The case for US food consumption. *Journal of Cleaner Production*, *299*, 126931. https://doi.org/10.1016/j.jclepro.2021.126931

Abdella, G. M., & Shaaban, K. (2020). Modeling the Impact of Weather Conditions on

Pedestrian Injury Counts Using LASSO-Based Poisson Model. *Arabian Journal for Science and Engineering*, 1–12. https://doi.org/10.1007/s13369-020-05045-w

Abdella, G., Yang, K., & Alaeddini, A. (2012). EFFECT OF LOCATION OF EXPLANATORY VARIABLE ON MONITORING POLYNOMIAL QUALITY PROFILES. *IJE Transactions A: Basics*, *25*(2), 131–140. https://doi.org/10.5829/idosi.ije.2012.25.02a.03

Abdur Rouf, K. B., Abdella, G. M., Al-Khalifa, K. N., & Alhajyaseen, W. (2018). *Ridge Penalization-based Generalized Linear Model (GzLM) for Predicting Risky-Driving Index*.

Al-Rumaihi, A., McKay, G., Mackey, H. R., & Al-Ansari, T. (2020). Environmental Impact Assessment of Food Waste Management Using Two Composting Techniques. *Sustainability, 12*(4), 1595. https://doi.org/10.3390/su12041595

Al Sheeb, B., Abdella, G. M., Hamouda, A. M., & Abdulwahed, M. S. (2019). Predictive modeling of first-year student performance in engineering education using sequential penalization-based regression. *Journal of Statistics and Management Systems*, *22*(1), 31–50. https://doi.org/10.1080/09720510.2018.1509817

Alamar, M. del C., Falagán, N., Aktas, E., & Terry, L. A. (2018). Minimising food waste: a call for multidisciplinary research. *Journal of the Science of Food and Agriculture, 98*(1), 8–11. https://doi.org/10.1002/jsfa.8708

Alemu, A. W., Ominski, K. H., & Kebreab, E. (2011). Estimation of enteric methane emissions trends (1990-2008) from Manitoba beef cattle using empirical and mechanistic models. *Canadian Journal of Animal Science*, *91*(2), 305–321. https://doi.org/10.4141/cjas2010-009

Alsarayreh, M. M. M., Alsuwaidi, M. F., Al Sharif, R. A., & Kutty, A. A. (2020). The

Factors Affecting CO Emission in the European Union Countries: A Statistical Approach to Sustainability across the Food Industry. *2020 IEEE 7th International Conference on Industrial Engineering and Applications, ICIEA 2020*, 599–604. https://doi.org/10.1109/ICIEA49774.2020.9102066

Aparicio, M., & Costa, C. J. (2014). Data Visualization. In *Communication Design Quarterly* (Vol. 3).

Arvanitoyannis, I. S. (2008). *Waste Management for the Food Industries* .

Aschemann-Witzel, J., de Hooge, I., Amani, P., Bech-Larsen, T., & Oostindjer, M. (2015). Consumer-Related Food Waste: Causes and Potential for Action. *Sustainability, 7*(6), 6457–6477. https://doi.org/10.3390/su7066457

Ascher, S., Li, W., & You, S. (2020). Life cycle assessment and net present worth analysis of a community-based food waste treatment system. *Bioresource Technology, 305*, 123076. https://doi.org/10.1016/j.biortech.2020.123076

Awanthi, M. G. G., & Navaratne, C. M. (2018). Carbon Footprint of an Organization: A Tool for Monitoring Impacts on Global Warming. *Procedia Engineering, 212*, 729–735. https://doi.org/10.1016/j.proeng.2018.01.094

Babiker, M., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M., & Waterfield, T. (n.d.). *Editorial Team: Annex I: Glossary*.

Becker, L. T., & Gould, E. M. (2019). Microsoft Power BI: Extending Excel to Manipulate, Analyze, and Visualize Diverse Data. *Serials Review, 45*(3), 184–188. https://doi.org/10.1080/00987913.2019.1644891

Bennbaia, S., Wazwaz, A., & Abujarbou, A. (2018). *Towards Sustainable Society: Design of Food Waste Recycling Machine*.

Boadi, D., Benchaar, C., Chiquette, J., & Massé, D. (2004). Mitigation strategies to reduce enteric methane emissions from dairy cows: Update review. In *Canadian Journal of Animal Science* (Vol. 84, Issue 3, pp. 319–335). Agricultural Institute of Canada. https://doi.org/10.4141/A03-109

Bragas, E., & Abundez, A. (2016). *A Case Study of Data Visualization in the Fire Safety Industry*. https://www.designmind.com/wp-content/uploads/DesignMind-Tableau-Dataviz-FireStats-Case-Study.pdf

Brancoli, P., Rousta, K., & Bolton, K. (2017). Life cycle assessment of supermarket food waste. *Resources, Conservation and Recycling*, *118*, 39–46. https://doi.org/10.1016/j.resconrec.2016.11.024

Brett, C. (2013). *Tackling waste in the global food supply chain | Guardian sustainable business | The Guardian*. https://www.theguardian.com/sustainable-business/food-waste-global-supply-chain

Broucek, J. (2014). Production of Methane Emissions from Ruminant Husbandry: A Review. *Journal of Environmental Protection*, *05*(15), 1482–1493. https://doi.org/10.4236/jep.2014.515141

Cakar, B., Aydin, S., Varank, G., & Ozcan, H. K. (2020). Assessment of environmental impact of FOOD waste in Turkey. *Journal of Cleaner Production*, *244*, 118846. https://doi.org/10.1016/j.jclepro.2019.118846

Caldeira, C., Corrado, S., & Sala, S. (2017). *Food waste accounting Methodologies, challenges and opportunities*. https://doi.org/10.2760/54845

Caldeira, C., De Laurentiis, V., Corrado, S., van Holsteijn, F., & Sala, S. (2019). Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. *Resources, Conservation and Recycling*, *149*, 479–488. https://doi.org/10.1016/j.resconrec.2019.06.011

Caro, M. P., Ali, M. S., Vecchio, M., & Giaffreda, R. (2018). Blockchain-based traceability in Agri-Food supply chain management: A practical implementation. *2018 IoT Vertical and Topical Summit on Agriculture - Tuscany, IOT Tuscany 2018*, 1–4. https://doi.org/10.1109/IOT-TUSCANY.2018.8373021

Cattaneo, A., Federighi, G., & Vaz, S. (2020). The environmental impact of reducing food loss and waste: A critical assessment. *Food Policy*, 101890. https://doi.org/10.1016/j.foodpol.2020.101890

Ciccullo, F., Cagliano, R., Bartezzaghi, G., & Perego, A. (2021). Implementing the circular economy paradigm in the agri-food supply chain: The role of food waste prevention technologies. *Resources, Conservation and Recycling*, *164*, 105114. https://doi.org/10.1016/j.resconrec.2020.105114

Commission on Environment, W. (1987). *Report of the World Commission on Environment and Development: Our Common Future Towards Sustainable Development 2. Part II. Common Challenges Population and Human Resources 4*.

Corrado, S., & Sala, S. (2018). Food waste accounting along global and European food supply chains: State of the art and outlook. In *Waste Management* (Vol. 79, pp. 120–131). Elsevier Ltd. https://doi.org/10.1016/j.wasman.2018.07.032

Čuček, L., Klemeš, J. J., & Kravanja, Z. (2012). A review of footprint analysis tools for monitoring impacts on sustainability. *Journal of Cleaner Production*, *34*, 9–20. https://doi.org/10.1016/j.jclepro.2012.02.036

De Laurentiis, V., Corrado, S., & Sala, S. (2018). Quantifying household waste of fresh fruit and vegetables in the EU. *Waste Management*, *77*, 238–251. https://doi.org/10.1016/j.wasman.2018.04.001

de Sadeleer, I., Brattebø, H., & Callewaert, P. (2020). Waste prevention, energy recovery or recycling - Directions for household food waste management in light of circular economy policy. *Resources, Conservation and Recycling*, *160*, 104908. https://doi.org/10.1016/j.resconrec.2020.104908

Depta, L. (2018). *Global Food Waste and its Environmental Impact | Green Living | RESET.org*. https://en.reset.org/knowledge/global-food-waste-and-its-environmental-impact-09122018

Dewan, P. (2015). Words Versus Pictures: Leveraging the Research on Visual Communication. *Partnership: The Canadian Journal of Library and Information Practice and Research*, *10*(1). https://doi.org/10.21083/partnership.v10i1.3137

Diaz-Ruiz, R., Costa-Font, M., López-i-Gelats, F., & Gil, J. M. (2019). Food waste prevention along the food supply chain: A multi-actor approach to identify effective solutions. *Resources, Conservation and Recycling*, *149*, 249–260. https://doi.org/10.1016/j.resconrec.2019.05.031

Dora, M., Biswas, S., Choudhury, S., Nayak, R., & Irani, Z. (2020). A system-wide interdisciplinary conceptual framework for food loss and waste mitigation strategies in the supply chain. *Industrial Marketing Management*. https://doi.org/10.1016/j.indmarman.2020.10.013

Duan, J., Zhang, C., Gong, Y., Brown, S., & Li, Z. (2020). A Content-Analysis Based Literature Review in Blockchain Adoption within Food Supply Chain. *International Journal of Environmental Research and Public Health*, *17*(5), 1784. https://doi.org/10.3390/ijerph17051784

Edjabou, M. E., Petersen, C., Scheutz, C., & Astrup, T. F. (2016). Food waste from Danish households: Generation and composition. *Waste Management*, *52*, 256–268. https://doi.org/10.1016/j.wasman.2016.03.032

Egilmez, G., Gumus, S., Kucukvar, M., & Tatari, O. (2016). A fuzzy data envelopment analysis framework for dealing with uncertainty impacts of input-output life cycle assessment models on eco-efficiency assessment. *Journal of Cleaner Production*, *129*, 622–636. https://doi.org/10.1016/j.jclepro.2016.03.111

Ejaz, N., Mehmood, I., Lee, J. J., Ji, S. M., Lee, M. H., Anh, S. M., & Baik, S. W. (2012). Interactive 3D visualization of soical network data using cloud computing. *Proceedings - International Conference on Cloud Computing and Social Networking 2012: Cloud Computing and Social Networking for Smart and Productive Society, ICCCSN 2012*. https://doi.org/10.1109/ICCCSN.2012.6215744

Elhmoud, E. R., & Kutty, A. A. (2020). Sustainability Assessment in Aviation Industry: A Mini-Review on the Tools, Models and Methods of Assessment. *International Conference on Industrial Engineering and Operations Management*, 7–10.

Eriksson, M., & Spångberg, J. (2017). Carbon footprint and energy use of food waste management options for fresh fruit and vegetables from supermarkets. *Waste Management*, *60*, 786–799. https://doi.org/10.1016/j.wasman.2017.01.008

Espinoza-Orias, N., Stichnothe, H., & Azapagic, A. (2011). The carbon footprint of bread. *International Journal of Life Cycle Assessment*, *16*(4), 351–365. https://doi.org/10.1007/s11367-011-0271-0

European Commission. (2010). *PREPARATORY STUDY ON FOOD WASTE ACROSS EU 27*. https://doi.org/10.2779/85947

European Commission. (2015). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. Closing the loop - An EU action plan for the Circular Economy*. https://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=CELEX%3A52015DC0614

FAO. (n.d.a). *Food groups and sub-groups | FAO/WHO GIFT | Food and Agriculture Organization of the United Nations*. Retrieved February 3, 2021, from http://www.fao.org/gift-individual-food-consumption/methodology/food-groups-and-sub-groups/en/

FAO. (n.d.b). *Food wastage footprint & Climate Change*. Retrieved February 6, 2021, from http://www.fao.org/3/a-bb144e.pdf

FAO. (2010a). *Greenhouse Gas Emissions from the Dairy Sector A Life Cycle Assessment*. http://www.foodsec.org/docs/GAUL_DISCLAIMER.pdf

FAO. (2010b). *Results | Global Livestock Environmental Assessment Model (GLEAM) | Food and Agriculture Organization of the United Nations*. http://www.fao.org/gleam/results/en/#c303615

FAO. (2013). *Food wastage footprint: Impacts on natural resources - Summary report*. www.fao.org/publications

FAO. (2014a). *SAFA SUSTAINABILITY ASSESSMENT OF FOOD AND AGRICULTURE SYSTEMS TOOL USER MANUAL VERSION 2.2.40*. http://www.fao.org/3/a-i4113e.pdf

FAO. (2014b). *The State of Food Insecurity in the World Strengthening the enabling environment for food security and nutrition*.

FAO. (2016). *The Global Dairy Sector: Facts*. https://www.fil-idf.org/wp-content/uploads/2016/12/FAO-Global-Facts-1.pdf

FAO. (2017a). *FAO - News Article: World hunger again on the rise, driven by conflict and climate change, new UN report says*. http://www.fao.org/news/story/en/item/1037253/icode/

FAO. (2017b). *Livestock solutions for climate change*.

http://www.fao.org/gleam/results/en/

FAO. (2018). *The Contribution of Agriculture to Greenhouse Gas Emissions*. http://www.fao.org/economic/ess/environment/data/emission-shares/en/

FAO. (2019). *Food loss and waste and value chains - Learning guide*. http://www.wipo.int/amc/en/mediation/rules

FAO Livestock Policy Brief. (n.d.). *Livestock Information, Sector Analysis and Policy Branch Animal Production and Health Division Pollution from industrialized livestock production*. Retrieved January 23, 2021, from http://www.fao.org/3/a-a0261e.pdf

Few, S. (2007). *Data Visualization - Past, Present, and Future*.

Fisher, K., & Whittaker, D. (2018). *Opportunities to Reduce Waste along the Journey of Milk, from Dairy to Home*. https://wrap.org.uk/sites/default/files/2020-10/WRAP-Report - Opportunities to reduce waste along the journey of milk PUB 11.2018.pdf

Flysjö, A. (2012). *Greenhouse Gas emissions in milk and dairy product chains improving the carbon footprint of dairy products* [AARHUS University]. www.digisource.dk

G. Hafner, J. Barabosz, F. Schneider, Dr. S. Lebersorger, S. Scherhaufer, H. Schuller, D. L. (2012). *Determination of discarded food and proposals for a minimization of food wastage in Germany*.

Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B., & Giljum, S. (2012). Integrating Ecological, Carbon and Water footprint into a “footprint Family” of indicators: Definition and role in tracking human pressure on the planet. *Ecological Indicators*, *16*, 100–112. https://doi.org/10.1016/j.ecolind.2011.06.017

Gao, A., Tian, Z., Wang, Z., Wennersten, R., & Sun, Q. (2017). Comparison between the Technologies for Food Waste Treatment. *Energy Procedia*, *105*, 3915–3921. https://doi.org/10.1016/j.egypro.2017.03.811

Grossi, G., Goglio, P., Vitali, A., & Williams, A. G. (2019). Livestock and climate change: impact of livestock on climate and mitigation strategies. *Animal Frontiers*, *9*(1), 69–76. https://doi.org/10.1093/af/vfy034

Gustavsson, J., Cederberg, C., & Sonesson, U. (2011). *Global Food Losses And Food Waste*. http://www.fao.org/3/a-i2697e.pdf

Hallström, E., Carlsson-Kanyama, A., & Börjesson, P. (2015). Environmental impact of dietary change: A systematic review. In *Journal of Cleaner Production* (Vol. 91, pp. 1–11). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2014.12.008

Hegnsholt, E., Unnikrishnan, S., Pollmann-Larsen, M., Askelsdottir, B., & Gerard, M. (2018). *TACKLING THE 1.6-BILLION-TON FOOD LOSS AND WASTE CRISIS*.

Holden, N. M., White, E. P., Lange, M. C., & Oldfield, T. L. (2018). Review of the sustainability of food systems and transition using the Internet of Food. *Npj Science of Food*, *2*(1), 1–7. https://doi.org/10.1038/s41538-018-0027-3

International Monetary Fund. Communications. (2019a). *Reaping What We Sow: Fighting Climate Change with Food*. https://www.imf.org/en/News/Podcasts/All-Podcasts/2019/12/10/nicoletta-batini-food

International Monetary Fund. Communications. (2019b). The Economics of Climate ©International Monetary Fund. Not for Redistribution. In *Reaping What We Sow: Smart changes to how we farm and eat can have a huge impact on our planet* (Vol. 56). INTERNATIONAL MONETARY FUND. https://doi.org/10.5089/9781498316880.022.A010

Jepsen, D., Ökopol, A. V., Eberle, U., Jacob, H., Znu, F., Prof, W., & Schomerus, T.

(2014). *Development of tools to prevent food waste*.

Jeswani, H. K., Figueroa-Torres, G., & Azapagic, A. (2021). The extent of food waste generation in the UK and its environmental impacts. *Sustainable Production and Consumption*, *26*, 532–547. https://doi.org/10.1016/j.spc.2020.12.021

Jurgilevich, A., Birge, T., Kentala-Lehtonen, J., Korhonen-Kurki, K., Pietikäinen, J., Saikku, L., & Schösler, H. (2016). Transition towards Circular Economy in the Food System. *Sustainability*, *8*(1), 69. https://doi.org/10.3390/su8010069

Kamilaris, A., Fonts, A., & Prenafeta-Boldύ, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. In *Trends in Food Science and Technology* (Vol. 91, pp. 640–652). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2019.07.034

Kim, B., Neff, R., Santo, R., & Vigorito, J. (2015). *The Importance of Reducing Animal Product Consumption and Wasted Food in Mitigating Catastrophic Climate Change*.

Kim, J., Abdella, G. M., Kim, S., Al-Khalifa, K. N., & Hamouda, A. M. (2019). Control charts for variability monitoring in high-dimensional processes. *Computers and Industrial Engineering*, *130*, 309–316. https://doi.org/10.1016/j.cie.2019.02.012

Kosseva, M., & Webb, C. (2020). Food Industry Wastes Assessment and Recuperation of Commodities. In *Food Industry Wastes*. Elsevier. https://doi.org/10.1016/c2018-0-01472-3

Kucukvar, M., Egilmez, G., & Tatari, O. (2016). Life Cycle Assessment and Optimization-Based Decision Analysis of Construction Waste Recycling for a LEED-Certified University Building. *Sustainability*, *8*(1), 89. https://doi.org/10.3390/su8010089

Kucukvar, M., Ismaen, R., Onat, N. C., Al-Hajri, A., Al-Yafay, H., & Al-Darwish, A.

(2019a). Exploring the Social, Economic and Environmental Footprint of Food Consumption: A Supply Chain-linked Sustainability Assessment. *2019 IEEE 6th International Conference on Industrial Engineering and Applications, ICIEA 2019*, 733–742. https://doi.org/10.1109/IEA.2019.8715234

Kucukvar, M., Onat, N. C., Abdella, G. M., & Tatari, O. (2019b). Assessing regional and global environmental footprints and value added of the largest food producers in the world. *Resources, Conservation and Recycling*, *144*, 187–197. https://doi.org/10.1016/j.resconrec.2019.01.048

Kucukvar, M., & Tatari, O. (2012). Ecologically based hybrid life cycle analysis of continuously reinforced concrete and hot-mix asphalt pavements. *Transportation Research Part D: Transport and Environment*, *17*(1), 86–90. https://doi.org/10.1016/j.trd.2011.05.006

Kumar, K., Bose, J., & Soni, S. K. (2018, October 9). A Generic Visualization Framework based on a Data Driven Approach for the Analytics data. *2017 14th IEEE India Council International Conference, INDICON 2017*. https://doi.org/10.1109/INDICON.2017.8487236

Kutty, A. A., & Abdalla, G. M. (2020). *Tools and Techniques for Food Security and Sustainability Related Assessments: A focus on the Data and Food Waste Management System*.

Kutty, A. A., Abdella, G. M., & Kucukvar, M. (2020a). Ridge Penalization-based weighting approach for Eco-Efficiency assessment: The case in the food industry in the United States. *IOP Conference Series: Materials Science and Engineering*, *947*(1), 012003. https://doi.org/10.1088/1757-899X/947/1/012003

Kutty, A. A., Abdella, G. M., Kucukvar, M., Onat, N. C., & Bulu, M. (2020b). A system thinking approach for harmonizing smart and sustainable city initiatives with

United Nations sustainable development goals. *Sustainable Development*, *28*(5), 1347–1365. https://doi.org/10.1002/sd.2088

Kutty, A. A., Yetiskin, Z., Abraham, M. M., Nooh, M. A., Kucukvar, M., & Abdella, G. M. (2020c). An Empirical Assessment on the Transportation Sustainability Indicators and their Impact on Economic Productivity. *Proceedings of the 5th NA Conference on Industrial Engineering and Operations Management*, 10–14.

Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R., Kitinoja, L., & Searchinge, T. (2013). *Reducing food loss and waste*. http://www.worldresourcesreport.org.

Loboguerrero, A. M., Thornton, P., Wadsworth, J., Campbell, B. M., Herrero, M., Mason-D'Croz, D., Dinesh, D., Huyer, S., Jarvis, A., Millan, A., Wollenberg, E., & Zebiak, S. (2020). Perspective article: Actions to reconfigure food systems. *Global Food Security, 26,* 100432. https://doi.org/10.1016/j.gfs.2020.100432

Markussen, M., Kulak, M., Smith, L., Nemecek, T., & Østergård, H. (2014). Evaluating the Sustainability of a Small-Scale Low-Input Organic Vegetable Supply System in the United Kingdom. *Sustainability,* *6*(4), 1913–1945. https://doi.org/10.3390/su6041913

Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Calvo, E., Priyadarshi, B., Shukla, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Pereira, J. P., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M., & Malley, J. (2019). *Climate Change and Land An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems Head of TSU (Operations) IT/Web Manager Senior Administrator*. www.ipcc.ch

Melikoglu, M., Lin, C. S. K., & Webb, C. (2013). Analysing global food waste problem: Pinpointing the facts and estimating the energy content. *Central European Journal* *of Engineering*, *3*(2), 157–164. https://doi.org/10.2478/s13531-012-0058-5

Midway, S. R. (2020). Principles of Effective Data Visualization. In *Patterns* (Vol. 1, Issue 9, p. 100141). Cell Press. https://doi.org/10.1016/j.patter.2020.100141

Moate, P. J., Williams, S. R. O., Grainger, C., Hannah, M. C., Ponnampalam, E. N., & Eckard, R. J. (2011). Influence of cold-pressed canola, brewers grains and hominy meal as dietary supplements suitable for reducing enteric methane emissions from lactating dairy cows. *Animal Feed Science and Technology*, *166–167*, 254–264. https://doi.org/10.1016/j.anifeedsci.2011.04.069

Montzka, S. A., Dlugokencky, E. J., & Butler, J. H. (2011). Non-CO 2 greenhouse gases and climate change. In *Nature* (Vol. 476, Issue 7358, pp. 43–50). Nature Publishing Group. https://doi.org/10.1038/nature10322

Morabito, V. (2016). Data Visualization. In *The Future of Digital Business Innovation* (pp. 61–83). Springer International Publishing. https://doi.org/10.1007/978-3-319-26874-3_4

Moss, A. R., Jouany, J.-P., & Newbold, J. (2000). Methane production by ruminants: its contribution to global warming. *Annales de Zootechnie*, *49*(3), 231–253. https://doi.org/10.1051/animres:2000119

Muralikrishna, I. V., & Manickam, V. (2017). Life Cycle Assessment. In *Environmental Management* (pp. 57–75). Elsevier. https://doi.org/10.1016/B978-0-12-811989-1.00005-1

Muthu., S. S. (2014). *Assessment of Carbon Footprint in Different Industrial Sectors, Volume 1*. Springer Verlag, Singapore.

Nairobi. (2016). *Quantifying environmental limits – a new approach*. United Nations Environment Programme (UNEP). https://www.unep.org/news-and-stories/story/quantifying-environmental-limits-new-approach

Notarnicola, B., Sala, S., Anton, A., McLaren, S. J., Saouter, E., & Sonesson, U. (2017a). The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. *Journal of Cleaner Production*, *140*, 399–409. https://doi.org/10.1016/j.jclepro.2016.06.071

Notarnicola, B., Tassielli, G., Renzulli, P. A., Castellani, V., & Sala, S. (2017b). Environmental impacts of food consumption in Europe. *Journal of Cleaner Production*, *140*, 753–765. https://doi.org/10.1016/j.jclepro.2016.06.080

Omolayo, Y., Feingold, B. J., Neff, R. A., & Romeiko, X. X. (2021). Life cycle assessment of food loss and waste in the food supply chain. In *Resources, Conservation and Recycling* (Vol. 164, p. 105119). Elsevier B.V. https://doi.org/10.1016/j.resconrec.2020.105119

Onat, N. C., Abdella, G. M., Kucukvar, M., Kutty, A. A., Al-Nuaimi, M., Kumbaroğlu, G., & Bulu, M. (2021). How eco-efficient are electric vehicles across Europe? A regionalized life cycle assessment-based eco-efficiency analysis. *Sustainable Development*, sd.2186. https://doi.org/10.1002/sd.2186

Onat, N., Kucukvar, M., Halog, A., & Cloutier, S. (2017). Systems Thinking for Life Cycle Sustainability Assessment: A Review of Recent Developments, Applications, and Future Perspectives. *Sustainability*, *9*(5), 706. https://doi.org/10.3390/su9050706

Opio C, Gerber P, Mottet A, Falcucci A, Tempio G, MacLeod M, Vellinga T, Henderson B, & Steinfeld. (2013). *Greenhouse gas emissions from ruminant supply chains*. Food and agriculture organization of the United Nations. www.fao.org/publications

Paes, M. X., de Medeiros, G. A., Mancini, S. D., Gasol, C., Pons, J. R., & Durany, X. G. (2020). Transition towards eco-efficiency in municipal solid waste management to reduce GHG emissions: The case of Brazil. *Journal of Cleaner Production*, *263*, 121370. https://doi.org/10.1016/j.jclepro.2020.121370

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 3065–3081. https://doi.org/10.1098/rstb.2010.0126

Parfitt, J., Woodham, S., Swan, E., Castella, T., & Parry, A. (2016). *Quantification of food surplus, waste and related materials in the grocery supply chain*. www.wrap.org.uk

Paritosh, K., Kushwaha, S. K., Yadav, M., Pareek, N., Chawade, A., & Vivekanand, V. (2017). Food Waste to Energy: An Overview of Sustainable Approaches for Food Waste Management and Nutrient Recycling. In *BioMed Research International* (Vol. 2017). Hindawi Limited. https://doi.org/10.1155/2017/2370927

Park, Y. S., Egilmez, G., & Kucukvar, M. (2015). A Novel Life Cycle-based Principal Component Analysis Framework for Eco-efficiency Analysis: Case of the United States Manufacturing and Transportation Nexus. *Journal of Cleaner Production*, *92*, 327–342. https://doi.org/10.1016/j.jclepro.2014.12.057

Patra, A. K. (2016). Recent advances in measurement and dietary mitigation of enteric methane emissions in ruminants. In *Frontiers in Veterinary Science* (Vol. 3, Issue MAY, p. 1). Frontiers Media S.A. https://doi.org/10.3389/fvets.2016.00039

Pocketbook, F. S. (2013). *Food Statistics Pocketbook 2013 in-year update*. www.nationalarchives.gov.uk/doc/open-govern-

Quested, T. (2009). *Household Food and Drink Waste in the UK*. www.wrap.org.uk

Raak, N., Symmank, C., Zahn, S., Aschemann-Witzel, J., & Rohm, H. (2017). Processing- and product-related causes for food waste and implications for the food supply chain. In *Waste Management* (Vol. 61, pp. 461–472). Elsevier Ltd. https://doi.org/10.1016/j.wasman.2016.12.027

Read, Q. D., Brown, S., Cuéllar, A. D., Finn, S. M., Gephart, J. A., Marston, L. T., Meyer, E., Weitz, K. A., & Muth, M. K. (2020). Assessing the environmental impacts of halving food loss and waste along the food supply chain. *Science of the Total Environment*, *712*, 136255. https://doi.org/10.1016/j.scitotenv.2019.136255

Rezaei, M., & Liu, B. (2017). Food Loss and Waste in the Food supply Chain. *International Nut and Dried Fruit Council*.

Ritchie, H., & Roser, M. (2020). CO_2 and Greenhouse Gas Emissions. *Our World in Data*. https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

Rodríguez-Enríquez, A. C., Alor-Hernández, G., Sánchez-Ramírez, C., & Córtes-Robles, G. (2015). Supply chain knowledge management: A linked data-based approach using SKOS. *DYNA*, *82*, 27–35. https://doi.org/10.15446/dyna.v82n194.54463

Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H., Nakamura, N., & Shiina, T. (2009). A review of life cycle assessment (LCA) on some food products. In *Journal of Food Engineering* (Vol. 90, Issue 1, pp. 1–10). Elsevier. https://doi.org/10.1016/j.jfoodeng.2008.06.016

Rübel, O., Weber, G. H., Huang, M. Y., Bethel, E. W., Biggin, M. D., Fowlkes, C. C., Luengo Hendriks, C. L., Keränen, S. V. E., Eisen, M. B., Knowles, D. W., Malik, J., Hagen, H., & Hamann, B. (2010). Integrating data clustering and visualization for the analysis of 3D gene expression data. *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, *7*(1), 64–79. https://doi.org/10.1109/TCBB.2008.49

Santagata, R., Ripa, M., Genovese, A., & Ulgiati, S. (2021). Food waste recovery pathways: Challenges and opportunities for an emerging bio-based circular economy. A systematic review and an assessment. In *Journal of Cleaner Production* (Vol. 286, p. 125490). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2020.125490

Scherhaufer, S., Moates, G., Hartikainen, H., Waldron, K., & Obersteiner, G. (2018). Environmental impacts of food waste in Europe. *Waste Management*, *77*, 98–113. https://doi.org/10.1016/j.wasman.2018.04.038

Scholz, K. (2013). *Carbon footprint of retail food wastage a case study of six Swedish retail stores*. Institutionen för energi och teknik Independent thesis.

Scholz, K., Eriksson, M., & Strid, I. (2015a). Carbon footprint of supermarket food waste. *Resources, Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2014.11.016

Scholz, K., Eriksson, M., & Strid, I. (2015b). Carbon footprint of supermarket food waste. *Resources, Conservation and Recycling*, *94*, 56–65. https://doi.org/10.1016/j.resconrec.2014.11.016

Shaikh, M. A., Kucukvar, M., Onat, N. C., & Kirkil, G. (2017). A framework for water and carbon footprint analysis of national electricity production scenarios. *Energy*, *139*, 406–421. https://doi.org/10.1016/j.energy.2017.07.124

SIANI. (2017). *Reducing food waste across global food chains*. https://www.siani.se/wp-content/uploads/2017/10/policy_brief.pdf

Slorach, P. C., Jeswani, H. K., Cuéllar-Franca, R., & Azapagic, A. (2019). Environmental and economic implications of recovering resources from food waste in a circular economy. *Science of the Total Environment*, *693*, 133516. https://doi.org/10.1016/j.scitotenv.2019.07.322

Solé, A., Miró, L., & Cabeza, L. F. (2018). Environmental Approach. In *High-*

Temperature Thermal Storage Systems Using Phase Change Materials (pp. 277–295). Elsevier Inc. https://doi.org/10.1016/B978-0-12-805323-2.00010-2

Solomon, S., Qin, D., Manning, M., Alley, R. B., Berntsen, T., Bindoff, N. L., ... & Wratt, D. (2007). *Technical summary*.

Staniškis, J. K. (2012). Sustainable consumption and production: How to make it possible. In *Clean Technologies and Environmental Policy* (Vol. 14, Issue 6, pp. 1015–1022). Springer Verlag. https://doi.org/10.1007/s10098-012-0535-9

Statista. (2017). *Food waste per capita of selected countries worldwide 2017* . https://www.statista.com/statistics/933059/per-capita-food-waste-of-selected-countries/

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & De Haan, C. (2006). *Livestock's long shadow environmental issues and options*. http://www.fao.org/3/a-a0701e.pdf

Stenmarck, A., Jensen, C., Quested, T., & Moates, G. (2016). *Estimates of European food waste levels*.

Stock, P., Campbell, H., & Rosin, C. (2012). *Food Systems Failure: The Global Food Crisis and the Future of Agriculture - Google Books*. https://books.google.com.qa/books?hl=en&lr=&id=dC9_6vYF6VAC&oi=fnd&pg=PP1&dq=Food+systems+failure&ots=VCTYF65x9M&sig=U9q1leUfn3jJZ10JfmmuccdrGqs&redir_esc=y#v=onepage&q=Food systems failure&f=false

Tan, A., O'Connor, C., Tostivint, C., & Mudgal, S. (2013). *Modelling of Milestones for achieving Resource Efficiency Turning Milestones into Quantified Objectives: Food waste*.

Tatari, O., & Kucukvar, M. (2012). Sustainability Assessment of U.S. Construction Sectors: Ecosystems Perspective. *Journal of Construction Engineering and*

Management, 138(8), 918–922. https://doi.org/10.1061/(asce)co.1943-7862.0000509

Teigiserova, D. A., Hamelin, L., & Thomsen, M. (2020). Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy. *Science of the Total Environment, 706*, 136033. https://doi.org/10.1016/j.scitotenv.2019.136033

Thyberg, K. L., & Tonjes, D. J. (2016). Drivers of food waste and their implications for sustainable policy development. In *Resources, Conservation and Recycling* (Vol. 106, pp. 110–123). Elsevier. https://doi.org/10.1016/j.resconrec.2015.11.016

Tian, F. (2017, July 28). A supply chain traceability system for food safety based on HACCP, blockchain & Internet of things. *14th International Conference on Services Systems and Services Management, ICSSSM 2017 - Proceedings*. https://doi.org/10.1109/ICSSSM.2017.7996119

Tonini, D., Albizzati, P. F., & Astrup, T. F. (2018). Environmental impacts of food waste: Learnings and challenges from a case study on UK. *Waste Management, 76*, 744–766. https://doi.org/10.1016/j.wasman.2018.03.032

Tonini, D., Wandl, A., Meister, K., Unceta, P. M., Taelman, S. E., Sanjuan-Delmás, D., Dewulf, J., & Huygens, D. (2020). Quantitative sustainability assessment of household food waste management in the Amsterdam Metropolitan Area. *Resources, Conservation and Recycling, 160*, 104854. https://doi.org/10.1016/j.resconrec.2020.104854

UNECE. (n.d.). *The Challenge | Methane Management*. Retrieved February 13, 2021, from https://unece.org/challenge

United Nations. (2015). World population prospects: The 2015 Revision, Key Findings and Advance Tables. In *United Nations*.

van de Kamp, M. E., van Dooren, C., Hollander, A., Geurts, M., Brink, E. J., van Rossum, C., Biesbroek, S., de Valk, E., Toxopeus, I. B., & Temme, E. H. M. (2018). Healthy diets with reduced environmental impact? – The greenhouse gas emissions of various diets adhering to the Dutch food based dietary guidelines. *Food Research International*, *104*, 14–24. https://doi.org/10.1016/j.foodres.2017.06.006

Vellido, A., Martín, J. D., Rossi, F., & Lisboa, P. J. G. (2011). *Seeing is believing: The importance of visualization in real-world machine learning applications*. http://crispdm.wordpress.com/2007/03/13/exploration-can-anyone-out-there-explain-it/

Venkat, K. (2012). The Climate Change and Economic Impacts of Food Waste in the United States | Venkat | I. *International Journal on Food System Dynamics*, *2*. http://centmapress.ilb.uni-bonn.de/ojs/index.php/fsd/article/view/247/182

Vidergar, P., Perc, M., & Lukman, R. K. (2021). A survey of the life cycle assessment of food supply chains. *Journal of Cleaner Production*, *286*, 125506. https://doi.org/10.1016/j.jclepro.2020.125506