Transformation of food systems considering the SDGs nexus and spillover effects

Food Security and the SDGs: The Role of Food Loss and Waste Control for its Accomplishing

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Abstract:

Worldwide, the number of people suffering from hunger is around 702 and 828 million, and 2.3 billion people have moderate or severe food insecurity. This situation is striking, considering that the vast amount of food discarded globally equals 1.3 billion tons annually. For this reason, in 2015, world leaders agreed to a global agenda for 2030, adopting the Sustainable Development Goals (SDGs). Among its objectives are to fight against poverty, hunger, and gender inequality worldwide and achieve environmental sustainability. With this framework, this article uses a top-down mass balance approach to calculate food loss and waste (FLW) by country's food security level. In addition, it explores the causes of FLW and its impacts on natural resources, climate change, food security, and the SDGs in countries with a weak and moderate level of food security. The estimated global FLW was 1498 million tons of food in 2017. The most food discarded was concentrated in countries with good food security, 894.3 million tons. In contrast, the lowest food discard occurred in countries with a weak level of food security, 11.4 million tons. The primary outcome of this paper is to establish a link between the levels of food security and food loss in different countries, which may serve as a guide for the design of specific public policies.

1. Introduction

Food poverty and insecurity affect broad population groups observing that in high-income countries, the everyday wastage of food has risen significantly, which has increased public attention (Galli et al., 2019). In 2021, approximately 702 and 828 million people worldwide were affected by hunger, and around 2.3 billion people had moderate or severe food insecurity (FAO, 2022). According to (Von Grebmer et al., 2020), global hunger was moderate in 2020, with a Global Hunger Index (GHI) score of 18.2, down from a severe level of 28.2 in 2000. However, hunger is a significant issue throughout South Asia (26.0) and

sub-Saharan Africa (27.8), partly because of undernourishment and child stunting. Moreover, the highest child mortality and wasting rates are in Africa (south of the Sahara) and South Asia. Looking by country, 31 countries have severe levels of hunger, and three countries have alarming levels. The COVID-19 pandemic and the prolonged war between Russia and Ukraine have caused a global economic recession and jeopardized food security, primarily related to the agricultural labor mobility restrictions (Corrado and Palumbo, 2022) and changes in imports of Ukrainian grains and Russian fertilizers (Celik and Dane, 2020; Janssen et al., 2021). In this context, the attention to the importance of food loss and waste becomes relevant due to the enormous amount of food lost in value chains.

The Food and Agriculture Organization (FAO) estimated in 2011, that globally, the amount of food discarded annually is equivalent to 1.3 billion tons per year. The situation is even more worrying when considering that for every ton of food produced and not consumed, significant amounts of labor, natural resources, and capital are also wasted (Shafiee-Jood and Cai, 2016; Sun et al., 2018). Resultantly, the adverse effects of FLW on the environment are multiple (FAO, 2013); they cause negative impacts on water, land, climate changes, and biodiversity (Feldstein, 2017; Skawińska and Zalewski, 2022).

During the term of the Millennium Development Goals (MDGs), worldwide efforts and initiatives were implemented to address the reduction in poverty and hunger and ensure trends of global environmental sustainability (UN, 2015). The agenda for 2030 is the continuity of these goals by establishing the 17 Sustainable Development Goals (SDGs). SDGs took up the commitment to achieve food security and solve environmental problems. FLW negatively impacts food security and the environment, hindering the achievement of SDGs (Dal'Magro and Talamini, 2019). SDG 1, "No Poverty," and SDG 2, "Zero Hunger", are related to food security. SDGs 6, 7, 11, 12, 13, 14, and 15 are connected directly or indirectly to the environment. There are complex relationships between food security, wealth, and environment, where weak and moderate food security countries are associated with mainly poor countries.

The world's population will continue increasing significantly, consequently triggering pressures on natural resources to meet the population's food needs (Caldeira et al., 2019). With constrained resources and changing climate, achieving food security for the world's population without compromising ecosystem quality and biodiversity (Godfray et al., 2010) requires a worldwide strategy. The focus must consider all food security dimensions and an integrated orientation. The Food Supply Chain (FSC) must be more efficient, and the amount of FLW must reduce (Wang et al., 2021; Foresight, 2011), and generate benefits for the environment (Cattaneo et al., 2021).

Multiple and multidirectional relationships exist between FLW, food security, natural resources sustainability, climate change, and SDGs. In the last decades, progress in technology and transport, trade barriers reduction (Veldhuizen et al., 2020), and climate change impacts on food systems (IPCC, 2019) have contributed to an FSC that is more globalized, specialized, and complex. Consequently, there is a mismatch between the places where food is produced and consumed (Princen et al., 2002), involving many horizontally and vertically connected actors. Then, the probability of FLW along FSC increases because of more transactions between different FSC actors. On the other hand, food security can improve because food producers and a population suffering from food insecurity increase their chances of connection. Mitigating FLW has positive results in various aspects. Firstly, it can enhance food security levels by increasing high-quality food availability (Lemaire and Limbourg, 2019) and improving food utilization (HLPE, 2014). Furthermore, a sustainable food system that contributes to less FLW might reduce food costs, improving vulnerable people's food access (HLPE, 2014) and the investment risk for enterprises. For instance, Lemaire and Limbourg, 2019 point out that FLW reduction or food donation can reduce the food cost if the cost of that action is lower than the cost of disposal of FLW. In addition,

mitigating FLW at the consumption stage of the FSC might increase the consumers' food budget and improve their access to food. According to Schanes et al (2018), the general intention behind FLW reduction at the family level is money-saving before environmental concerns. On the other hand, sustainable food systems may reduce food price volatility, increasing the food supply's stability (FAO, 2017). Secondly, mitigation of FLW may improve the efficiency and productivity of natural resource uses. According to Chen et al (2020) and Del Borghi et al (2020), the water–energy–food nexus shows a clear relationship between food and the depletion of resources. For example, Kummu et al (2012) estimated that 24% of total freshwater used in crop production, 23% of the total global cropland area, and 23% of complete global fertilizer used are wasted, producing food that will not be consumed. Furthermore, FLW has enormous potential for resource sustainability. For example, for compost returning mineral nutrients into the soil (Borrello et al., 2017), recovering and reusing phosphorus (Yuan et al., 2018), or using FLW to produce energy. On the other hand, FLW causes CO_2, methane, and nitrogen emissions that cause climate change and adverse effects on biodiversity (Scherhaufer et al., 2028) and humanity (Chen et al., 2022). According to Salemdeeb et al. (2017) and Bernstad et al. (2015), prevention of FLW can save from 800 to 4400 kg CO_2 equivalent per ton of food waste. Environmental degradation adversely affects agriculture, causing a vicious circle (IFPRI, 2019). Therefore, climate change events are already contributing to reducing the yield of agricultural and livestock production (IFPRI, 2022). Therefore, accounting for FLW at the national, continental, or global level is crucial to prioritize interventions, design public policies for FLW reduction (Caldeira et al., 2019), and achieve the SDGs. This knowledge allows us to (1) build a guideline to measure progress in reducing FLW; (2) supervise food generation over time; (3) decide the way to reduce food waste along the FSC; and (4) establish the pathways for potential food waste valorization. Nevertheless, although interest in this issue has grown recently, FLW accounting needs to be expanded [19], especially in developing countries.

2. Definition of Food Losses and Waste and literature review

There needs to be a universal agreement on the FLW definition and its terminologies for food waste and loss. Literature has different meanings and is often controversial (Scherhaufer et al., 2018). FLW definitions are expressed in different terms: intended or not for human consumption; in relation to the time (pre-harvest, ready for harvest, post-harvest); considering criteria such as the edibility, use, or nutrition; the perspective adopted (social, environmental, food security); and finally, the type (quantitative or qualitative) (Chaboud and Daviron, 2017). On the other hand, there is no consistent definition of food loss and food waste (Roodhuyzen et al., 2017). Most researchers distinguish both terms regarding the stage of FSC (Spang and Stevens, 2018). Food loss refers to the diminished bulk of consumable food that happens from production to the processing stages in the FSC (Vilariño et al., 2017; Huang et al., 2020). Food waste indicates the amount of food with good quality that is unsuitable for human consumption and then wasted at the end of the FSC in distribution, retail, or consumption stages (Huang et al., 2020; Parfitt et al., 2010). Despite these differences, at least two main approaches describe FLW. The food focus contemplates the discarded edible food destined initially for human consumption as FLW. The waste focus studies FLW as both edible and inedible food discarded; however, only some FLW approaches consider FLW food meant for other uses, such as animal feed, energy production, and seed (Bellemare et al., 2017).

This paper uses, on the one hand, the FAO definition of FLW, which tries to harmonize different concepts and align them with SDG 12.3. Moreover, it defines it as the reduction in quality or quantity of food along the FSC, from harvest, slaughter, and catch-up, not including the retail level. The case of food waste

occurs at the retail and consumption level (Alexander et al., 2017). This paper also focuses on three concepts to implement the above definition of FLW. First, the food loss and waste rate (FLWR) are the food loss and waste ratio to total food production; second, the allocation factors determine the proportion of food destined for human consumption; and finally, the conversion factors for assessing the percentage of edible food.

In relation to FLW calculation, a literature review shows a proliferation in the last fifteen years of studies for estimating FLW worldwide. FAO (2011) and Gustavsson et al. (2013) estimated that 1300 million tons of food per year are wasted worldwide, equivalent to 33% of the total food production. Kummu et al (2012) and Alexander et al (2017) measure food waste in kilocalories, implying a percentage of food loss between 24% and 20% dumped in the FSC. Porter et al (2016) estimated that 1646 million tons of food were discarded in 2011. FAO (2019), using the Food Loss Index, estimated that globally nearly 14% of the food produced worldwide is lost during production before being sold in stores. Regarding food waste, UNEP (2021) estimated an amount of 931 million tons of waste each year from different sectors related to the human food supply chain, of which 570 million tons directly come from households. Other studies collected by (Xue et al., 2017) have focused on quantifying food loss in specific countries. In contrast, others, for example, (Schanes et al., 2018), have focused on the household level with attention to types of food and food loss. Furthermore, countries have different causes of FLW. In industrialized countries, most FLW occurs in the food supply chain's retail, food service, and household phases (Thyberg and Tonjes, 2016). Examples include food not consumed in time, spoiling, burning, personal preferences, or leftover waste (Jellil et al., 2018). In developing and underdeveloped nations, FLW is primarily due to a lack of infrastructure, knowledge, and storage technology investment (Cicatiello et al., 2016).

The previous studies have provided valuable knowledge on the trends and scale of FLW, although they have yet to be exempt from criticism, as compiled in the work of (Spang et al., 2019; Hoehn et al., 2023). On the other hand, these studies have yet to estimate the FLW considering the countries' food security level. This paper addresses these limitations by estimating FLW by the country's level of food security, by different food groups, and including all stages of the FSC. Then, it analyses the causes of FLW according to the level of food security. Finally, it briefly explores FLW's impact on natural resources, climate change, food security, and the SDGs in countries with a weak and moderate level of food security.

3. Calculation of Food Loss and Waste

The mass balance method designed by (FAO, 2011; Gustavsson et al., 2013) is used in this research. This method calculates the amount of FLW as the difference between inputs and outputs of food, their stock variations, and weight changes during the process (Hanson et al., 2016). The accounting approach to estimate FLW is described in Annex 1 (Tostivint et al., 2016; Durán-Sandoval et al., 2021). The mass balance method is appropriate. It covers FSC worldwide, in all stages, and includes a wide range of food products. In addition, the amount of FLW estimated for each country was associated with its level of food security, using the four clusters formed by the Global Food Security Index (GFSI) designed by The Economist Intelligence Unit. These clusters are "very good", "good", "moderate", and "weak". Moreover, it added a new category for countries where The Economist Intelligence Unit did not calculate the level of food security. This category was labeled as countries "without EIU Index" and a set of indicators calculates them based on four categories related to food security: affordability, availability, quality, and safety, and natural resources and resilience. The GFSI is calculated for 113 countries, while FLW is estimated for 171 countries, gathering a population of 7369 million people in 2017; therefore, the rest of the countries were classified in a "without EUI index" cluster. Except for countries without EIU Index (63

countries), the most significant number of countries are in the category of good and moderate levels of food security, in total 88 countries. Most of the world's population also lives in these two types of countries, that is 6345 million people, 86% of the world's population. A considerable contribution to the population comes from China (1452 million people) and India (1338 million people) for good and moderate levels of food security, respectively.

Analyzing the absolute volume of total domestic food supply, countries with good food security hold the most significant amount of available food, 4734 million tons. Nevertheless, as expected in per capita terms, there is a positive correlation between food security and the amount of per capita food available. Thus, countries with very good levels of food security had 1912 kg per capita, while countries with weak levels of food security had 481 kg per capita, which means four times less than countries with the highest level of food security. Regardless of the level of food security, cereals represented the most significant food group available in every type of country. In contrast, the second largest food group available changes with the level of food security. In countries with very good food security, milk is the second largest food group available, followed by oil crops. In these countries, the number of vegetables, fruit, and meat is similar, around 115 kg per capita, higher than in countries with low levels of food security. In countries with moderate and weak levels of food security, the second largest food group available is starchy roots. In addition, countries with a moderate and weak level of food security have low availability of dairy products and meat, corroborating their poor diet (Schonfeldt and Gibson, 2012), which supports the argument that countries with a high level of food security usually have high incomes per capita. They have access to a more varied, balanced, and healthy diet than those with a low level of food security (Schonfeldt and Gibson, 2012).

Table 1. Domestic supply quantity in a million tons by country's level of food security and by each food group in 2017. Number of countries by level of food security and population in a million people. Own elaboration based on FAOSTAT data (2017), World Bank data (2019), and The Economist Intelligence Unit data (2019).

	Level of food security					
Food group	Very good	Good	Moderate	Weak	Without EUI Index	Total
Cereals - Excluding Beer	940.4	439.2	241.4	179.8	305.8	2106.6
Eggs	16.9	17.6	3.7	2.5	7.0	47.7
Fish, Seafood	29.2	35.3	9.3	9.2	10.9	93.9
Fruits - Excluding Wine	113.3	112.1	65.0	49.8	89.1	429.3
Meat	107.1	60.1	10.8	25.3	32.4	235.8
Milk - Excluding Butter	291.8	79.4	103.0	43.2	90.0	607.3
Oilcrops	198.9	197.6	46.7	18.6	31.1	492.9
Pulses	10.9	6.6	20.2	5.8	8.3	52.0
Starchy Roots	87.3	116.3	121.7	117.6	64.0	506.8
Vegetables	115.8	243.7	83.0	29.2	129.9	601.5
Total	1911.5	1307.9	704.8	481.0	768.6	5173.9
N° Countries	14	52	36	6	63	171
Population (Million people)	610.8	3619.7	2725.6	110.4	302.8	7369.3

3.1. Overall FLW by Food Security Level and Stage of the FSC

The total FLW was 1498.2 million tons of food in 2017. The greatest discard, 894.3 million tons, was concentrated in countries with good food security. In contrast, the lowest food discard, 11.4 million tons, occurred in countries with weak food security. This result is expected due to the difference in both

countries' total domestic food supply. In addition, FLW in China, equivalent to 402 million tons, contributes significantly to the high amount of FLW in countries with good food security. FLW represents around 20% of the total domestic food supply in countries with good, moderate, and weak food security. In contrast, in countries with very good food security, FLW represents 14%. The reasons that explain FLW in countries with different levels of food security vary from country to country. In general, countries with a very good and good level of food security are those with high and medium income, while countries with a moderate and weak level of food security are those with a reasonable and low-income level. The reasons for FLW in high/medium-income countries are related to consumer behavior and a lack of coordination between actors in the FSC (FAO, 2011; Degueurce et al., 2019; Holsteijn and Kemna, 2018). In contrast, in countries with moderate/low-income levels, the reasons for FLW are financial and managerial, some limitations are related to harvesting techniques, lack of storage, and cooling facilities in countries with difficult climatic conditions, infrastructure, packaging, and marketing systems (Krzywoszynska, 2011; Thi et al., 2015). Analyzing by stage of the FSC, the hotspots of FLW differ depending on the country's food security level (Table 2). In countries with a very good level of food security, FLW occurred mainly in the consumption stage of the FSC, around 43% of the total FLW in these countries. According to Han et al (2018), FLW at the consumption stage of the FSC is directly related to social factors, such as the level of education and cultural behaviors. In turn, Benyam et al (2018) takes a more complex approach than (Han et al., 2018), considering that psychological, socioeconomic, environmental, and regulatory factors affect consumers' attitudes towards FLW. Another reason that might explain FLW at the consumption stage is the inconsistency between the consumer's demand and a need for more general awareness of the existing waste problem (Alexander et al., 2017).

Table 2. FLW in a million tons calculated for the country's level of food security and FSC stage in 2017.

Level of Food Security	Domestic supply quantity (Mt)	Food losses and waste (Mt)						Food waste/Domestic supply quantity
		Agricultural production	Postharvest and storage	Processing and packaging	Distribution	Consumption	Total FLW by	
Very good	1167.6	46.3	15.7	11.9	18.2	68.3	160.5	14%
Good	4734.3	259.3	207.9	75.8	132.2	219.1	894.3	19%
Moderate	1921.1	122.3	130.5	22.3	76.5	36.8	388.3	20%
Weak	53.1	3.5	3.3	1.0	2.1	1.5	11.4	21%
Without EUI Index	232.7	13.5	10.3	2.7	8.8	8.4	43.7	19%
Total	8108.8	444.8	367.8	113.7	237.7	334.1	1498.2	18%

FLW is distributed more equally among the stages of FSC in countries with a good level of security than in countries with other food security groups. One of the reasons to explain this pattern is that this category gathers countries with a high heterogeneity with each other. For instance, the most significant amount of FLW in this category of countries occurred in China. The FLW mainly happened at the end of the FSC, 129 (32%) and 109 (27%) million tons in the agricultural production and consumption stages, respectively, with considerable FLW in post-harvest and storage and distribution stages, 89 (22%) and 63 (16%) million tons, respectively. However, in Chile, FLW mainly occurred at the first two stages of the FSC, namely, agricultural production and post-harvest and storage stages, with 2897 (60%) thousand tons of FLW. The other three stages represent a similar percentage, around 13% of total FLW. In contrast with the countries with a very good level of food security, in countries with a moderate and weak level of food security, FLW occurred mainly in the first two stages of the FSC, namely, agricultural production and post-harvest and storage. The reasons that explain the FLW in these stages are several: for instance, difficulties in

managing the factors that affect the agricultural production process, such as weather conditions (Adamashvili et al., 2019); lack of efficient irrigation systems (Spang and Stevens, 2018); insects, diseases, rodents, weeds, inefficient seeding, and severe weather conditions during planting (Liu, 2014); death and disease, such as animal death during breeding for bovine, poultry, and pork meat, discards during fishing for fish, and decreases in milk production due to dairy cow diseases such as mastitis (Liu, 2014); mechanical damage during harvesting (Lemaire and Limbourg, 2019); market prices lower than the harvesting cost (Lemaire and Limbourg, 2019); and poor storage facilities and lack of infrastructure (FAO, 2011).

3.2.. Overall FLW by Food Security Level and Food Group

The analysis of FLW by food group and in terms of volume shows that in countries with very good levels of food security, FLW occurred mainly in five food groups. These are vegetables, milk, starchy roots, cereals, and fruit, with about 25 million tons of each food group. Pulses, eggs, fish, and seafood showed the lowest FLW, between 0.4 and 3.4 million tons. Food groups with the highest FLW as a percentage of the domestic food supply quantity were starchy root, vegetables, and fruit, 52%, 40%, and 36%, respectively. However, meat, fish and seafood, milk, and eggs also showed a significant amount of FLW compared with the domestic supply quantity, between 15% and 20%. In every food group, FLW occurred mainly in the consumption stage. However, for starchy roots, vegetables, milk, and fruit, the agricultural production stage also concentrated a significant amount of FLW.

In countries with good food security, FLW mainly occurred in vegetables, 273.4 million tons, equivalent to 31% of the total FLW in this category of countries. An exceptional case is Chinese FLW which represents 66% of the total FLW of vegetables in this category of countries. Other groups with a significant amount of FLW are fruit and cereals, with around 150 million tons each. Food groups with the highest FLW as a percentage of the domestic food supply quantity were fruit, vegetables, and starchy root, 37%, 31%, and 30%, respectively. However, the rest of the food groups also showed a significant amount of FLW compared with the domestic supply quantity, a range between 12% and 19%, except for cereals and pulses, which have a low level of FLW. Analyzing by stage of the FSC, in countries with a good level of food security, FLW is more equally distributed through the FSC than in countries with the best level of food security. The exception is the processing and packaging stage, which is small in every food group except for oil crops.

The reasons that explain FLW in this category of countries are like the causes that explain FLW in countries with a very good level of food security. Nevertheless, it is possible to mention some additional reasons related to the agricultural, post-harvest, and storage stages. Firstly, some characteristics of fruits, vegetables, starchy roots, and cereals production reduce the possibility of predicting supply and demand volumes. This situation hinders the capacity of FSC operators to adapt to changing markets, which generates FLW (Canali et al., 2016). An example of this situation is at the agricultural production stage; the uncertainties in weather conditions, frosts, droughts, rodents, or disease might cause the FLW of fruits, vegetables, and starchy roots. This situation induces farmers to overplant to avoid the risks of not fulfilling their contract conditions. Consequently, unsold and unharvested products are generated (Buchner et al., 2012). Secondly, many fruits and vegetables are delicate by nature, which renders them vulnerable to injury during automated or human harvesting and handling (Canali et al., 2016). Thirdly, different conditions, such as bites of birds, frosts, droughts, and weather conditions, provoke the FLW of these products (FAO, 2015). The conditions above also cause the vegetables, fruits, and starchy roots

not to satisfy the market standards, such as appearance, shape, and weight. Hence, farmers discard them to avoid harvesting costs (Mena et al., 2011).

In countries with moderate food security, the largest FLW occurred in the starchy root, 106.6 million tons, equivalent to 27% of the total FLW in this category of countries (Figure 4). Other groups with a significant amount of FLW are vegetables, cereals, fruit, and milk. Starchy root, vegetables, and fruit groups have the highest FLW as a percentage of the domestic food supply quantity, around 32% of each group. However, the rest of the food groups also showed a significant amount of FLW compared with the domestic supply quantity, between 10% and 19%. Analyzing by stage of the FSC, in countries with moderate food security, almost every food group FLW is concentrated mainly in the first two stages of the FSC. Nevertheless, a significant amount of FLW occurred in the distribution stage. The causes that explain FLW at the agricultural and post-harvest and storage stages in this category of countries are related to the lack of infrastructure, knowledge, and investment in storage technologies (Krzywoszynska, 2011; Thi et al., 2015) and limited capacity to face environmental and weather conditions and climate change (Atanda et al., 2011; Lundqvist et al., 2008), for instance: (i) inadequate systems of control in production and processing, for example, slaughtering and processing losses in the meat industry (Whitehead et al., 2011); (ii) suboptimal operation and ease of use of equipment (Mena et al., 2011); (iii) poor storage handling (Atanda et al., 2011; George et al., 2010); (iv) damage during transport due to suboptimal transport infrastructure (Canali et al., 2016); (v) cold chain inefficiencies (George et al., 2010); (vi) incorrect application or absence of inventory turnover (Canali et al., 2016); (vii) and lack of finance that hinders the setting of facilities for proper conservation and processing of food (FAO, 2011; Canali et al., 2016). In countries with the worst level of food security, the largest FLW occurred in the starchy root, 4.1 million tons, equivalent to 36% of the total FLW in this category of countries, a very high percentage compared with the other food groups (Figure 5). In this category, FLW occurred mainly in the first two stages of the FSC. Some reasons for this are the lack of storage infrastructure and technology to control pests, rodents, insects, diseases, weeds, inefficient seeding, and extreme weather conditions (Liu, 2014). In fruit and cereals, a significant amount of FLW occurred, 2.13 and 1.85 million tons, respectively. Food groups of fruit, vegetables, and starchy root represent a high amount of FLW as a percentage of the domestic food supply quantity, 39%, 38%, and 32%, respectively. Nevertheless, the rest of the food groups also showed a significant amount of FLW compared with the domestic supply quantity, ranging between 15% and 20%. The only exceptions are cereals and pulses with 9% of FLW. As a percentage of the domestic food quantity, countries with a weak level of food security lost the same or even more fruit and vegetables than countries with a very good and good level of food security. This situation is consistent with the diet of these countries, which can be more diversified, mainly based on starchy roots, cereals, and vegetables due to their lower cost than other food groups, such as meat or fish. In this sense, the main reasons for FLW are the lack of storage infrastructure and investment in agricultural technologies, the lack of knowledge of proper technology use (Krzywoszynska, 2011), and a limited ability to adapt to changing environmental and meteorological circumstances and climate change. In countries with a weak level of food security, FLW is concentrated in distinct stages of the FSC, depending on the food group. In the starchy root, 80% of FLW occurred in the first two stages of the FSC. FLW in fruit was concentrated in agricultural production and distribution, but a necessary amount of FLW also happened in the other stages. In cereals, the hotspot is the consumption stage, with 41% of the FLW in this food group. The causes that explain FLW in this category of countries are like those in countries with a moderate level of food security. Nevertheless, in countries with a weak level of food security, political instability or even wars significantly impact the sustainability of food systems, therefore, their FLW.

4. Conclusions

This article estimated the FLW by the country's level of food security, by different food groups, including all stages of the FSC. It analyzed the causes of FLW according to the level of food security and explored the impact of FLW on natural resources, climate change, and SDGs. The estimated global FLW was 1498 million tons of food in 2017. The greatest discard was concentrated in countries with good food security, 894.3 million tons. In contrast, the lowest food discard occurred in countries with a weak level of food security, 11.4 million tons. FLW represents around 20% of the total domestic food supply in countries with good, moderate, and inadequate food security. By contrast, in countries with a very good level of food security, FLW represents 14% of it, and the hotspot of FLW is mainly concentrated in the consumption phase. However, in countries with good food security, FLW is generated primarily in the last step of the FSC. On the other hand, in countries with moderate and weak food security, FLW occurred mainly in the first two stages of the FSC.

It was observed that countries with a moderate and weak level of food security must face significant challenges to achieve the SDGs. Another challenge for scientists, government, policymakers, and civil organisms is to improve statistical data on FLW, especially primary data. Efforts must be oriented to obtain more accurate FLWR, conversion, and allocation factors for every country, especially those with a weak and moderate level of food security that usually need more precise and reliable statistical information. Furthermore, quantitative connections between FLW and the SDGs indicators are needed to comprehend better how they affect food safety, the environment, and broader sustainable development trajectories. Despite these challenges, the economic, social, and environmental impact of FLW is enormous. Therefore, considering that in countries with a weak and moderate level of food security, FLW accounted for 21% and 20% of the domestic food supply, respectively, it is possible to argue that there is a gap in contributing to the achievement of SDGs through reducing FLW. It is necessary to enhance food security, lift people from poverty, and achieve environmental sustainability.

For this purpose, public policies play a crucial role in designing measures according to the food security dimension to which they contribute. Public policies can improve the efficiency of productive processes, translating to decreased food costs and, therefore, a possible price reduction. Additionally, the design of public policies must consider each country's different economic, institutional, human resources, and infrastructure contexts. In addition to these public policy solutions, others are proposed for structural causes of food loss and waste. These measures involve the entire food chain and require the participation of multiple actors.

Finally, in the actual development of a circular economy, it is of great importance to provide value to the rescued surplus food and the by-products, which can be used in other production processes as inputs, thus, contributing to better use of resources and reduction in environmental impact.

In this sense, possible future research lines are improving primary statistical data on FLW in weak and moderate food security countries and analyzing the quantitative relationships between FLW and the SDG's performance, and investigating the impacts of the global food supply chain in the generation of FLW in weak and moderate food security countries and proposing circular economy models to reduce FLW in countries with problems of food security.

References

1. Galli, F.; Cavicchi, A.; Brunori, G. Food waste reduction, and food poverty alleviation: A system dynamics conceptual model. *Agric. Hum. Values* **2019**, *36*, 289–300.
2. Food and Agriculture Organization (FAO). *The State of Food Security and Nutrition in the World. Repurposing Food and Agriculture Policies to Make Healthy Diets More Affordable*; Food and Agriculture Organization (FAO): Rome, Italy, 2022.
3. Von Grebmer, K.; Bernstein, J.; Wiemers, M.; Acheampong, K.; Hanano, A.; Higgins, B.; Ní Chéilleachair, R.; Foley, C.; Gitter, S.; Ekstrom, K.; et al. *Global Hunger Index, One Decade to Zero Hunger Linking Health and Sustainable Food Systems*; Welthungerhilfe: Bonn, Germany; Concern Worldwide: Dublin, Ireland, 2020.
4. Corrado, A.; Palumbo, L. Essential farmworkers and the pandemic crisis: Migrant labour conditions, and legal and political responses in Italy and Spain. In *Migration and Pandemics: Spaces of Solidarity and Spaces of Exception*; Springer: Cham, Switzerland, 2022; pp. 145–166. https://doi.org/10.1007/978-3-030-81210-2_8.
5. Celik, B.; Dane, S. The effects of the COVID-19 pandemic outbreak on food consumption preferences and their causes. *J. Res. Med. Dent. Sci.* **2020**, *8*, 169–173.
6. Janssen, M.; Chang, B.P.; Hristov, H.; Pravst, I.; Profeta, A.; Millard, J. Changes in food consumption during the COVID-19 pandemic: Analysis of consumer survey data from the first lockdown period in Denmark, Germany, and Slovenia. *Front. Nutr.* **2021**, *8*, 635859. https://doi.org/10.3389/fnut.2021.635859.
7. Food and Agriculture Organization (FAO). *Global Food Losses and Food Waste—Extent, Causes and Prevention*; Food and Agriculture Organization (FAO): Rome, Italy, 2011.
8. Shafiee-Jood, M.; Cai, X. Reducing food loss and waste to enhance food security and environmental sustainability. *Environ. Sci. Technol.* **2016**, *50*, 8432–8443. https://doi.org/10.1021/acs.est.6b01993.
9. Sun, S.; Lu, Y.; Gao, H.; Jiang, T.; Du, X.; Shen, T.; Wu, P.; Wang, Y. Impacts of food wastage on water resources and environment in China. *J. Clean. Prod.* **2018**, *185*, 732–739. https://doi.org/10.1016/j.jclepro.2018.03.029.
10. Food and Agriculture Organization (FAO). *Food Wastage Footprint Impacts on Natural Resources. Summary Report*; Food and Agriculture Organization (FAO): Rome, Italy, 2013.
11. Feldstein, S. Wasting biodiversity: Why food waste needs to be a conservation priority. *Biodiversity* **2017**, *18*, 75–77. https://doi.org/10.1080/14888386.2017.1351891.
12. Skawińska, E.; Zalewski, R.I. Combining the Water–Energy–Food and Food Waste–Food Loss–Food Security Nexuses to Reduce Resource Waste. *Energies* **2022**, *15*, 5866.
13. Caldeira, C.; De Laurentiisa, V.; Corrado, S.; van Holsteijnb, F.; Sala, S. Quantification of food waste per product group along the food supply chain in the European Union: A mass flow analysis. *Resour. Conserv. Recycl.* **2019**, *149*, 479–488. https://doi.org/10.1016/j.resconrec.2019.06.011.
14. Godfray, H.; Beddington, J.; Crute, I.; Haddad, L.; Lawrence, D.; Muir, J.; Pretty, J.; Robinson, S.; Thomas, S.; Toulmin, C. Food security: The challenge of feeding 9 billion people. *Science* **2010**, *327*, 812. https://doi.org/10.1126/science.1185383.
15. Wang, Y.; Yuan, Z.; Tang, Y. Enhancing food security and environmental sustainability: A critical review of food loss and waste management. *Resour. Environ. Sustain.* **2021**, *4*, 100023. https://doi.org/10.1016/j.resenv.2021.100023.
16. Foresight. *The Future of Food and Farming*; Final Project Report; The Government Office for Science: London, UK, 2011.

17. Cattaneo, A.; Sánchez, M.V.; Torero, M.; Vos, R. Reducing food loss and waste: Five challenges for policy and research. *Food Policy* **2021**, *98*, 101974. https://doi.org/10.1016/j.foodpol.2020.101974.
18. United Nations (UN). *Transforming Our World: The 2030 Agenda for Sustainable Development*; A/RES/70/1; United Nations (UN): New York, NY, USA, 2015.
19. Xue, L.; Liu, G.; Parfitt, J.; Liu, X.; Van Herpen, E.; Stenmarck, Å.; O'Connor, C.; Ostergren, K.; Cheng, S. Missing food, missing data? A critical review of global food losses and food waste data. *Environ. Sci. Technol.* **2017**, *51*, 6618–6633. https://doi.org/10.1021/acs.est.7b00401.
20. Gustavsson, J.; Cederberg, C.; Sonesson, U.; Emanuelsson, A. *The Methodology of the FAO Study: "Global Food Losses and Food Waste—Extent, Causes and Prevention"—FAO, 2011*; The Swedish Institute for Food and Biotechnology: Gothenburg, Sweden, 2013.
21. Kummu, M.; de Moel, H.; Porkka, M.; Siebert, S.; Varis, O.; Ward, P. Lost food wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Sci. Total Environ.* **2012**, *438*, 477–489. https://doi.org/10.1016/j.scitotenv.2012.08.092.
22. Alexander, P.; Brown, C.; Arneth, A.; Finnigan, J.; Moran, D.; Rounsevell, M. Losses, inefficiencies, and waste in the global food system. *Agric. Syst.* **2017**, *153*, 190–200. https://doi.org/10.1016/j.agsy.2017.01.014.
23. Porter, S.; Reay, D.; Higgins, P.; Bomberg, E. A half-century of production-phase greenhouse gas emissions from food loss and waste in the global food supply chain. *Sci. Total Environ.* **2016**, *571*, 721–729. https://doi.org/10.1016/j.scitotenv.2016.07.041.
24. Food and Agriculture Organization (FAO). *The State of Food and Agriculture 2019. Moving Forward on Food Loss and Waste Reduction*; Food and Agriculture Organization (FAO): Rome, Italy, 2019.
25. United Nations Environment Programme (UNEP). *Food Waste Index Report 2021*; United Nations Environment Programme (UNEP): Nairobi, Kenya, 2021.
26. Schanes, K.; Dobernig, K.; Gözet, B. Food waste matters -A systematic review of household food waste practices and their policy implications. *J. Clean. Prod.* **2018**, *182*, 978–991. https://doi.org/10.1016/j.jclepro.2018.02.030.
27. Thyberg, K.L.; Tonjes, D.J. Drivers of food wastage and their implications for sustainable policy. *Resour. Conserv. Recycl.* **2016**, *106*, 110–123.
28. Jellil, A.; Woolley, E.; Rahimifard, S. Towards integrating production and consumption to reduce consumer food waste in developed countries. *Int. J. Sustain. Eng.* **2018**, *11*, 294–306. https://doi.org/10.1080/19397038.2018.1428834.
29. Cicatiello, C.; Franco, S.; Pancino, B.; Blasi, E. The Value of Food Waste: An Exploratory Study on Retailing. *J. Retail. Consum. Serv.* **2016**, *30*, 96–104. https://doi.org/10.1016/j.jretconser.2016.01.004.
30. Spang, E.; Moreno, L.; Pace, S.; Achmon, Y.; Donis-Gonzalez, I.; Gosliner, W.; Jablonski-Sheffield, M.; Momin, A.; Quested, T.; Winans, K.; et al. Food loss and waste: Measurement, drivers and solutions. *Annu. Rev. Environ. Resour.* **2019**, *44*, 117–156.
31. Hoehn, D.; Vázquez-Rowe, I.; Kahhat, R.; Margallo, M.; Laso, J.; Fernández-Ríos, A.; Ruiz-Salmón, I.; Aldaco, R. A critical review on food loss and waste quantification approaches: Is there a need to develop alternatives beyond the currently widespread pathways? *Resour. Conserv. Recycl.* **2023**, *188*, 106671. https://doi.org/10.1016/j.resconrec.2022.106671.
32. Scherhaufer, S.; Moates, G.; Hartikainen, H.; Waldron, K.; Obersteiner, G. Environmental impacts of food waste in Europe. *Waste Manag.* **2018**, *77*, 98–113. https://doi.org/10.1016/j.wasman.2018.04.038.

33. Chaboud, G.; Daviron, B. Food losses and waste: Navigating the inconsistencies. *Glob. Food Secur.* **2017**, *12*, 1–7.
34. Roodhuyzen, D.M.A.; Luning, P.A.; Fogliano, V.; Steenbekkers, L.P.A. Putting together the puzzle of consumer food waste: Towards an integral perspective. *Trends Food Sci. Technol.* **2017**, *3*, 7–50. https://doi.org/10.1016/j.tifs.2017.07.009.
35. Spang, E.; Stevens, B. Estimating the blue water footprint of in-field crop losses: A case study of U.S. potato cultivation. *Sustainability* **2018**, *10*, 2854. https://doi.org/10.3390/su10082854.
36. Vilariño, M.V.; Franco, C.; Quarrington, C. Food loss and waste reduction as an integral part of a circular economy. *Front. Environ. Sci.* **2017**, *5*, 21. https://doi.org/10.3389/fenvs.2017.00021.
37. Huang, C.H.; Liu, S.M.; Hsu, N.Y. Understanding Global Food Surplus and Food Waste to Tackle Economic and Environmental Sustainability. *Sustainability* **2020**, *12*, 2892. https://doi.org/10.3390/su12072892.
38. Parfitt, J.; Barthel, M.; Macnaughton, S. Food waste within food supply chains: Quantification and potential for change to 2050. *Philos. Trans. R. Soc. B* **2010**, *365*, 3065–3081. https://doi.org/10.1098/rstb.2010.0126.
39. Bellemare, M.F.; Çakir, M.; Peterson, H.H.; Novak, L.; Rudi, J. On the measurement of food waste. *Am. J. Agric. Econ.* **2017**, *99*, 1148–1158. https://doi.org/10.1093/ajae/aax034.
40. Veldhuizen, L.; Giller, K.; Oosteveer, P.; Brouwer, I.; Janssen, S.; Zanten, H.; Slingerland, M. The Missing Middle: Connected action on agriculture and nutrition across global, national, and local levels to achieve Sustainable Development Goal 2. *Glob. Food Secur.* **2020**, *24*, 100336. https://doi.org/10.1016/j.gfs.2019.100336.
41. Intergovernmental Panel on Climate Change (IPCC). Summary for Policymakers. In *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*; Shukla, P.R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H.-O., Roberts, D.C., Zhai, P., Slade, R., Connors, S., van Diemen, R., et al., Eds.; Cambridge University Press: Cambridge, UK, 2019. https://doi.org/10.1017/9781009157988.001.
42. Princen, T.; Maniates, M.; Conca, K. *Confronting Consumption*; The MIT Press: Cambridge, MA, USA, 2002.
43. Lemaire, A.; Limbourg, S. How can food loss and waste management achieve sustainable development goals? *J. Clean. Prod.* **2019**, *234*, 1221–1234. https://doi.org/10.1016/j.jclepro.2019.06.226.
44. High Level Panel of Experts (HLPE). *Food Losses and Waste in the Context of Sustainable Food Systems. A Report by the High-Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*; High Level Panel of Experts (HLPE): Rome, Italy, 2014.
45. Food and Agriculture Organization (FAO). *Reflexiones Sobre el Sistema Alimentario y Perspectivas para Alcanzar su Sostenibilidad en América Latina y el Caribe*; FAO en Chile: Santiago, Chile, 2017.
46. Chen, C.; Chaudhary, A.; Mathys, A. Nutritional and environmental losses embedded in global food waste. *Resour. Conserv. Recycl.* **2020**, *160*, 104912. https://doi.org/10.1016/j.resconrec.2020.104912.
47. Del Borghi, A.; Moreschi, L.; Gallo, M. Circular economy approach to reduce water-energy-food nexus. *Curr. Opin. Environ. Sci. Health* **2020**, *13*, 23–28. https://doi.org/10.1016/j.coesh.2019.10.002.

48. Borrello, M.; Caracciolo, F.; Lombardi, A.; Pascucci, S.; Cembalo, L. Consumers' perspective on circular economy strategy for reducing food waste. *Sustainability* **2017**, *9*, 141. https://doi.org/10.3390/su9010141.
49. Yuan, Z.; Jiang, S.; Sheng, H.; Liu, X.; Hua, H.; Liu, X.; Zhang, Y. Human perturbation of the global phosphorus cycle: Changes and consequences. *Environ. Sci. Technol.* **2018**, *52*, 2438–2450. https://doi.org/10.1021/acs.est.7b03910.
50. Cheng, M.; McCarl, B.; Fei, C. Climate change and livestock production: A literature review. *Atmosphere* **2022**, *13*, 140. https://doi.org/10.3390/atmos13010140.
51. Salemdeeb, R.; Font Vivanco, D.; Al-Tabbaa, A.; Zu Ermgassen, E. A holistic approach to the environmental evaluation of food waste prevention. *Waste Manag.* **2017**, *59*, 442–450. https://doi.org/10.1016/j.wasman.2016.09.042.
52. Bernstad Saraiva Schott, A.; Cánovas, A. Current practice, challenges, and potential methodological improvements in environmental evaluations of food waste prevention—A discussion paper. *Resour. Conserv. Recycl.* **2015**, *101*, 132–142. https://doi.org/10.1016/j.resconrec.2015.05.004.
53. International Food Policy Research Institute (IFPRI). *2019 Global Food Policy Report*; International Food Policy Research Institute (IFPRI): Washington, DC, USA, 2019.
54. International Food Policy Research Institute (IFPRI). *2022 Global Food Policy Report: Climate Change and Food Systems*; International Food Policy Research Institute (IFPRI): Washington, DC, USA, 2022. https://doi.org/10.2499/9780896294257.
55. Dal'Magro, G.; Talamini, E. Estimating the magnitude of the food loss and waste generated in Brazil. *Waste Manag. Res.* **2019**, *37*, 706–716. https://doi.org/10.1177/0734242X19836710.
56. Hanson, C.; Lipinski, B.; Robertson, K.; Días, D.; Gavilan, I.; Gréverath, P.; Ritter, S.; Fonseca, J.; Van Otterdijk, R.; Timmermans, T.; et al. *Food Loss and Waste Accounting and Reporting Standard*; World Business Council for Sustainable Development: Geneva, Switzerland, 2016.
57. Tostivint, C.; Östergren, K.; Quested, T.; Soethoudt, J.M.; Stenmarck, A.; Svanes, E.; O'Connor, C. *Food Waste Quantification Manual to Monitor Food Waste Amounts and Progression*; FUSIONS Report; EU FUSIONS: Neuilly-sur-Seine, France, 2016.
58. Durán-Sandoval, D.; Durán-Romero, G.; López, A.M. Achieving the Food Security Strategy by Quantifying Food Loss and Waste. A Case Study of the Chinese Economy. Sustainability 2021, 13, 12259. https://doi.org/10.3390/su132112259
59. Schonfeldt, H.; Gibson, N. Dietary protein quality and malnutrition in Africa. *Br. J. Nutr.* **2012**, *108*, 869–876. https://doi.org/10.1017/S0007114512002553.
60. Degueurce, A.; Picard, S.; Peu, P.; Trémier, A. Storage of food waste: Variations of physical-chemical characteristics and consequences on biomethane potential. *Waste Biomass Valoriz.* **2019**, *11*, 2441–2454. https://doi.org/10.1007/s12649-018-00570-0.
61. Holsteijn, F.; Kemna, R. Minimizing food waste by improving storage conditions in household refrigeration. *Resour. Conserv. Recycl.* **2018**, *128*, 25–31. https://doi.org/10.1016/j.resconrec.2017.09.012.
62. Krzywoszynska, A. Spotlight on… Waste: Uncovering the global food scandal. *Geography* **2011**, *96*, 101–104.
63. Thi, N.B.; Kumar, G.; Lin, C.Y. An overview of food waste management in developing countries: Current status and future perspective. *J. Environ. Manag.* **2015**, *157*, 220–229. https://doi.org/10.1016/j.jenvman.2015.04.022.

64. Han, Z.; Liu, Y.; Zhong, M.; Shi, G.; Li, Q.; Zeng, D.; Zhang, Y.; Fei, Y.; Xie, Y. Influencing factors of domestic waste characteristics in rural areas of developing countries. *Waste Manag.* **2018**, *72*, 45–54. https://doi.org/10.1016/j.wasman.2017.11.039.
65. Benyam, A.; Kinnear, S.; Rolfe, J. Integrating community perspectives into domestic food waste prevention and diversion policies. *Resour. Conserv. Recycl.* **2018**, *134*, 174–183. https://doi.org/10.1016/j.resconrec.2018.03.019.
66. Adamashvili, N.; Chiara, F.; Fiore, M. Food loss and waste a global responsibility? *Econ. Agro-Aliment./Food Econ.* **2019**, *21*, 825–846. https://doi.org/10.3280/ecag2019-003014.
67. Liu, G. *Food Losses and Food Waste in China: A First Estimate*; OECD Food, Agriculture and Fisheries Papers, No 66; OECD Publishing: Paris, France, 2014.
68. Canali, M.; Amani, P.; Aramyan, L.; Gheoldus, M.; Moates, G.; Östergren, K.; Silvennoinen, K.; Waldron, K.; Vittuari, M. Food waste drivers in Europe, from identification to possible interventions. *Sustainability* **2016**, *9*, 37. https://doi.org/10.3390/su9010037.
69. Buchner, B.; Fischler, C.; Gustafson, E.; Reilly, J.; Riccardi, G.; Ricordi, C.; Veronesi, U. *Food Waste: Causes, Impacts and Proposals*; Barilla Center for Food & Nutrition: Parma, Italy, 2012.
70. Food and Agriculture Organization (FAO). *Pérdida y Desperdicio de Alimentos en América Latina y el Caribe*; Boletin N° 2; Food and Agriculture Organization (FAO): Rome, Italy, 2015.
71. Mena, C.; Adenso-Diaz, B.; Yurt, O. The causes of food waste in the supplier-retailer interface: Evidence from the UK and Spain. *Resour. Conserv. Recycl.* **2011**, *55*, 648–658. https://doi.org/10.1016/j.resconrec.2010.09.006.
72. Atanda, S.; Pessu, P.; Agoda, S.; Isong, I.; Ikotun, I. The concepts and problems of post-harvest food losses in perishable crops. *Afr. J. Food Sci.* **2011**, *5*, 603–613.
73. Lundqvist, J.; De Fraiture, C.; Molden, D. *Saving Water: From Field to Fork. Curbing Losses and Wastage in the Food Chain*; SIWI Policy Brief; Stockholm International Water Institute (SIWI): Stockholm, Sweden, 2008.
74. Whitehead, P.; Palmer, M.; Mena, C.; Williams, A.; Walsh, C. *Resource Maps for Fresh Meat across Retail and Wholesale Supply Chains*; Waste and Resources Action Programme (WRAP): Banbury, UK, 2011.
75. George, R.; Burgess, P.; Thorn, R. *Reducing Food Waste through the Chill Chain*; Waste and Resources Action Programme (WRAP): Banbury, UK, 2010.

ANNEX 1.

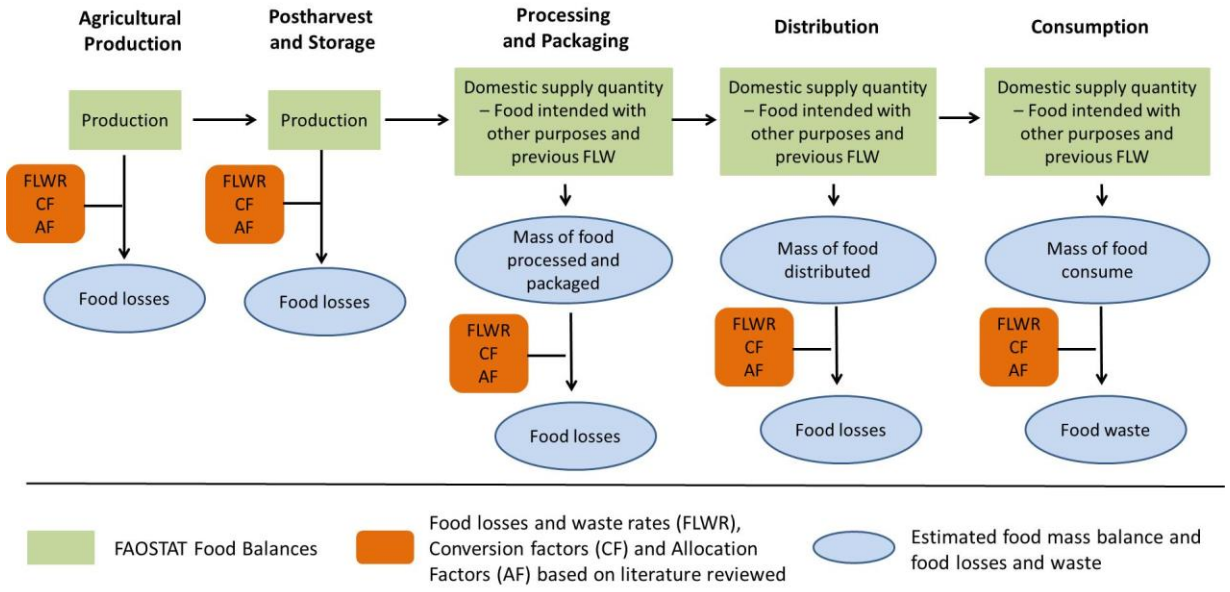

Figure 1. Accounting approach to estimate FLW.

The following equations represent the estimation of FLW and pooling.

$$FLW_k = \sum_{i=1}^{n} QA_{ijk} * \alpha_{ijk} * \beta_{ijk} * \gamma_{ijk} \quad (1)$$

$$FLW = \sum_{l=1}^{5} FLW_{kl} \quad (2)$$

where

- *i* is the food group: fruit, cereals, milk, fish and seafood, meat, eggs, starchy roots, pulses, oil crops, and vegetables;
- *j* is the stage of the FSC: agricultural production, post-harvest, storage, processing and packaging, distribution, and consumption;
- k is the country;
- l is the level of food security according to the Global Food Security Index of The Economist Intelligence Unit, which are very good, good, moderate, weak, very weak, and without EIU Index;
- QA_{ijk} is the domestic food supply quantity, which is the quantity of food available in the food group i in stage j of the FSC in the country k.
- α_{ijk} is the food loss and waste rate (FLWR) in the food group i in stage j of the FSC in the country k, defined as the ratio of food loss and waste to the total amount of food production;
- β_{ijk} is the allocation factor in the food group i in stage j of the FSC in the country k, which defines the proportion of the food meant for human consumption.

- γ_{ijk} is the conversion factor in the food group i in stage j of the FSC in the country k, which defines the proportion of edible food.
- FLW_{kl} is the food loss and waste in the country k with the level l of security.

The mass balance method distinguishes between edible and non-edible food. Regarding FLW, quantification only considers edible food and discordance in the FLW estimation. Several causes contribute to decreased edible food mass in FSC stages [63]. In this sense, food loss occurs at all stages except consumption when food waste occurs [32,39].
Therefore, the FLW is calculated, by multiplying the amount of food available at each step of the food chain by FLWR and the allocation and conversion factors. Finally, the FLW considers the country's level of food security.
Then, the following equation was used to calculate the per capita FLW.

$$FLW_{PC} = \frac{FLW}{P_n} \quad (3)$$

where FLW_{PC} is the per capita food loss and waste and P_n is the population.
The geographical area selected for this study is worldwide, using the FAOSTAT datasets for 2017 for the production and yield of food information. The per capita results are calculated using population data from the World Bank. FLWR, conversion and allocation factors were taken from [8,21] and contrasted with [20]. The Global Food Security Index of December 2019, designed by The Economist Intelligence Unit, indicated the different countries' food security levels.