Dairy Wastage Footprint Analysis: A Farm-to-Fork Life Cycle Approach Across Dairy Supply Chain.

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Abstract

Decarbonizing practices in the food industry act as an obstacle in achieving sustainability despite climate change concerns. Roughly one-third of all food produced globally is wasted across the value chain generating 1.6 billion tons of food waste. Regardless of efforts to decrease carbon emissions from the agri-food system, the agricultural sector generates approximately 4.4 gigatonnes of greenhouse gas emissions annually from natural sources for producing food that is ultimately lost along the food supply chain. Although the dairy sector is a primary source of milk, cheese, yogurt, and cream, livestock's supply chain, including their wastes, releases a considerable greenhouse gas such as methane, nitrous oxide, and carbon dioxide. The presented paper has proven that food waste in mass does not necessarily indicate the corresponding food waste-related emissions. Animal-containing products have comparatively low waste in terms of mass. However, the polluting emissions released from the dairy sector are relatively high regarding global warming potential (Kg C02 eq) and carbon footprint. The study results showed that milk dominates the majority of carbon intensity accounted for 50%, followed by cheese 24%, yogurt 20%, and cream 7%. The consumption stage responsible for 50% of dairy food waste in terms of mass. In contrast, the primary production stage accounts for the majority of the dairy sector's carbon intensity. The paper provides recommendations on research direction for mitigating food waste and supports the transitions towards a sustainable food system.

Keywords: Carbon Footprint, Dairy Waste, Waste Management, Sustainability Assessment.

1. Introduction

The livestock sector has acquired extensive focus from several researchers for the prospective contribution of ruminant animals to increase polluting emissions and other ecological aspects (Steinfeld et al., 2006). Discarded edible food generates waste, which causes the loss of several valuable sources subjected to deficiency, consisting of waste, land, and fuel for electrical energy (Depta, 2018). Roughly 4.4 gigatonnes of greenhouse gas emissions are released each year from natural sources for producing food ultimately lost along the food supply chain (Rezaei and Liu, 2017). The excessive loss of natural resources along the value chain is an emerging critical global issue (Hegnsholt et al., 2018). Although some food waste components are unavoidable, minimizing food waste volume will significantly impact global food security and sustainable agricultural development (Gheorghescu and Balan, 2019). Tackling food waste in an integrated sustainable way is increasingly seen as the right opportunity to feed individuals worldwide and enhance natural and economic resources simultaneously (Rezaei and Liu, 2017).

Decomposed discarded foods kept in the garbage dumps generate methane (Alsarayreh et al., 2020), a powerful GHG with a GWP of 25, even more than carbon dioxide (Depta, 2018). The carbon footprint released from the food waste, including dairy waste products, is estimated at 3.3 billion tonnes of carbon dioxide equivalent annually (FAO, 2013). Eco-efficiency supports the transition towards a sustainable agricultural system (Abdella et al., 2021a); Kutty et al., 2020); (Abdella et al., 2021b). Approximately 60% of global methane emissions are raised by human activities (UNECE, n.d.). The agricultural industry, including the livestock dairy sector, is one of the primary contributors to anthropogenic methane emissions (Saunois et al., 2016). According to FAO (2013), the agricultural sector is in charge of most plant risks and animal species. The reduction of polluting emissions plays a substantial role in achieving a healthy environment making the world much more inhabitable (Scholz, 2013).

Ruminant animal activities significantly affect numerous aspects of the environment. Nearly all ecological elements, including air, water, land, climate change, and also biodiversity, are drastically affected by the production of dairy products of the livestock sector (Steinfeld et al., 2006). The livestock production system of dairy products is

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continuously contributing to influence the water, land, biodiversity resources, climate change, and polluting gases (FAO, 2010, 2016, 2017). Animals and their wastes contribute directly and indirectly through grazing and feed crop production to climate change (Steinfeld et al., 2006). Unsurprisingly, the ruminant animals share approximately 18% of GHG anthropometric emissions measured in carbon dioxide equivalent (Steinfeld et al., 2006). The livestock field shares a substantial quantity of greenhouse gases, estimated by 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 generated by the livestock sector, is roughly 296 times greater than the warming potential of carbon dioxide (FAO, 2005).

2. Research Rationale

Minimizing dairy product's food waste has been expanding research interest in the agricultural industry (Raak et al., 2017). Several efforts, researches, and initiatives are intended to enhance food waste problems, elevate individuals' recognition, and foster partnership throughout the food supply chain to minimize food waste as well as equivalent emissions (SIANI, 2017). Nonetheless, research on food waste is still an emerging field as expertise and knowledge are absent regarding dairy value chain function, the quantity of food being thrown away along the dairy value chain, and the corresponding causes of food waste internationally (SIANI, 2017). Ruminant animals are a substantial source of meat and milk products; nevertheless, animals' supply chain, including their wastes, releases a significant greenhouse gas such as methane, nitrous oxide, and carbon dioxide (FAO, 2017); (Kim et al., 2015). According to FAO (2010), the dairy value chain emissions from the livestock sector accounted for approximately 50% methane, 24% nitrous oxide, and 26% carbon dioxide. Batini (2019) has proven that the livestock sector emissions are equivalents to all the world's emissions from cars, trucks, airplanes.

Recent research has shown that animal-containing food waste, consisting of dairy food waste products, is progressively seen as a potential factor affecting the environment. Despite its relatively low waste in mass, animal-containing food waste has the bulk share of discharges related to climate change classification (Brancoli et al., 2017). These results are acknowledged by Jeswani et al. (2021) and Scherhaufer et al. (2018), revealing that although livestock food waste, including dairy products, stands for only 10% of the total food waste, their substantial factors of food waste-related emissions is relatively high. FAO showed the distribution of dairy food waste along Food Supply Chain (FSC), as shown in Figure 1. Dairy waste mainly occurs during the consumption stage, especially in Europe, America, and Asia. Carr et al. (2014) have shown that most UK dairy waste occurs in the consumption stage.

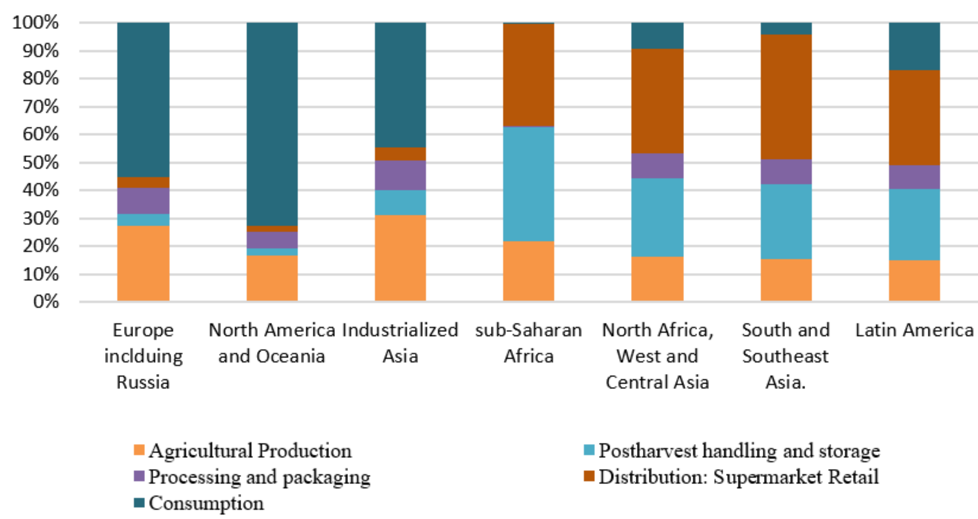

Figure 1. Percentage of dairy food waste, including milk, along with FSC at different regions.

The existing food system failed to secure dairy food products for humanity and respect the maximum limit of anthropometric emissions (Loboguerrero et al., 2020). As pointed previously, the dairy industry encounters actual difficulty in raising food manufacturing to fulfill population growth needs and lowering greenhouse gas emissions. The anthropometric dairy emissions are not purely restricted to carbon dioxide, one of the leading chemical gases contributing significantly to the greenhouse effect. Carbon dioxide is not the only factor in greenhouse gases (Khalil, 1999). Various polluting gasses such as methane, oxide, nitrous, and ozone-depleting substances likewise influence

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the planet's environment. According to Montzka et al. (2011), the agricultural industry releases several non$-CO_2$ emissions are contributing to the total anthropogenic emissions. 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.

3. Research Methodology

Life cycle assessment is a commonly used tool for assessing the environmental impact of the product's life cycle stages (Roy et al., 2009); (Elhmoud and Kutty, 2021); (Onat et al., 2021). In this study, farm-to-fork lifecycle-based assessment is used within the dairy value chain context, comprising dairy production, processing and packaging, retail and distribution, and consumption. Figure 2 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 dairy products and emissions from waste treatment management are excluded from the study.

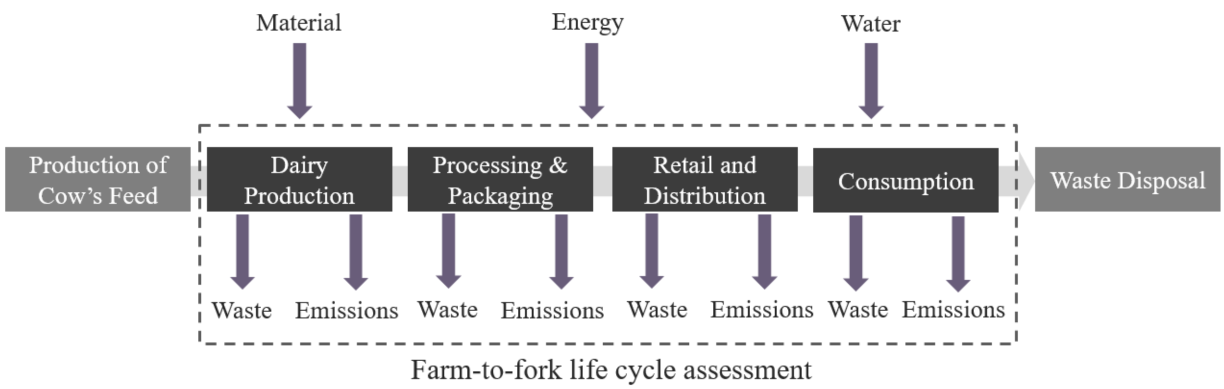

Figure 2. The system boundary of dairy food waste and waste-related emissions.

Milk and milk products are divided into four categories: milk, fragmented milk product, cream, and cheese, as shown in Table 1. Milk is the first category comprising only fresh and processed milk, where fermented milk products such as whey, cheese, and other milk products are excluded. The second category is fermented milk products, including fermented milk products such as flavored and non-flavored yogurts, sour and fermented milk. Cream and cheese are the third and fourth dairy food categories corresponding to their definitions are shown in Table 1. Making use of a common food classification and standard food definitions based on FAO definitions contributes to harmonizing food data globally and reaching coordinated and consistent outcomes.

Table 1. Milk and milk product categories are classified based on FAO definitions.

Dairy Categories	Definition
Milk	Fresh and processed milk are considered in the milk dairy category. Processed fermented milk products including, yogurt, cream, whey, butter, cheese, and other milk products, are excluded from this category. The milk considered in this category is obtained from cattle and mammals. 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.
Fermented milk products	Fermented milk products, including yogurts, kephir, kumis, and fermented milk, flavored and non-flavored manufactured commodities derived from mammal's milk, fall 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 category. As

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	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 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.

Milk and milk product's carbon footprint (CF) values are expressed in carbon dioxide equivalent per product (kg). Gasses such as carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) are comprised 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). The wastage CF is acquired from the existing literature on dairy food waste based on Flysjö (2012). There are mainly four dairy food waste products, as shown in Table 2, corresponding to their wastage CF. The wastage CF for each dairy waste category is split into four stages considering farm-to-fork lifecycle-based assessment starting from the farm level up to the consumption phase. The categorization of the wastage CF of the dairy products followed each dairy waste category initiated by Flysjö (2012). For example, whole milk, semi-skimmed milk, and skimmed milk fall under the milk category and similarly for cheese, yogurt, and cream. Throughout the presented study, the carbon footprint of dairy food waste along the dairy value chain will be calculated to analyze the discrepancies between dairy food waste quantities, mass, and wastage carbon footprint derived from dairy food products.

Table 2. Carbon footprint (kg CO2e per kg product) of different dairy products.

Dairy Category	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

In this study, the wastage carbon footprint for all dairy food waste categories has been calculated to assess the environmental impact of dairy food waste from farm-to-fork lifecycle-based assessment, including primary production, processing, retailing, and consumption. Equation (1) is used for calculating the total environmental impact of food waste at the primary production stage ($I_{FW/PP}$). The impact for the processing, retailing, and consumption stage will be calculated likewise. Equation (2) calculated the environmental impact of milk at the primary production stage, which will also be applied to cheese, yogurt, and cream. Equation (3) is mainly used for calculating the total impact of food waste (I_{MW}) along the dairy value chain, including primary production ($I_{MW/PP}$), processing ($I_{FW/FP}$), distribution & retail ($I_{FW/RD}$), and consumption ($I_{FW/FC}$).

$$\sum I_{FW/PP} = I_{PP1\text{-}9} * m_{FW1\text{-}9/PP} + I_{PP1\text{-}9} * m_{FW1\text{-}9/FP} + \ldots + I_{PP1\text{-}9} * m_{FW1\text{-}9/FC} \quad (1)$$

$$\sum I_{MILK/PP} = I_{PP/MILK} * [m_{MILK/PP} + m_{MILK/FP} + m_{MILK/RD} + m_{MILK/FC}] \quad (2)$$

$$\sum I_{FW} = \sum I_{FW/PP} + \sum I_{FW/FP} + \sum I_{FW/RD} + \sum I_{FW/FC} \quad (3)$$

These three equations have been used to obtain the numerical values for food waste in mass and food waste-related impact, which will be later processed and visualized into Microsoft Excel and Microsoft Power BI to create customized visualization dashboards. The dairy food waste data are mainly collected from FAOSTAT & OECD online databases. To avoid misleading or inaccurate visualization results, data has been categorized, cleaned, and filtered based on the study's objective. Figure 3 shows the sequential steps of data visualization, from collecting data to categorizing, cleaning, and eventually visualization to provide an interactive, customizable dashboard. Microsoft Power BI can picture information derived from multiples resources right into aesthetic figures, charts, and graphs that are understandable with the capability to share numerous dashboards and control data in real-time (Becker and Gould, 2019).

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Figure 3. Data visualization steps.

4. Results and Discussion

The outcome of the presented study is mainly split into three substantial subsections, namely, a) developing a comprehensive picture of food waste impact assessment in Europe as an attempt to identify the position of dairy waste among other food waste categories b) quantifying the four categories of dairy food waste accumulated from farm-to-fork life cycle based assessment and, c) evaluating the corresponding wastage carbon footprint released from dairy waste emissions to identify the stages along the value chain that contribute potentially to the dairy food waste-related emissions. This section compares and discusses the wastage carbon footprint of dairy waste categories highlighting the dairy value chain stages responsible for accumulating food waste.

4.1 Food Waste Related Impact Assessment

Analyzing food waste environmental impact is progressively seen as a vital aspect due to its considerable contribution to anthropometric emissions and global warming potential (Al-Rumaihi et al., 2020). The first interactive dashboard provides insight into the environmental impact, explicitly the global warming potential measured in 1000 tonnes of carbon dioxide equivalent, of nine food waste categories. The Global Warming Potential (GWP) for different food waste categories, including dairy/milk waste products, is analyzed considering the four main supply chain stages: production, processing, retailing, and consumption. Animal-containing food wastes, including milk, beef, pork, chicken, and other categories such as bread, tomato, and potato, are considered as shown in Figure 4. The dashboard shows the percentage share of dairy waste along the supply chain regarding mass and their corresponding global warming potential. Animal-containing food waste, comprising dairy milk, represents a significant factor of food waste coupled with the global warming potential emissions. As shown in Figure 4, dairy milk occupied the 4th most wasted food category among all different waste categories contributing to global warming potential. Although animal-containing food waste, mainly beef, has comparatively low waste in mass, their contribution to the environment is relatively high. Therefore, food waste in mass does not necessarily indicate the environmental impact released from the dairy waste sector.

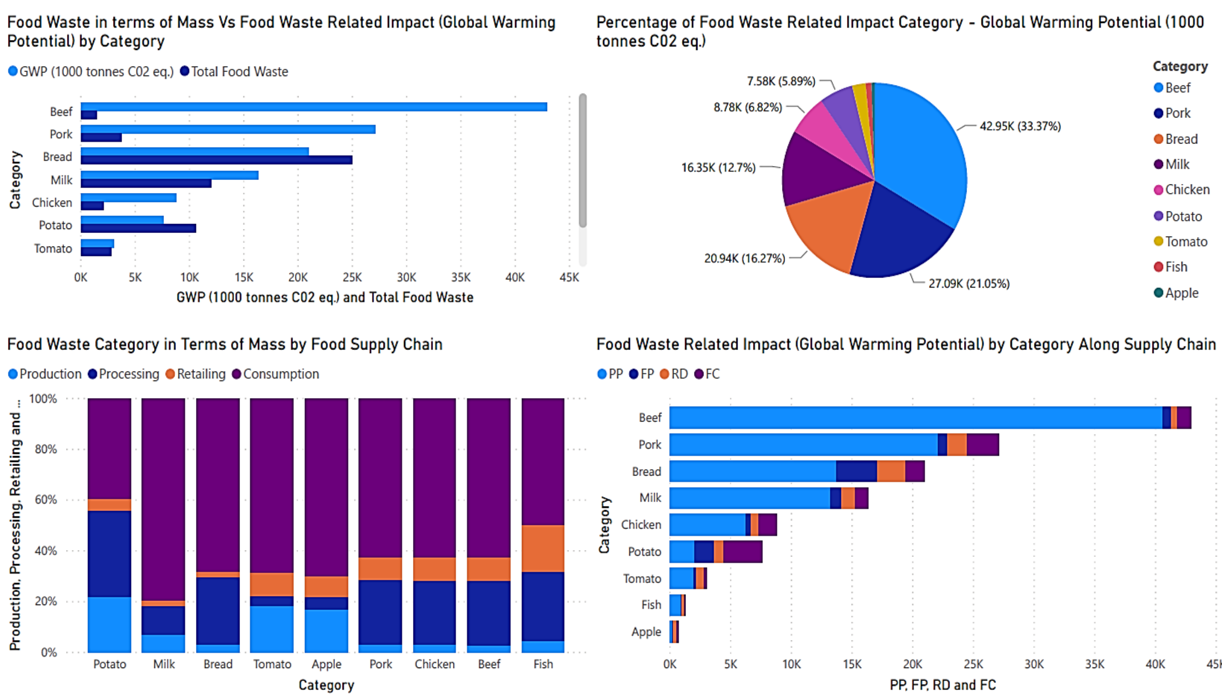

Figure 4. Food Waste Related Impact Assessment (Dashboard 1).

In this study, customizable dashboards are presented to fit the purpose of each section. For example, the first dashboard is customized and divided into four main visual elements, including charts and graphs, as shown in Figure 4. The

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interactive dashboard shown in Figure 4 is customized and divided into four main visual elements, including charts and graphs. The top-left portion shows the food waste categories mass chart compared to the corresponding global warming potential measured in 1000 tonnes CO2 eq. The top-right pie chart illustrates the percentage share of food waste global warming impact categories showing that milk is one of the top four wastage categories responsible for food waste-related impact. The bottom-left chart demonstrates the percentage waste in terms of mass along the value chain, showing that most food waste categories, including milk food waste, are wasted mainly in the consumption stage. Nonetheless, food waste-related impacts derived from animal-containing products are originated from the production stage, as shown in the bottom-right chart.

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 chains. The section digs down into dairy food waste categories along the value chain from farm-to-fork, including producing, processing, retailing, and consuming. Figure 5 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.

Practical initiatives have been started to measure food waste driven by the demand to confine the range of food waste worldwide (Parfitt et al., 2010). This section digs down to quantify and visualize the four categories of dairy food waste accumulated from farm to fork along the value chain, including producing, processing, retailing, and consuming. As pointed previously, customizable dashboards are generated depending on the purpose of the visualization dashboard. Figure 5 shows the 2nd interactive dashboard used for visualizing the dairy waste products across the dairy value chain divided into two main visual elements. The left side highlights dairy waste products and demonstrates a miniature online globe map revealing the five leading countries contributing to dairy waste. In contrast, the opposite right-side shows the accumulation of dairy food waste per stage responsible for dairy waste volume. It additionally reveals the various dairy products waste groups at various phases in the food supply chain.

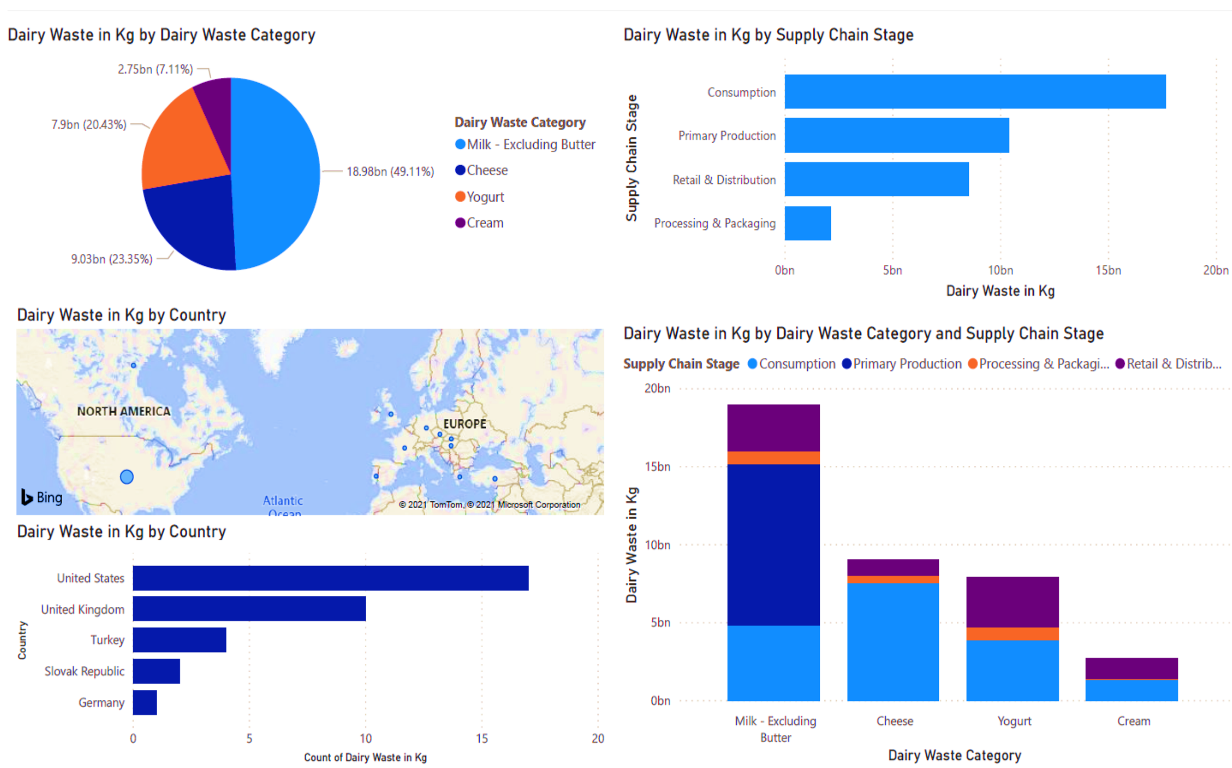

Figure 5. Dairy food waste is categorized by product across the food supply chain (Dashboard 2).

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The outcomes reveal that dairy food waste categories, comprising milk, cream, yogurt, and cheese, are primarily lost at the consumption phase. Several studies pointed out that food waste mainly occurs in the consumption supply chain stage including (Caldeira et al., 2019); (Carr et al., 2014). According to Gustavsson et al. (2011), roughly 40-65% of total food waste occurs at the consumption level, especially in Europe, North America, Oceania, and industrialized areas. A report initiated by FAO (2019), showed the real causes behind wasting food, mostly at the consumption level. Excessive food is being wasted during vacations, religious holidays, weddings, ceremonies, gatherings, restaurants, and hotels. Although the share percentage of dairy food waste differs among different geographical locations, dairy waste in terms of mass mainly occurs at the consumption level, followed by production/manufacturing, processing, and retailing. In terms of dairy waste ranking, milk is the topmost wasted category accounted for almost 50% of dairy food waste along the value chain, followed by cheese 23%, yogurt 20%, cream 8%. The result is acknowledged by Tonini et al. (2018), revealing that milk is one of the most wasted dairy products standing for nearly 50% of the United Kingdom's dairy food waste. As illustrated in Figure 5, The United States dominates most dairy waste quantities, followed by the United Kingdom, Turkey, the Slovak Republic, and Germany.

4.3 Wastage Carbon Footprint of Dairy Products.

Measuring the wastage carbon footprint enables a sustainable agricultural system (Scholz et al., 2015). This section demonstrates the released emissions from the dairy sector and explains the discrepancy between dairy waste in terms of mass and dairy waste-related emissions. The 3rd interactive dashboard, as shown in Figure 6, is customized and split right into two main portions. As illustrated in Figure 6, the left-hand portion compares the share percentage of the dairy waste categories and the wastage carbon footprint against different countries. Likewise, the right-hand portion shows a dairy waste pie chart compared to wastage CF providing details related to CO2-eq emissions along different stages along the dairy value chain.

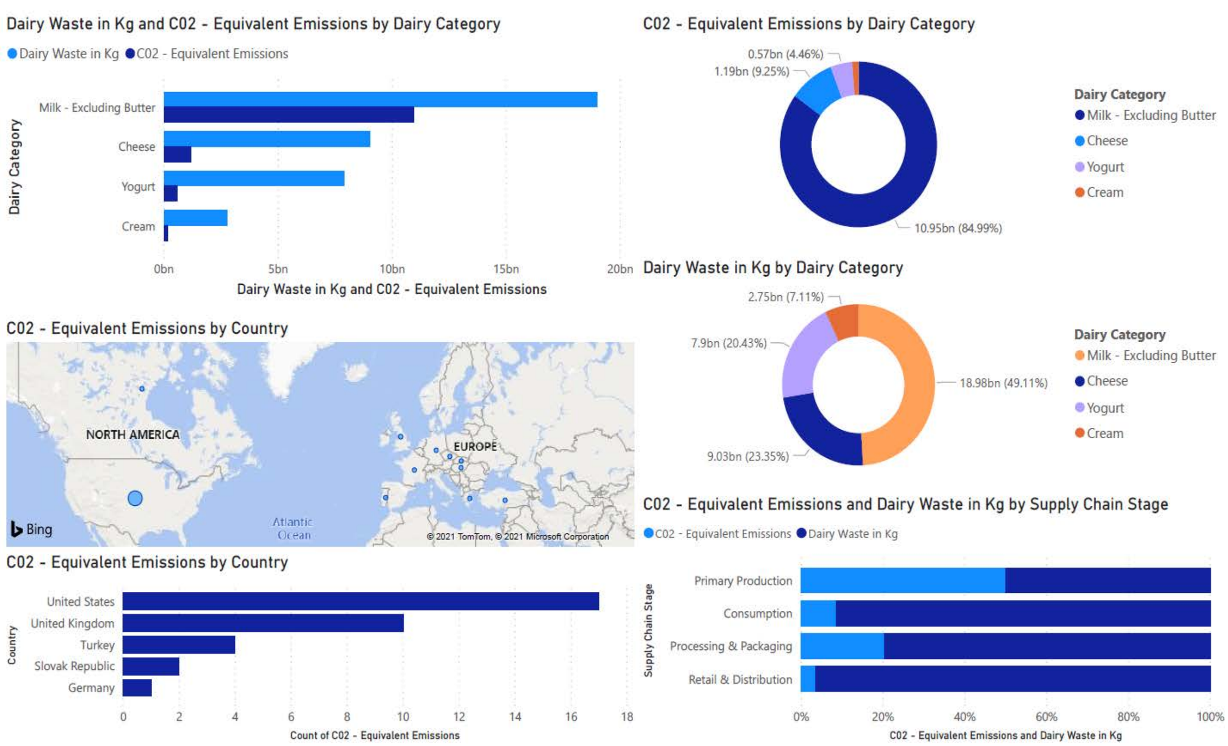

Figure 6. The wastage carbon footprint of dairy products (Dashboard 3).

The results reveal that dairy food waste emissions mainly occur in the primary account for almost 50% of the wastage carbon footprint, followed by processing 20%, consuming 10%, and retailing 5%, as shown in Figure 6. Even though food consumption is accounted for the majority of food waste-related impacts (Notarnicola et al., 2017); (Tan et al., 2013); (Scialabba, 2015), the production stage is in charge of carbon footprint intensity in the dairy sector. This result is acknowledged by Scherhaufer et al. (2018), verifying that the GHG emissions drive the majority of the ecological impact of animal-containing food waste at the production level. . Besides the wastage CF originated from the dairy

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food waste at the primary production, methane representing the potent source of GHG emissions, are also generated during the natural enteric fermentation process of ruminant animals (Broucek, 2014); (Moss et al., 2000); (Alemu et al., 2011).

Dairy food waste categories, including milk and milk products, intensifies carbon footprinting. As pointed out earlier, milk is the top dairy waste category responsible for most dairy waste along the value chain. Similarly, milk dominates most carbon intensity representing around 50%, followed by cheese 24%, yogurt 20%, and cream 7%, as shown in Figure 6. The equivalent carbon emissions for each dairy waste category and the percentage share are summarized in Table 3. Carbon intensity varied based on the geographical location depending on their manufacturing system as well as management techniques (Opio et al., 2013); (Alamar et al., 2018); (Venkat, 2012), (Cakar et al., 2020). When it comes to wastage CF among different geographical locations, United States occupies the first place in wastage carbon footprinting of dairy products, followed by the United Kingdom, Turkey, Slovak Republic, and Germany.

Table 3. 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%

5. Conclusion and Recommendations

Analyzing the wastage carbon footprint of dairy categories is required as animal-containing products tend to be responsible for most environmental factors related to carbon emissions. Therefore, it becomes substantial to mitigate the wastage CF across the value chain (Scholz et al., 2015). The presented study intends to emphasize that quantifying dairy food waste is not enough as it does not provide adequate information on dairy waste-related impact. Throughout this research work, three main integrated visualization dashboards are created to provide a clear understanding to recognize the position of dairy waste amongst various other food waste groups, evaluate various dairy products food waste products, and analyze the wastage CF released from dairy products in different geographical locations.

Even though the ideal method of reducing food waste is by saving it, some food waste categories are unpreventable. There is an emerging need for undertaking policy recommendations to adopt practical procedures to mitigate food waste burdens (Paritosh et al., 2017). The authors recommend the following actions to mitigate the catastrophic impact of dairy food waste along the value chain instead of focusing on a single solution:

1. A circular food economy tends to reduce the catastrophic impact of food waste along the value chain (Kucukvar et al., 2019; Kucukvar et al., 2019a; Kutty and Abdella., 2020). Instead of discarding dairy food waste in landfills emitting around 95% of GHG emissions (Melikoglu et al., 2013); (Gao et al., 2017). Food waste can be treated and recycled to generate organic fertilizers. Over the last decades, different food waste management techniques have been established to treat food waste, including anaerobic digestion, in-vessel digestion, and waste composting (de Sadeleer et al., 2020); (Slorach et al., 2019); (Tonini et al., 2020); (Paritosh et al., 2017).
2. Blockchain modern technology has been recognized as an effective alternative to improve the procedure of tracking, transferring, and marketing food electronically in the agricultural industry (Kamilaris et al., 2019). Blockchain provides detailed, clear, and accurate details about the food items being shipped, including their batch number, storage temperature, expiry date, and shipping details stored in blocks (Caro et al., 2018). Blockchain technology works by storing tracking records of food batches in blocks along every stage of the food supply chain. Such technology allows food traceability, supply chain transparency, and audibility, which eventually reduces the amount of food being wasted along the value chain (Kamilaris et al., 2019); (Duan et al., 2020); (Tian, 2017).
3. Innovative food waste management technologies should be adopted to ensure the transition towards sustainable agricultural systems. According to Babbitt (2017), the current waste treatment options are not offering an environmentally sustainable solution for food waste management as it is still facing economic and technological obstacles. Therefore, establishing innovative food waste treatments that avoid endangering human health without enforcing extra prices or harming the environment is critically needed to reduce food waste risks (Arvanitoyannis, 2008).
4. Raising public awareness about food waste prevention plays a vital role in triggering the changes, reducing the waste. Developing alternatives for saving food such as shop smart, save leftovers, and donate might be useful. As pointed previously, dairy food waste mainly occurs at the consumption level; therefore consumers' motivation to

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avoid food waste should be prioritized as it has a tremendous influence on the consumer's food waste behaviors (Aschemann-Witzel et al., 2015).

5. Adopting sustainable governmental protocol is progressively viewed as a vital element in tackling and assessing food waste accumulated along the dairy value chain (Lipinski et al., 2013). Sustainable is of profound significance (Kutty at al., 2020a); (Kutty et al., 2020b). There are no feasible actions that can be applied to decrease food waste-related problems if food waste is not determined or measured.

In addition, cutting down carbon emissions along the value chain requires a thorough understanding of various tools and techniques used in food sustainability assessment (Kutty and Abdella 2020; Kutty et al., 2020b; Alsarayreh et al., 2020). Statistical and machine learning techniques provide integrated insights on food waste management (Abdella et al., 2020; Kutty et al., 2020b). Integrated and holistic frameworks based on machine learning techniques become necessary when addressing the sustainability concerns across the food industry from multiple dimensions (Abdella et al., 2020). Kucukvar et al. (2019) applied statistical techniques to provide a comprehensive understanding across the 4 sustainability metrics, including carbon footprint, to globally analyze the environmental and socioeconomic impacts of the largest food producers. In the context of statistical techniques, the authors suggest applying time series analysis, factor analysis, correlation, and online control charts for detecting any fluctuations that might occur in sustainability assessment of the food industry over time (Abdella et al., 2017; Kim et al., 2019; Yang et al., 2012). The multiple objective-based best-subset approaches adopted by Abdella et al. (2019) can also promote the accuracy of the sustainability assessment in the food industry. To better understand several empirical assessment techniques that can widely be applied in the field of sustainability research, the readers can refer to Abdella et al. (2016), Abdur-Rouf et al. (2018), Al-Sheeb et al. (2019), Abdella et al. (2019a), Abdella and Shaaban, (2020), Abdella et al., (2020a). Also, recycling food waste using food recycling machines and converting food waste into fertilizers can reduce food waste-related emissions. Finally, although the sustainable alternatives for mitigating food waste across the value chain can reduce GHG emissions, it is everyone's responsibility to save food across the value chain and reduce the amount of food waste accumulation across the global food value chain.

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