Waste Quantification Solutions to Limit Environmental Stress

Lead Partner: SDU
Month 12 – December 2023

D1.2 - Report on improved framework for FLW measurement & monitoring

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Executive Summary

Food Loss and Waste (FLW) issues challenge European Union (EU)'s commitment to advancing Green Deal, transforming food system, as well as promoting a circular economy. As the major inefficiency within the Food Supply Chain (FSC), it is essential to better understand the nature of FLW, identify their hotspots, and develop efficient prevention and reduction strategies. Data collection for FLW measurement is the key step in addressing FLW issues. Given the complexity of the diverse FSCs among EU Member States (MSs) and across various food categories, a harmonized framework is advantageous. Such a framework would facilitate comprehensive data collection and analysis, upscale successful reduction strategies, and enhance effects to tackle climate change.

WASTELESS project aims to develop and test a mix of innovative Tools and Methodologies (T&M) for FLW measurement and monitoring. Work Package (WP) 1 is mainly devoted to the practices and legislation mapping, as well as framework development. The current Deliverable (D) 1.2 (D1.2), "Report on improved framework for FLW measurement & monitoring" was developed based on the task 1.2 of WP 1 to be submitted at Month (M) 12, M12 – December 2023. Specifically, this deliverable aims to provide recommendations on the FLW measurement and monitoring framework harmonization and enriched with barriers and solutions identification. To achieve these objectives, a three-round of literature were conducted to better understand the research status and inform framework development. An expert consultation with online survey was carried out to include expert's insight in framework key elements, drivers, barriers, and solutions identifications.

Three rounds of literature review focused on FLW frameworks, FLW definitions, and FLW system definitions development, respectively. The first two rounds of literature provided with a general overview of the current FLW frameworks on quantification, as well as perveance FLW conceptual definitions from FAO, JRC, FUSIONS, WRAP, etc. To better develop a harmonized framework for the FLW data collection and analysis, this study first gave attention on four specific food categories: 1) Fruits, vegetables, fruit juices; 2) Meat products; 3) Potato products and cereal products; 4) Dairy products. System definitions were developed by adopting existing frameworks and tailoring to each of those food categories. Informed by those specific food category-focused frameworks and aligned with current ones, for example JRC FLW quantification and estimation frameworks, and FUSIONS definitional framework, this study categorized the general FSC into four key processes: Primary Production (PP), Processing and Manufacturing (P&M), Retail and Distribution (R&D), and Public and Household Consumption (PHC). Raw food products are produced in the PP sector and processed in the P&M sector. Final food products are distributed in the R&D sector and consumed in the PHC sector. Related to each of these key processes, the FLW collection sector has been integrated to account the potential FLW generated at each stage. Two market sectors were involved after PP and P&M sectors, considering the potential intra-EU and international food products trades.

Targeting the FLW measurement and monitoring framework harmonisation, expert survey unclosed expert's perspective. Multiple key framework elements identified framework were actual weighing methods, primary data collection, distinguished edible/inedible food parts, FLW destinations identification, etc. Environmental, economic, and social metrics could be included in the data collection to enrich data analysis. In addition, feedback acquisition from stakeholders, pilots study implementation, transparent communications among all actors, and compulsory legislations on data collection and reporting are all considered crucial in a harmonized framework.

Drivers and barriers identification show that multiple of benefits like economic benefits of FLW reduction, public interests and awareness in FLW issues, enhanced data collection and analysis methods, good governess, and related legislative drivers could be leveraged to promote the framework harmonization. In contrast, knowledge deficiency, low awareness, inefficient management, data issues, and the absence of a well-defined framework registered as the main barriers for the

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framework harmonization. To address these barriers, 32 solutions were identified informing by experts' insights, which were categorized into seven groups: 1) Research investment; 2) Cooperation with market and business; 3) Stakeholder motivation; 4) Knowledge and skill enhancement: 5) Effective framework implementation; 6) Governance improvement; 7) Data collection improvement.

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List of Acronyms

Abbreviation / acronym	Description
AIJN	European Fruit Juice Association
ANOVA	Analysis of variance
D	Deliverable
EU	European Union
Eurostat	European Statistical Office
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
FL	Food Loss
FLW	Food Loss and Waste
FLWP	Food Loss + Waste Protocol
FSC	Food Supply Chain
FW	Food Waste
JRC	Joint Research Centre
KPI	Key Performance Indicator
M	Month
MFA	Material Flow Analysis
MSs	Member States
PIPs	Perceived Inedible Parts
P&M	Processing and Manufacturing
PHC	Public and Household Consumption
PP	Primary Production
R&D	Retail and Distribution
SD	Standard deviation
SDG	Sustainable Development Goal
T&M	Tools and Methodologies
USDA	United States Department of Agriculture
WP	Work Package
WS	Waste Statistics

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1. Background

Food Loss and Waste (FLW) registered as a significant inefficiency of the Food Supply Chain (FSC). Globally, it is witnessed that one third of food being discarded from the FSC (FAO, 2011). Among them, 14% of food is discarded from the FSC when they haven't reached the retail phase (FAO, 2019), and start from retail another 17% of food ready for human consumption is wasted (UNEP, 2021). FLW also shows huge regional differences around the world in terms of its distribution in different sections of the FSC. The industrialized countries or regions witnessed huge consumption stage Food Waste (FW), it's mainly contributed by household FW generally caused by human behaviours. While at the rather less industrialized countries or regions, FLW mainly reported from the production and processing sectors, as the outdated technology and inefficient management usually the main FLW drivers here.

Among European Union (EU), data shows that the major FLW is generated from household consumption, where contributed more half the total FLW at a level of 70 kg per inhabitant per year. The figure for manufacturing sector is 23 kg, followed by 14 kg in primary production, 12kg in restaurants and food services, and 9kg from retail and distribution sectors[1]. FLW issues challenges European Union's commitment to advancing Green Deal (EU, 2019), transforming food system (EU, 2020a), as well as promoting a circular economy (EU, 2020b). In align with the global commitment to fighting against FLW, as outlined in the Sustainable Development Goal (SDG) 12.3 by halving FW and significantly reducing Food Loss (FL) (UN, 2015), EU has established specific targets for reducing FLW. Illustrated in the most update directive proposal (European Commission, 2023), EU is going to tackle FLW issues both at Processing and Manufacturing (P&M) sectors as well as Retail and Distribution (R&D), and Public and Household Consumption (PHC) sector. Specifically, given the baseline FLW level monitored in the year of 2020, EU is going to set legally binding FW reduction targets, by the end of the year 2027, all member states should reduce FW: 1) by 10%, in processing and manufacturing, 2) by 30% (per capita), jointly at retail and consumption (restaurants, food services and households).

FLW definitions play a crucial role in FLW measurement framework development. Until today, the literature lacks a common definition of the terms 'food loss' and 'food waste' (Lombardi & Costantino, 2020; Spang et al., 2019). Instead, the terms FL and FW are used along all FSC stages and even as synonyms. For example, it was stated that FL appears during the PP and M&P stages, while FW occurs during retail and final consumption only (FAO, 2019; Gustavsson et al., 2011; Ingrao et al., 2018; Östergren et al., 2014; Parfitt et al., 2010). In turn, other authors described FL and FW as synonyms, including inedible parts of food (Beretta et al., 2013; Galanakis, 2020). This inconsistency in the definition of FL and FW in the scientific literature leads to an overlap of these two terms and ultimately, a lack of clarity. Measuring FLW efficiently and in a harmonised framework is therefore a major challenge. Consequently, the development of specific prevention and reduction strategies is difficult. The first step towards the accurate and scientific recording of FLW is the precise description and definition of the topic and the terms needed to describe it. Based on this, further analyses can then be carried out using a common and unambiguous language.

To better collect FLW data, research developed and tested plenty of methods. Measurement practices and data collection methods for FLW vary across the FSC, depending on the sector, available techniques or tools, and the nature of FLW. Within the scope of the FLW protocol, a guidance on FLW quantification methods has been shared, and the information followed has been extracted from there (WRI, 2016). Primary data on FLW is obtained by measurements and approximations through digital weighing, counting, assessing volume through visual estimation, waste composition analysis, diaries, surveys, and interviews. FLW can also be estimated through calculations using proxy data, mass balances, and modelling techniques. While some measurement tools address the entire FSC, many

[1] Food waste: 127 kg per inhabitant in the EU in 2020. https://ec.europa.eu/eurostat/web/products-eurostatnews/-/ddn-20220925-2

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focuses on household waste. At the household level, surveys and interviews are widely preferred as a cost-effective means of collecting data on a large scale. Digital weighing is a well-established approach to directly quantify and monitor FLW throughout the entire FSC. The 'count and weigh' technique is useful for single, countable food products. Volume assessment is applicable to liquid, semi-solid, and certain solid materials, providing a means to measure or approximate the space occupied by FLW, which can then be converted to weight. Weighing may be employed as a stand-alone method or in combination with other approaches, such as waste composition analysis. Waste composition analysis involves the physical separation, weighing, and categorization of FLW, offering detailed information about its composition and possible reasons for its generation, particularly when combined with surveys or diaries. Diaries, which entail a daily tracking of FLW and related information, are well-suited for quantifying FLW in situations where direct access to the waste is limited, providing insights into behaviours related to the amounts and types of food wasted. This technique is extensively utilized in the retail sector.

A mass-balance method, also known as Material Flow Analysis (MFA), relies on calculations to infer FLW by measuring inputs and outputs, changes in stock levels, and alterations in food weight during processing. This method is applicable at various stages FSC where reliable measurement or approximation is challenging. Two other calculation-dependent methods are modelling and proxy data. Mathematical models, drawing information from disciplines such as statistics, economics, and operational research, can estimate FLW based on the interaction of multiple factors influencing its generation. These models may incorporate climatic, agricultural, or other data, demonstrating scientifically calculated FLW values. Proxy data, not initially part of the FLW inventory, can be used in calculations to infer FLW quantities within the entity's inventory scope. Entities may resort to proxy data when direct measurement or approximation is impractical. However, it is generally not recommended to monitor FLW reduction targets using estimates derived from proxy data due to differing scopes.

Ideally, FLW quantification involves a combination of these techniques. Employing surveys and questionnaires alongside digital weighing, especially at the consumption stage (including households and foodservice sectors), is recommended for accurate data collection (Silvennoinen et al., 2019). Measuring and monitoring FLW at Primary Production (PP) and P&M sectors can be more complex. A practical FLW measurement approach involves the development of key figures (coefficients) linked to produced volumes or turnover in specific industries. This approach, coupled with data collection from various sources like interviews, surveys, company reports, and statistics, exemplifies good practice for measuring FLW at these stages of the FSC (Miljøstyrelsen, 2021). Data collection typically occurs through surveys distributed among companies and stakeholders in the FSC. In some cases, data are collected through online platforms, such as the EU Platform on Food Losses and Food Waste, established in 2016.

Given these complexities in addressing FLW issues, EU project WASTELESS[2] aims to measure and monitor FLW across EU Member States (MSs). Work Package (WP) 1 contributes to the project by focusing on FLW measurement and monitoring framework harmonization, and the previous Deliverable (D) 1.1 in Task 1.1 aimed to map the existing FLW data collection practices and legislation actions might impact on them. Building upon the D 1.1 works, this report is integrated in the WP 1 Task 1.2, which is going to serve the WASTELESS project by recommending a harmonised methodological Framework for FLW quantification. The objective of this report is to document the improved framework for FLW measurement & monitoring that has been discussed and agreed upon by the project partners. It will include drivers, barriers, and successful practices for such a harmonised framework.

[2] WASTELESS - Waste Quantification Solutions to Limit Environmental Stress. https://wastelesseu.com/

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2. Methodology and materials

This study applied a mix of methodologies include both qualitative and quantitative research to achieve the objective of recommending a harmonised framework. First, literature review was conducted to better understand the current state of FLW measurement frameworks and definitions. Then, to further enhance the framework development by identifying key elements, drivers, barriers, and solutions, this study carried out the expert consultation through online survey. Key findings from the literature review were discussed and refined in a series of knowledge sharing and discussion sessions. Expert recruitment, survey questionnaire design, and survey data analysis were conducted in those sessions as well. Figure 1 provided an overview of the methodology development.

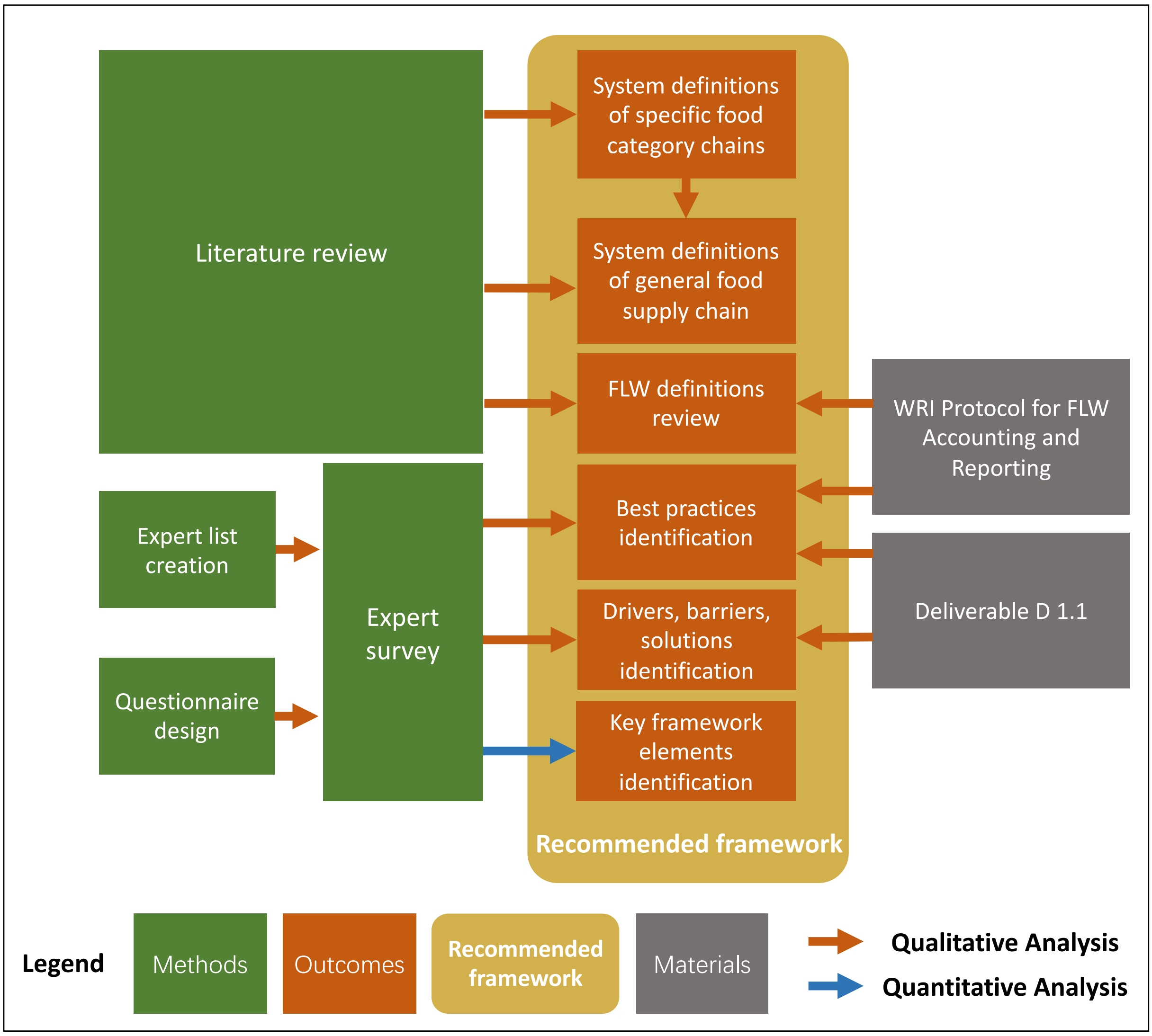

Figure 1 Integrated overview of framework recommendation process

2.1 Literature review

This study carried out three rounds of literature review. At the first round, we reviewed studies which developed FLW framework, including both peer-reviewed articles and grey literature. The scope of framework ranged from FLW quantification and measurement (Eriksson et al., 2018; FAO, 2019), to drivers identification (FUSIONS, 2014c; Hebrok & Boks, 2017), and FLW impacts assessment (Xue et al., 2019, 2021), as well as FLW Protocol (Hanson et al., 2016).

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In the second round of literature review, this report conducted deep analysis of the various FLW definitions. To better analyse these definitions, this study has established a set of criteria to access FLW definitions' relevance and applicability:

- Criterion 1. Is FL included in the definition, and if so, is it defined as a concept independent from FW?
  Criterion 1 aimed to check whether 'food loss' is defined clearly in the FLW definitions. For example, within the Food Loss + Waste Protocol (FLWP) (?) framework, FLW were jointly defined as 'aspects of food and/or associated inedible parts removed from the FSC' (Hanson et al., 2016), at this point, food loss lacks a dedicated and distinct definition.

- Criterion 2: If food clearly defined in the definitional framework?
  Criterion 2 focused on determining whether 'food' is defined along with the FLW definitions and identify any potential connections between FLW definitions.

- Criterion 3: Quality or quantity loss or waste?
  Criterion 3 aimed to identify the FLW definitions were defined in terms of whether quality or quantity loss or waste. Quality loss or waste refers to the decrease of quality attributes of food (HLPE, 2014), which could be reflected in nutritional and economic values or food safety (FAO, 2015), and quantity loss or waste refers to the decrease of food in terms of weight or volume.

- Criterion 4. Are inedible parts accounted as FLW?
  Inedible parts refer to the food components that are not intended to be consumed by humans (Hanson et al., 2016). Consequently, edible parts refer to those components that are intended to be consumed by humans. At some other studies, for example WRAP household FW measurement, a distinction is made between 'avoidable' and 'unavoidable' waste, mainly based on whether the food is edible or inedible (WRAP, 2020). In their definitions, inedible parts are measured independently.

- Criterion 5. Are animal feed and industrial use included in the FLW definition?
  This criterion focused on if animal feed and/or industrial use are defined as FLW.

- Criterion 6: Are human behavioural aspects considered in the FLW definition?
  Human behavioural aspects or decisions were considered in several definitional frameworks, for example FAO (2019) defined FW as the food quantity or quality decrease caused by decisions and actions from retailers, food services, and consumers. Human behaviours play a significant role in driving FLW (Vittuari et al., 2023). Therefore, incorporating human behavioural insights into the definitions of FLW could greatly enhance the effectiveness of these reduction strategies.

- Criterion 7. Are FLW definition determined based on their destinations?
  FLW destination refers to where FLW is directed (Hanson et al., 2016). This criterion aimed to identify whether the FLW are defined basing on the directions when they are discarded from the food supply chain.

The third round of literature review concentrated specifically on food supply chain boundaries determination. FLW studies that apply the approach of MFA, or life cycle approaches were included in the analysis, given that these methodologies could offer a comprehensive perspective in FLW quantification and FSC system boundaries identification. Four food categories were given devoted attention at this round of literature review, namely, 1) fruits, vegetables, fruit juices; 2) meat products; 3) potato products and cereal products; 4) dairy. The main objective of this round of literature review was to determine and outline the system definitions for each food category basing on the existing frameworks. These system definitions finally informed the recommendation on the general FSC system definition.

Drawing on their collective expertise and experience, all Task 1.2 partners collaborated to create the literature inventory. This inventory encompasses FLW frameworks relevant to the framework that is going to be developed in this study. To better analyse and refine the key findings of the literature review, this study organized several knowledges sharing and discussion sessions among Task 1.2 consortium. During the discussion sessions, all task 1.2 partners presented their key findings of framework literature review and proposed ideas about framework harmonization.

Following each food category framework, this study further examined the data availability and quality. Data examination carried out with the objective to identify relevant data sources for each FSC stages, markets, and FLW collection and measurement stages. Data quality assessment followed below the criteria:

- High quality: first-hand data available, like the Eurostat database.
- Middle quality: only literature or proxy data available, like the food loss and waste rate/coefficient estimation.
- Low quality: limited data available and cannot cover all the activities at a certain stage.

2.2 Expert survey

2.2.1 Survey implementation

This study conducted online expert surveys with the goal of identifying the key elements of a harmonised framework, along with its potential drivers and barriers, as well as solutions for effective framework harmonisation. Expert surveys were carried out using the online form collaboratively designed by Task 1.2 members. The questionnaire, available in Appendix I, was structured into four sections: data collection and reporting, monitoring and evolution, stakeholder engagement, and drivers and barriers identification. Each section comprised multiple questions, mostly seeking expert's evaluation on the importance of framework elements (Likert scale questions), along with open-ended questions asking their opinion on the drivers, barriers, and solutions of the framework harmonisation. Questions asking for experts' contact information (email address) as well as their professional roles were added into the questionnaire three days after the starts of the survey.

To better engage a diverse group of experts with varied research or professional backgrounds, all task 1.2 partners first contributed to creating a experts list before the launching of online survey. The list encompassed experts involved in FLW projects, researchers, FSC practitioners, NGO/Non-profit representatives, government officials specializing in FLW measurement or legislations. Survey invitations were distributed to these experts via emails. Follow up reminders were sent to those haven't provided respondence one week after the initial invitation.

2.2.2 Survey data analysis

The expert survey received 47 responses until the drafting of this report. However, 10 of these responses were excluded from the analysis, as they were received almost simultaneously, and all answers (both Liker scale and open-ended questions) turned out to be identical. The distribution of answers across experts' professional roles was as follows: 25 researchers, 3 Food Supply Chain practitioners, 6 non-profit/NGO representatives, and 3 policy makers and government officials. The analysis of the survey data incorporated both quantitative and qualitative approaches. Quantitative analysis was applied to the data from the Likert scale questions, using average, median, standard

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deviations, and identifying minimum and maximum ranks. Here described how those statistical indicators contributed to the framework elements identification:

- Average refers to the mean score of a specific Liker scale question, representing the perceived importance of the certain framework element.
- The median, on the other hand, refers to the middle score of the same question, it generally represents a typical value without the influence of outliers. In our study, the median value of the expert's ranks on the framework key element served as a complementary measure to the average value, especially where outliers were present.
- Standard deviations (Sd) measured the spread of experts' opinion on the importance of certain framework elements. A lower Sdvalue suggests a more unified view among experts. In particularly, when the average scores on the importance of specific framework elements are close, the Sd value ensure the understanding of whether there is a tendency to have a greater consensus about their importance among experts.
- The minimum and maximum values represent the lowest and highest scores ranked by experts, respectively.

The open-ended responses were analysed using MAXQDA software (Kuckartz & Rädiker, 2019), which facilitated the manual answers coding and clustering. In this study, we carried out the qualitative analysis in MAXQDA in four steps. First, a deep reading of all responses was conducted for general familiarization of the data. Second, all the responses were distilled into specific drivers. For example, for the question asking about the drivers of the harmonised framework, responses like "saving money" was categorized under the driver "Economic benefits" as it referred to the economic benefit of a harmonised FLW framework. Third, all the codes were refined by merging the similar and overlapped ones, and all codes were clustered into corresponding themes. Taking the drivers identification question as an example again, the driver "Economic benefits" was clustered into the theme of "Benefits identification" which encompassed all the potential benefits of a harmonised FLW measurement framework. The final step was visualization, all drivers and the categorized themes were presented along with the distributions across different professional role groups.

2.3 Identifying best practices and drivers/barriers through D 1.1 integration

Deliverable D 1.1 - *White book for FLW reduction, measurement, and monitoring practices* aimed to map current FLW measurement and monitoring practices, the relevant legislations impacting FLW measurement and reduction, across member states and food supply chain sectors. Building on the practice and legislation inventory, D 1.1 conducted a SWOT analysis to assess them. This study employed the D 1.1 SWOT analysis findings to inform the framework drivers, barriers, and solutions identification with the SWOT analysis findings.

To identify the best practices from D 1.1 inventory, this study integrated the key findings from expert survey and the Food Loss and Waste Accounting and Reporting Standard (Hanson et al., 2016). The expert survey highlighted that actual weighing as one of the key elements in a harmonized framework. FLWP proposed 10 specific FLW quantifying methods, 7 of them is clustered as "measurement or approximation", which refers to these methods that a FLW measurement actor could get direct access to the FLW. Those FLW quantifying methods include direct weighing, counting, assessing volume, waste compositing analysis, records, diaries, and surveys. Another 3 methods that could be used when actors cannot direct access to the FLW, for example mass balance, modeling, and proxy data are categorized as inference by calculation. Hence, this study applied a criterion in good practices identification: FLW measurement data collection practice should conduct by actual weighing or any other methods through directly accessing the FLW. FLWP emphasized that weighing FLW usually produces the most accurate results, while other methods like records, diaries, and surveys may generate varied accuracy data depends on the way in which they are collected (Hanson et al., 2016).

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Therefore, this study inferred those approaches such as direct weighing, counting, volume assessment, and waste composition analysis are more robust with greater precision and reliability. In addition, this study defined that a good practice should align with a clear FLW definition. Primary data sources are recommended basing on the expert survey results regarding the importance of primary and secondary data.

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3. Results and Discussions

3.1 Framework literature review

Literature review reports that FLW Standard (Hanson et al., 2016) is one of the most relevant frameworks to be adopted internationally, for the measurement of FLW. While the FUSIONS framework (FUSIONS, 2014) is often cited as well, but its application is more compliant to an EU context, as well as the Refresh frameworks (Refresh, 2017&2019). MFA models (and their improvements) like the JRC framework (Caldeira et al., 2019) is adopted widely in FLW research given their high accuracy. In addition, the UNEP Food Waste Index 2021 Report was also documented in the literature review.

The FLW Standard (Hanson et al., 2016) recommends conducting FLW quantification through two phases: i) the definition of material types and possible destinations (Figure 6) and ii) setting of a FLW inventory (Figure 2). The first phase mainly works to define FLW and determine their destinations (this part will be clarified in later the FLW definitions review section). The second phase, setting of a FLW inventory involves two parts, namely, i) 'What' is the scope of inventory, including the timeframe, the material type, destination, and boundaries, and ii) 'How' the quantification could be done, relying on quantification methods provided.

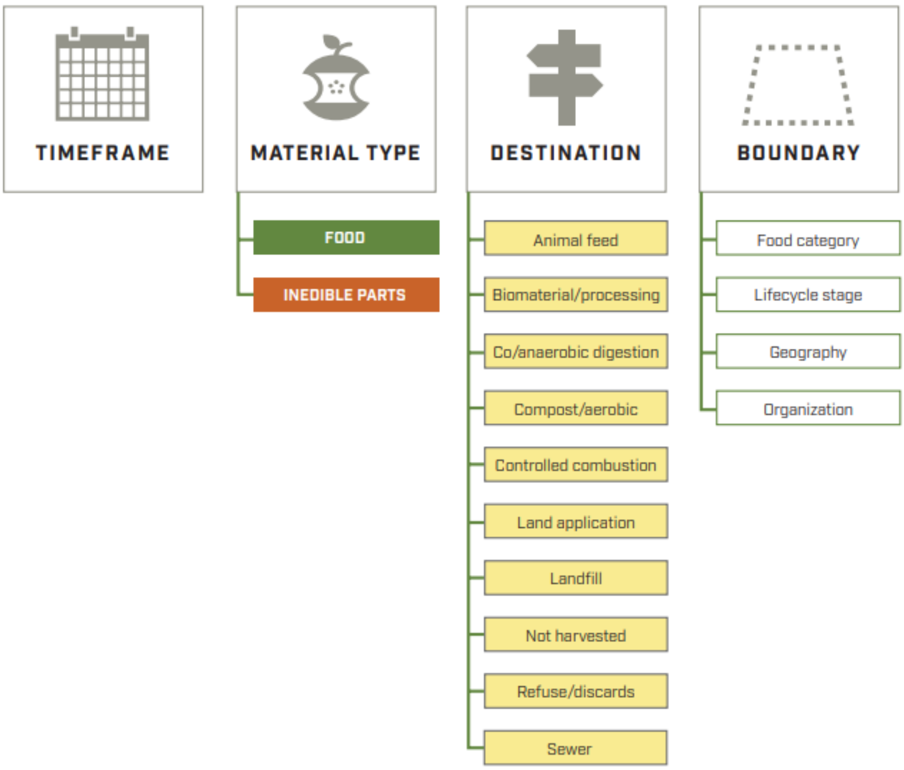

Figure 2 The scope of a FLW inventory under the FLW Standard (Hanson et al., 2016).

Conducting FLW quantification mainly depends on the users to define the timeframe and the targeting material types (Hanson et al., 2016). FLWP provides different potential destinations for FLW. FLWP gives users the possibility to identify or determine the "new" destinations adopting to their food business activities (e.g., use as fertilizer) or interactions with other businesses (e.g., selling to other business activities for extraction of bioactive compounds). For the identification of the boundary, the FLW standard also develops a list of classification to be able to increase transparency and comparability among FLW inventories. The implementation of the FLW Standard is required to follow 10 specific steps: define, review, establish, decide, gather, calculate, assess, perform, report, and set target. These

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steps should be aligning to specific requirements (Table 1), which are deeply described and clarified in the FLW Standard.

Table 1 Summary of requirements under the FLW Standard (Hanson et al., 2016).

REQUIREMENT	CHAPTER IN *FLW STANDARD*
1. **Base FLW accounting and reporting on the principles of relevance, completeness, consistency, transparency, and accuracy**	Chapter 5
2. **Account for and report the physical amount of FLW expressed as weight** (e.g., pounds, kilograms, tons, metric tons)	Chapter 7
3. **Define and report on the scope of the FLW inventory** a. ***Timeframe.*** Report the timeframe for which the inventory results are being reported (including starting and ending date) b. ***Material type.*** Account for and report the material type(s) included in the FLW inventory (i.e., food only, inedible parts only, or food and associated inedible parts). *See Box 1 for definitions* If food or associated inedible parts removed from the food supply chain are accounted for separately in the inventory: ► Describe the sources or frameworks used to categorize a material as food or as inedible parts. This includes stating any assumptions that were used to define whether or not material was "intended" for human consumption ► Describe the approach used to calculate the separate amounts. If applicable, describe all conversion factors used and their sources c. ***Destination.*** Account for and report the destinations included in the FLW inventory (i.e., where material removed from the food supply chain is directed). If the destination is unknown, then report the initial path(s) at a minimum. *Table 1 outlines the options* d. ***Boundary.*** Report the boundary of the FLW inventory in terms of the food category, lifecycle stage, geography, and organization (including the sources used to classify them). *See Table 2* e. ***Related issues.*** *Packaging and other non-FLW material.* Exclude from the FLW inventory any material (and its weight) that is not food or associated inedible parts removed from the food supply chain (i.e., FLW). If a calculation is needed to separate the weight of FLW from non-FLW materials (e.g., subtracting the weight of packaging), describe the approach and calculation used *Water added/removed from FLW.* Account for and report the weight of FLW that reflects the state in which it was generated before water was added, or before the intrinsic water weight of FLW was reduced. If a calculation is made to estimate the original weight of FLW, describe the approach and calculation used *Pre-harvest losses.* Exclude pre-harvest losses from the scope of the FLW inventory. Users may quantify such losses but shall keep data separate from the FLW inventory results	Chapter 6
4. **Describe the quantification method(s) used.** If existing studies or data are used, identify the source and scope	Chapter 7
5. **If sampling and scaling of data are undertaken,** describe the approach and calculation used, as well as the period of time over which sample data are collected (including starting and ending dates)	Chapter 8
6. **Provide a qualitative description and/or quantitative assessment of the uncertainty** around FLW inventory results	Chapter 9
7. **If assurance of the FLW inventory is undertaken** (which may include peer review, verification, validation, quality assurance, quality control, and audit), create an assurance statement	Chapter 12
8. **If tracking the amount of FLW and/or setting an FLW reduction target,** select a base year, identify the scope of the target, and recalculate the base year FLW inventory when necessary	Chapter 14

EU project FUSIONS, as one of the main contributors in the development of the FLWP, have developed a FLW methodological framework (FUSIONS, 2014a) adopted to the EU context (FUSIONS, 2014b). FUSIONS framework suggests that a reliable FW estimation could be repeated over time, through a robust methodological framework. Correspondingly, FUSIONS framework includes: i) consistent FW definition (and its component), and ii) consistent system boundaries within the FSC stages. Without a framework, datasets are not always transparent and comparable between each other.

FUSIONS framework started from a generic definition of resource flows within a food system, and their destination (Figure 3). The generic framework is divided in four sections: 1) major steps from production to consumption (i.e., FSC stages); 2) FW destinations for food and inedible parts; 3) a dedicated section for feed destination from primary production pre-harvest, and 4) non-food destinations (e.g., bio-materials, biofuel) from primary production pre-harvest and post-harvest. The generic framework from Figure 3 has been used by FUSIONS to clear boundaries in the FSC and provide a more compliant definition of FW (FUSIONS definitions will be clarified later). From this, the FUSIONS framework (Figure 7) divided (and defined) FW as every food and inedible part removed from the FSC

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(indicated in B-ii). Animal feed and different kind of bio-valorisation has been classified under 'Valorisation & Conversion' (indicated in B-i). The framework does not include the primary production pre-harvest (A1), as part of the FSC, considering its contribution to FL generation, and/or to animal feed and non-food supply chains.

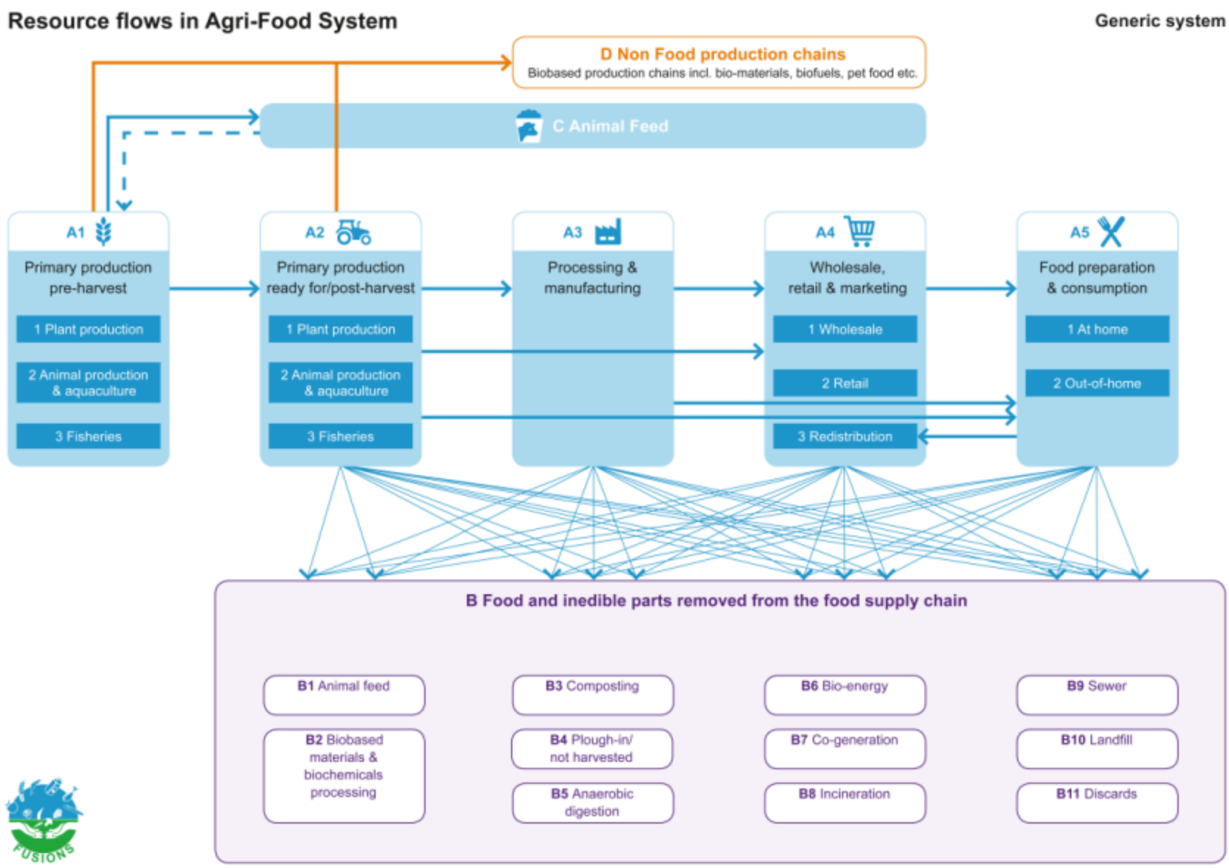

Figure 3 Generic system framework presented by EU project FUSIONS (FUSIONS, 2014).

EU project Refresh, which focused on the reduction of avoidable waste and improved valorisation of food resources, established specific FSC definitions to identify FW drivers (Refresh, 2017). Through the bottom-up analysis, Refresh (2017) identified FW drivers of various food categories. These categories include bread, dairy, potatoes and tomatoes, processed meat & poultry, prepared meals (sandwiches). Refresh (2017) distinguished FW drivers within different FSC process sectors, which were primary production, processing & packaging, retail & logistics, and foodservice & household.

To better highlight the role of FW reduction in improving the agri-food system sustainability, Refresh project integrated life cycle cost and life cycle assessment into the analysis (Refresh, 2019). Specific attentions were given to the German meat supply chain, as well as EU tomato case. Material Flow Analysis approach was employed in the FSC system definitions establishment. Both German meat and EU tomato supply chains were comprehensively defined tailoring to their production, processing, retailing, and consumption activities. Within those system definitions, FLW generated in each key processing sectors were defined along with their management approaches.

JRC MFA model framework (Caldeira et al., 2019) was developed basing on 'Practical Handbook of Material Flow Analysis (Brunner & Rechberger, 2004) and principles of life cycle thinking (e.g., LCA). The model includes these different aspects:

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- a detailed compilation of coefficients to fill data gaps which may derive from the definition of FW flows,
- a breakdown for each FSC stage for different food groups (or categories),
- circular flows for FW to be destined to other uses (e.g., feed), referred to as 'by-product'.

JRC framework works efficiently when no specific data exists or are available, and it could serve as a complement to direct data measurements (e.g., waste composition analyses, surveys, diaries). The framework relies on a mass balance approach, following the principle of mass conservation, or using coefficients from the literature or statistics data from databases (e.g., FAOSTAT, Prodcom). The model starts from primary production (excluding pre-harvest losses) values calculated from FAO Commodity Balance Sheets[3] (CBS), obtaining the 'total yield', which include also pre-harvest losses. Coefficients from the literature are also included. Imports and exports of raw materials and manufactured products are determined from trade flows reported in FAOSTAT[4] and Prodcom[5] statistics. These statistics data should be carefully considered, since they may contribute to the uncertainty in the FW accounting, together with systematic errors and other sources of error. Both FAOSTAT and EUROSTAT have strong limitations (e.g., data may be missing for some MS, or data are provided for previous years which are not representative of the current situation), and the coefficients may not be representative of the EU.

The MFA model developed by Caldeira et al., 2019 has been compared with a Waste Statistics (WS) model, using data from Eurostat, collected on the basis of MS reporting on their FW generation levels, using the European Waste Classificatio for statistical purposes (ECW-Stat) from the Regulation (EC) No 2150/2002 (Caldeira et al., 2021). It permits to estimates FW amounts in each MS. These two models (Figure 22) were assessed in three MS (i.e., Germany, Italy, Denmark), with the MFA model (version 1.0, available also in De Laurentiis et al., 2021) being updated for the inclusion of FW definition from the WFD, and the inclusion of other data sources, such as industry associations data.

As a result, JRC model reports higher FW levels, compared to WS model. This difference is attributed to a potential underreporting of FW collected by different MS, and other issues related to data collection (e.g., FW weight influenced by water content, discrepancies between national and EU waste codes). Considering how the MFA model is structured, the quantification is more reliable, but there are problems derived from the need of (also) reliable FW coefficients and FW data, which are often not available, as discussed above.

The JRC MFA model has another possible function, which is the quantification of food amount consumed within the EU, and its MS. A comparison was made with the EFSA Comprehensive European Food Consumption Database[6], to perform a plausibility check of the MFA model itself. Also, in this case, the amounts quantified with the MFA model are higher than EFSA data, which derives from national consumers surveys. They may underestimate the amount of food consumed since e.g., some food categories are ingredient of processed products, and they may not be counted in these surveys. A reliable food amount quantification is necessary, since this data is exploited by EFSA also for the risk assessment of different regulated products (e.g., *novel foods*), which has to be accurate, in order to avoid potential risk for consumers' health.

Version 2.0 of JRC MFA model (De Laurentiis et al., 2023) reports the calculation procedure for food loss, and its application in the FSC for different food categories. To improve the MFA model, sales data were considered, and overcome limitations from the low availability of official statistics data. Their use is not direct, but they are meant to derive FW estimates from statistics of production and selling of fresh and processed food, after determine specific coefficients.

[3] https://www.fao.org/faostat/en/#data/CB
[4] https://www.fao.org/faostat/en/#data/TCL
[5] https://ec.europa.eu/eurostat/databrowser/product/view/ds-056120
[6] https://www.efsa.europa.eu/en/data-report/food-consumption-data

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Other improvements are the breakdown of food categories (e.g., apple and pears FW quantification in the 'fruit' food category), and improving the modelling of manufacturing stage, considered as the most complex part of the MFA model, since statistics data have lower availability, in comparison to other FSC stages. Trade associations were involved to obtain necessary statistics data. In the case of fruit juice FSC, data obtained were useful to further disaggregated FW amounts and determine 'by-products' levels and their destination.

UNEP framework (UNEP, 2021) consists for three levels (Figure 4), to be used by a country to measure and monitor the FW generated internally. Level 1 is used to obtain approximate estimations for the country where the method is used. It is considered generally as insufficient, being based on proxy data, and direct measurement of FW is required. Level 2 and Level 3 are based on FLW Standard and are interconnected with each other. Level 3 is meant to provide further information obtained from Level 2, such as disaggregation of FW (e.g., edible and inedible parts), inclusion of other FW destinations, report of FW level not covered by the Index.

Level 1 estimations take into account national FW estimates made previously performed, and assess their compliance with the SDG 12.3 target. If these national estimations are not available, Level 1 estimates are determined, using national studies (if available) and extrapolations from estimates observed in other countries. Level 1 method consists of 5 stages. The stages are summarised below:

1) Search and collate existing data: from literature reviews to collect FW estimations in the world, considering also FSC stages, and national and sub-national level studies;
2) Filter data: to consider only data from direct measurement studies;
3) Adjust some data: data points were corrected to guarantee the comparison (e.g., estimation of FW inedible parts, when only FW edible parts are known);
4) Extrapolate for countries without data: the sum of estimates is normalised to give the FW amount per capita per year, used to estimate FW level in countries without available studies;
5) Assign confidence rating: the rating indicates the suitability of the estimation for FW tracking over time. The ratings are divided in high, medium, low and very low. Methodological details (e.g., geographic coverage, sample size, adjustment need) determine the attributed confidence rating. It is to note that it is not a quality judgment.

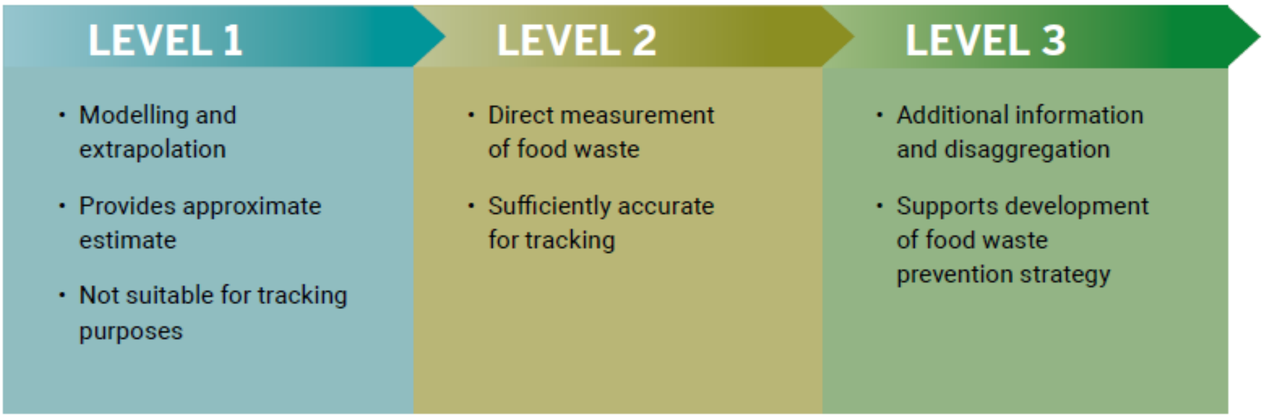

Figure 4 Index Levels proposed by UNEP (2021) as frameworks for the quantification of FW.

3.2 FLW definitions overview

This study examined various FLW definitions used in EU project (FUSIONS, 2014), peer-reviewed article (JRC, 2023), technical report (FAO, 2019), and industrial protocol (Hanson et al., 2016) (see Table 2). We found that the FLW definitions were inconsistently applied across studies. Results showed that the

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definitions of food loss were missing in most of the studies, including EU project (FUSION, 2014), WRAP (2020), and FLW Protocol (Hanson et al., 2016). Notably, the JRC study included food loss definition but failed to differentiate it from food waste, which covers all the lost or wasted food across the whole FSC. Results showed that while all definitions described 'food' clearly, they varied in whether to include inedible parts. FAO (2019) food definition excludes inedible parts, which on the other hand was included in JRC (2023) food definition. WRAP (2020) did not define inedible parts as food unless they are edible food spoilage. FUSIONS (2014) excluded inedible parts food and also highlighted that if the food divert to non-food supply chains will stop being defined as food. The variances in defining food impact the difference in FLW or FW definitions. FAO (2019) didn’t account the inedible parts in FLW, while JRC (2023) included, this respected to their food definitions. FUSIONS (2014) and WRAP (2014) accounted the inedible parts waste in their FW definitions even though inedible parts were not considered as food. This might be due to their FW definitions were made aligning with FLW destinations. To be detailed, WRAP (2020) provided a food waste destination list, which all the food and inedible parts ended there would be regarded as food waste. Same concept is found in FUSIONS (2014) as they divide the food waste destinations into two parts: valorisation and conversion, and food waste. Human behaviour included in the FAO (2019) definitional framework as they defined the FLW as the consequences of human decisions and actions. Details of all these definitions are described later.

Table 2 FLW definitions summary.

#	Source	Criterion 1[7]		Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7
1	FAO (2019)	Y	Y	Y	Both	N	N	Y	N
2	JRC (2023)	Y	N	Y	NA	Y	N	Y	N
3	WRAP (2020)	N	N	Y	NA	N	N	N	Y
4	FLW Protocol (2016)	N	N	Y	NA	Y	N	N	N
5	FUSIONS (2014)	N	N	Y	NA	Y	Y[8]	N	Y

Table legend. “Y” stands for “Yes”, indicating that the corresponding definition meets the specified criterion. “N” stands for “No”, indicating that the corresponding definition does not meet the specified criterion. “NA” stands for “Not Available”, indicating that the corresponding definition does not include the elements the specified criterion aimed to determine.

FAO (2019) proposed a comprehensive conceptual framework on the definitions related to FLW. The terms ‘Food loss’ and ‘Food waste’ are distinctly defined: ‘Food waste’ is generated at the retail and consumption levels, whereas ‘Food loss’ occurs in the earlier FSC stages. FAO (2019) defines clearly what is ‘food’, which refers to any substance that intended for human consumption. At this point, inedible parts like banana peels were excluded from the definitions of food. Correspondingly, inedible parts are not accounted in FLW. Additionally, economically productive uses like feed, industrial use, are not considered as FLW (Figure 5). Both quantity and quality loss and waste considered in the FAO (2019) definitional framework. And both FL and FW are defined as outcomes of human decisions and actions, integrating behaviour aspects at this point.

In Europe, food is defined slightly different in the Regulation (EC) No 178/2002[9] (i.e., *General Food Law*) as ‘any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans. Inedible parts like banana peels included in this

[7] The left column of Criterion 1 represents whether there is a “food loss” definition, and the right column represents whether it is distinguished from “food waste” definition.

[8] Industrial use except animal feed, biobased materials and biochemical processing are defined as food waste.

[9] European Parliament and Council. (2002). Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety.

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definition of food, but animal feed is not (JRC, 2023). And mainly building on this definition, Joint Research Centre (JRC) (2023) defined FW as all food that has become waste (waste is defined in Directive 2008/98/EC (European Parliament and Council, 2008) as 'any substance or objective which the holder discards or intends or is required to discard'). Hence, we can conclude that, inedible parts of food are accounted in the FW, animal feed and other industry use that are not intended for human consumption are excluded from this FW definition. However, FL is not defined independent from FW, as they are defined as 'Food crops left on field and ploughed in, mortality of the animals ready for slaughter, both during transport to slaughterhouse and rejects at slaughterhouse.' (JRC, 2023). Since all kinds of waste of food defined as FW, here FL may overlap with the FW definition as it mainly refers to the FW which occurs at the PP. In addition, we didn't see any clear definitions regarding the quantitative and qualitative FLW.

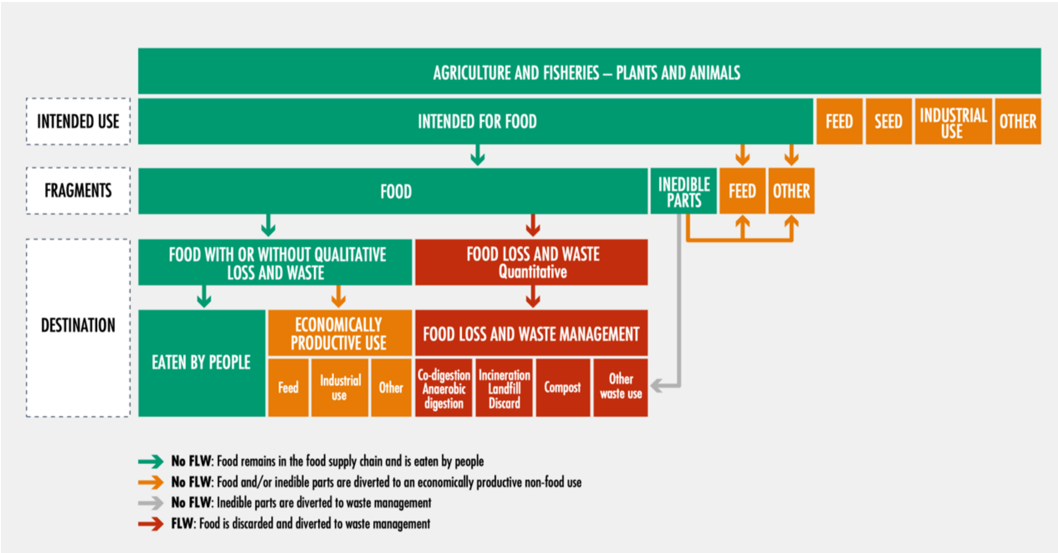

Figure 5 Conceptual framework for FLW from FAO (2019)

WRAP defines 'food' as any substance that is – or was at some point – intended for human consumption (WRAP, 2020). Both food and drink are encompassed in this definition, but inedible parts are not. Inedible parts are components that are associated with food but are not intended for human consumption. WRAP (2020) highlights that foods that are spoiled and no longer edible also included in the definition of food since they were intended for human consumption. While food and inedible parts are defined separately and distinct from each other, waste from both are accounted in FW. FW in WRAP (2020) is defined based on their destinations, as WRAP (2020) provides a list of food destinations, like landfill, composting/aerobic processes. Only food or inedible parts ended in these destinations are defined as FW. Animal feed, industrial use, and redistribution to people are not in the list, but rather as food surplus. No FL definition defined in WRAP (2020) as the FW definitions cover all stages of the supply chain. And it is not clear whether FW definition encompasses both quantity and quality loss and waste.

Food Loss+ Waste Protocol (FLWP, 2016) adopts the definitions of 'food' and 'inedible parts' from FAO (Codex Alimentarius Commission, 2013), which align with the definitions from FAO (2019). Food redistributed to other people does not belong to FLW, nor does animal feed and industrial use (see in the figure 6). FLWP provides a set of possible FLW destinations for food/inedible parts that are removed from the food supply chain. However, it does not provide clear definitions on food loss and food waste, just collectively refers to them together to simplify the categorization of food and/or inedible parts that are removed from the food supply chain. FLWP highlights that it is up to the standard users to define FLW adopting to their own interests and quantification goals. In addition, it is not clear of whether quantity and quality loss and waste defined in the FLWP definitional framework, either no human behaviour aspects used in the definitions.

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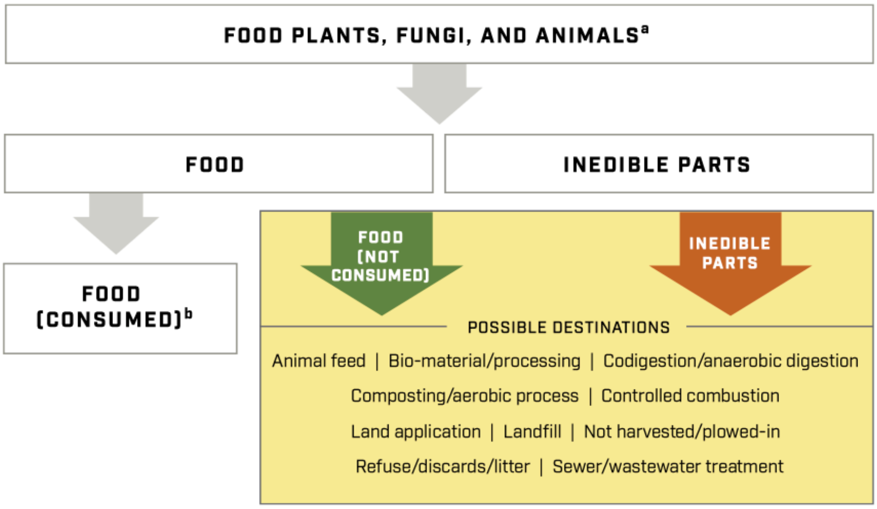
FUSIONS, the EU funded project which worked towards a more resource efficient Europe by significantly reducing FW. In its definitional framework for FW, FUSIONS defined food as 'any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be eaten by humans'. Inedible parts are not included in this food definition but are accounted together with food to define the FW. A definition to the FSC is also provided in FUSIONS framework. Regarding the destinations, which refer to the directions after food and/or inedible parts being removed from the FSC, FUSION (2014) provides a list of specific destinations. Correspondingly, all the food and/or inedible parts that are removed from the supply chain and into these destinations are defined as FW (the section of B-ii Food Waste in figure 7), excluding animal feed, biobased materials and biochemical processing. This definitional framework does not mention both quantity and quality loss and waste, as well as the human behaviour aspects. In addition, no FL definition provided as the FW definitions in FUSIONS (2014) cover the whole supply chain.



[a] Intended for human consumption (i.e.., excludes crops intentionally grown for bioenergy, animal feed, seed, or industrial use)
[b] At some point in the food supply chain (including surplus food redistributed to people and consumed)
Source: Adapted from FAO. 2014. Definitional Framework of Food Loss. Working paper of the Global Initiative on Food Loss and Waste Reduction. Rome, Italy: FAO.

Figure 6 Figure of material types and possible destinations under the FLW standard from FLWP (2016)

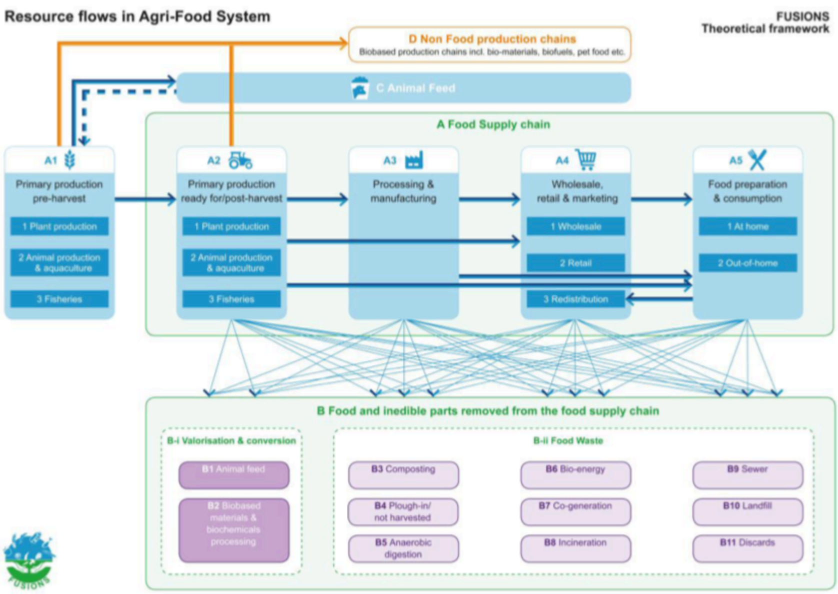


Figure 7 The FUSIONS theoretical framework from FUSIONS (2014)

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3.3 FLW framework development

3.3.1 Framework of fruits, vegetables, fruit juices

'Fruits' are considered as a subcategory of vegetables consisting of the seeds and surrounding pulpy tissues. There are some exclusions which are often applied, such as nuts, cereal grains, seeds, coffee and cacao beans (IARC, 2003).

There are different plants species which produce fruits (i.e., true fruits and false fruits) destined for human consumption. Each type of fruit consists of edible and inedible parts (Figure 8), whose distinction is usually linked to cultural differences, or different perception of potential health risks (e.g., contaminants or chemical residual in the fruit peel) (Hoehn et al., 2023). There are also social norms, attitude and perceived behavioural control, which applies also to the so-called 'perceived inedible parts' (PIPs) (e.g., stalks, leaves, peels, and seeds), which contribute to total FLW amount (Gallagher et al., 2022). There are also parts which must necessarily be considered as 'inedible' (e.g., apple cores, grape rasps) (Beretta et al., 2013). As regards peels, a classification for 'edible peels' and 'inedible peels' of fruits is provided by FAO in the Codex Alimentarius CXA 4-1989 (FAO, 1993).

Edible fruits are generally part of the angiosperms (*Angiospermae*) division of the *Plantae* kingdom. They consist of three parts, which form the fruit pericarp, namely i) exocarp (i.e., outer epidermis); ii) mesocarp (i.e., tissue between 'endocarp' and 'exocarp', and iii) endocarp (i.e., inner epidermis and internal tissue inside vascular ones), Another division made is between fleshy fruits (e.g., apples, peaches), made of succulent tissues and dry fruits (e.g., walnut, almond, hazelnut fruits[10]), with a high dehydrated pericarp (IARC, 2003; Cerri & Reale, 2020; Mendelson et al., 2020). Considering the different species, the 'mesocarp' is the usual edible part (e.g., apple), but there are cases where also the 'exocarp' (e.g., grape peel) and the 'endocarp' (e.g., orange, melon) may contribute to the edible part of the fruit. It is not possible to identify univocally the edible part of a fruit, considering the anatomic structure.

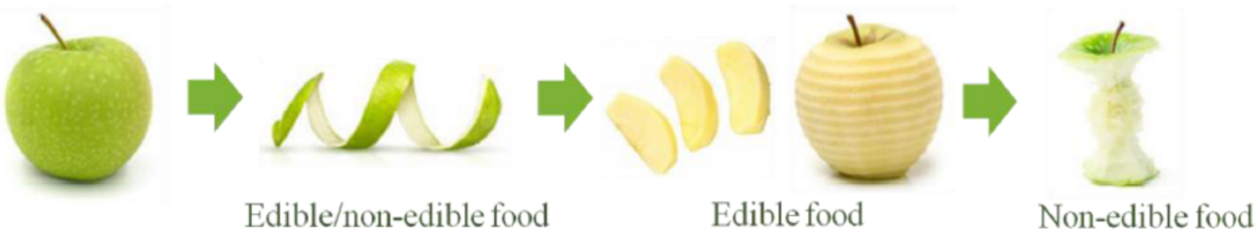

Figure 8 The distinction of edible and inedible parts of a fruit (e.g., apple), including parts which may be considered as both (e.g., peel) (source: Hoehn et al., 2023)

Fruits may be destined to be sold fresh[11] or to be processed to obtain different products, such as fruit juice[12]. The FSC has been described by De Laurentiis et al., 2023, and it starts with fruits which leave PP. They may be destined to distribution as fresh product, and/or manufactured to obtain processed products (e.g., fruit juice). The residual parts of the manufacturing process are considered as 'by-product' or 'FW', according to the case and the potential destination. This model includes 'by-products'

[10] In these cases, the edible part for human consumption is the seed. The fruit parts are generally destined to use as animal feed, extraction of bioactive compounds, energy production or other uses.
[11] There are marketing standards defined by Regulation (EU) No 1308/2013 and Commission Delegated Regulation (EU) 2023/2429. They are listed in Annex I, Part IX of Regulation (EU) No 1308/2013 (fruit and vegetables).
[12] Fruit juices are regulated by Directive 2001/112/EC. They are listed in Annex I, Part X of Regulation (EU) No 1308/2013 (processed fruit and vegetables).

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and 'FW' only as 'inedible part' of the fruits, and does not consider added ingredients and evaporated water (the latter is considered by the "improved" model by Dong et al., 2022). It refers only to the M&P of the FSC. The R&D stage, and consumption stage (i.e., food service and households) is generically described by De Laurentiis et al., 2021 (Figure 11). It was also possible to disaggregate 'fruit category' in specific 'fruit groups' (e.g., apples, bananas, grapes). The valorisation of fruit waste has been studied by Dulo et al., 2022, including e.g., feed uses, bioenergy production, different industrial applications.

The fruit juice modelling has been realized with the support of the European Fruit Juice Association (AIJN) data, permitting the disaggregation of waste and by-products. There is no sufficient availability of data related to the amount of fruit used for fruit juice production in each country[13]. When data is available, the model update should provide a more efficient modelling of the fruit juice supply chain.
The botanical definition of 'vegetable[14]', which include 'fruit' as a subcategory, refers to any kind of plant, without consideration for its edibility. For nutrition purposes, the term refers to a refers to a plant cultivated for its edible part(s), or refers to the edible parts of a plant, which include the stems and stalks, roots, tubers, bulbs, leaves, flowers and fruits (e.g., carrots, broccoli, spinaches) (IARC, 2003). The same considerations described above apply to edible and inedible parts (PIPs included) of vegetables (FAO, 1993; Gallagher et al., 2022; Hoehn et al., 2023) and waste valorization routes (Dulo et al., 2022). There are some products usually considered only as 'vegetables', which are classified as 'fruits' from a botanical point of view. This is the case of e.g., eggplants, cucumbers, peppers and legumes[15] (Mendelson et al., 2020). Both vegetables and fruits may be consumed fresh, but they are exploitable for the production of different processed products (e.g., juices, jams, preserves) and the residues by-products or wastes (e.g., peels, seeds, skins) may be used for the extraction of bio-active compounds or for innovative uses, such as the production of edible films (Majerska et al., 2019).

The vegetable supply chain (Figure 11) is also similar to the fruit supply chain described above by De Laurentiis et al., 2023, for the M&P stage. It is also possible to refer to Figure 10 (generic stage) for R&D, and consumption stages.

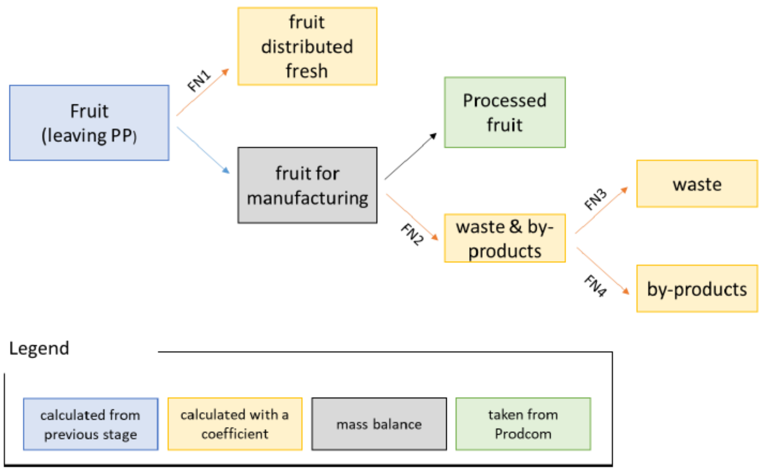

Figure 9 The fruit FSC described by De Laurentiis et al., 2023.

[13] At the moment, the model estimates the total amount of fruit used for processed fruit products, due to lack of more disaggregated data.
[14] A list of vegetables is included in the Directive 2002/55/EC, referring to plants for agricultural and horticultural production, but not for ornamental uses. Similar to fruits, there are marketing standards defined by Regulation (EU) No 1308/2013 and Commission Delegated Regulation (EU) 2023/2429. They are listed in Annex I, Part IX of Regulation (EU) No 1308/2013 (fruit and vegetables) and in Annex I, Part X of Regulation (EU) No 1308/2013 (processed fruit and vegetables).
[15] The edible part of legumes are the seeds, while the fruit (i.e., pod) is the part where seed are contained. In some cases, it is also eaten together with the seeds (e.g., string beans).

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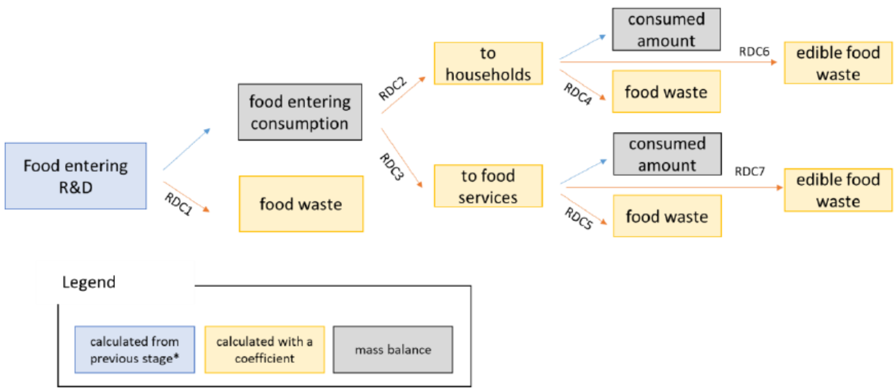

Figure 10 The generic FSC described by De Laurentiis et al., 2021 for the R&D and the consumption stages.

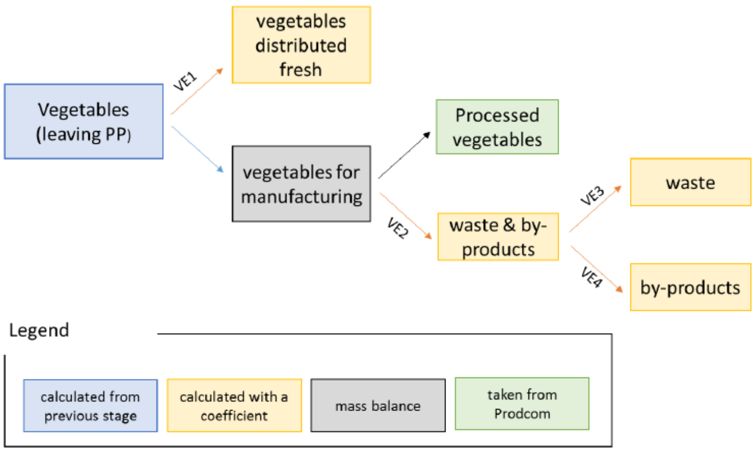

Figure 11 The vegetable FSC described by De Laurentiis et al., 2023.

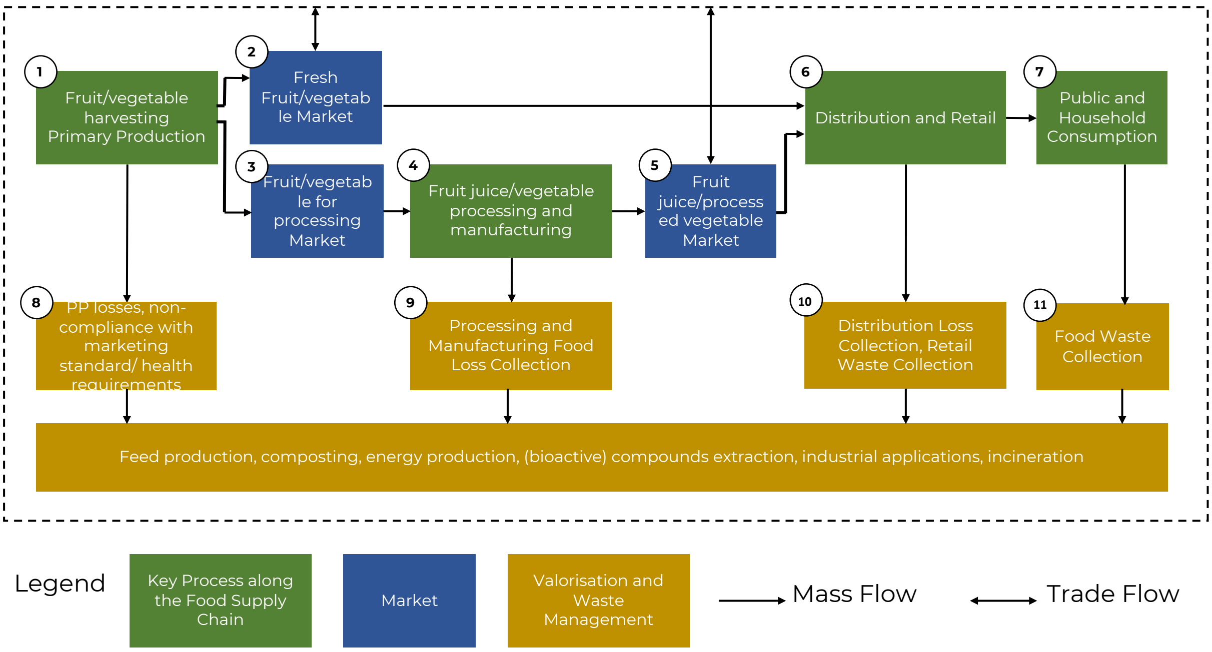

Figure 12 System definition of fruits, fruit juices, and vegetables supply chain

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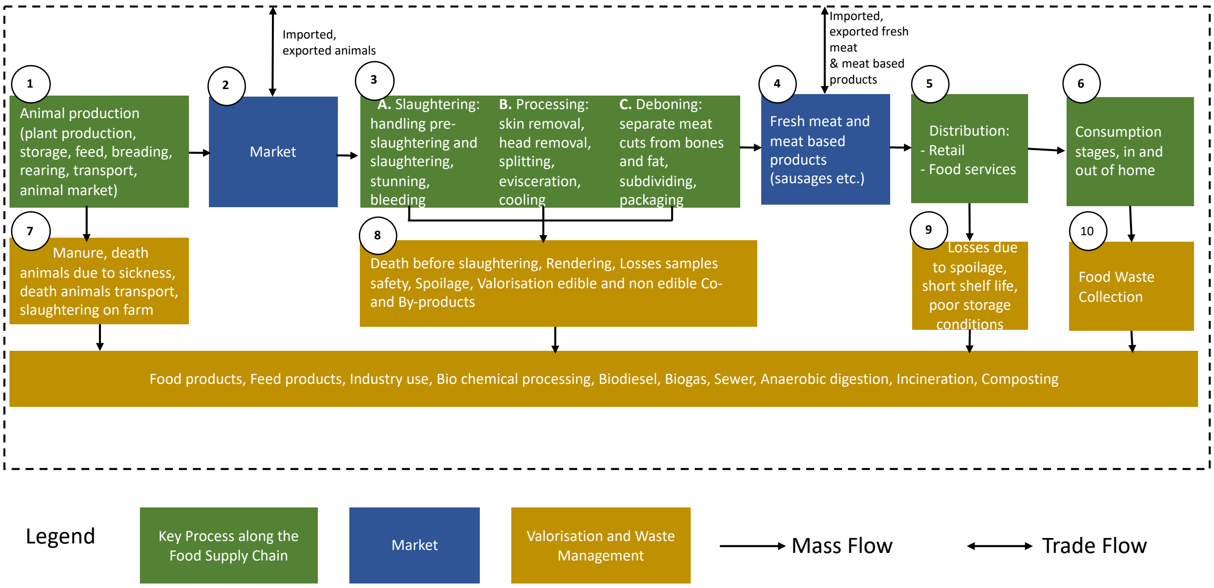
3.3.2 Framework of meat products

Due to following reasons, it seems important to distinguish and adapt MFA based on animal species. For example, animal's body composition will directly impact the quantity of meat loss during the processing (e.g, blood quantity loss: cows ~3-4%, horses ~9.9%, pork ~3.3% of living weight) (Belitz et al., 2008). Further, larger animal species do have an increased level of cutting and processing (cattle, sheep, pig) compared to smaller animal species (chicken, trout) (Beretta et al., 2013). Moreover, poultry meat production is significantly different from beef and pork production (e.g., chicken thighs and chicken wings are consumed with bones) (Amicarelli et al., 2021). Differences based on animal species can be seen in the following numbers from total FL from PP to processing step per meat category (Redlingshöfer et al., 2019):

- beef meet: 8.7% (0.3% valorisation for human consumption or animal feed)
- pork meat 6.9% (0.9% valorisation for human consumption or animal feed)
- poultry: 5.7% (0.9% valorisation for human consumption or animal feed)
- sheep meat: 2.8% (0.1% valorisation for human consumption or animal feed)

Besides different amounts of meat losses between species, a recent study found further differences in meat waste among consumers within the same meat category, depending on the meat product category such as organic whole chicken, diced chicken breasts, chicken breasts smaller quantity, chicken escalope and chicken breasts higher quantity (Cooreman-Algoed et al., 2022). Moreover, the age of animals and their sex influence as well the average slaughter loss (Belitz et al., 2008).



(Adapted based on Amicarelli et al., 2021, Beretta et al., 2013, 2019, Xue et al., 2019, Caldeira et al., 2019, Riedlingshöfer et al., 2017, 2019, Östergren 2014)

Figure 13 System definition of meat products supply chain

The definitions of Inedible parts of meat from common animal species are as follows: hides, skins, bones, tendons, feathers, blood, (inedible) offal, (with the exception of offal for which there is a human food market) (Amicarelli et al., 2021; Redlingshöfer et al., 2019). However, these definitions might change based on specific country and culture.

To get an overview of existing MFA, a total of eight studies focusing on the meat sector were investigated (Figure 14). Developed system definition of the industrial meat sector, based on material flow analysis specific targeting the meat sector (Amicarelli et al., 2021; Redlingshöfer et al., 2017, 2019;

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Xue et al., 2019; Refresh, 2019) or general food categories, including meat (Beretta et al., 2013; Beretta & Hellweg, 2019; Caldeira et al., 2019; Östergren et al., 2014).

Developed system definition of the industrial meat sector, based on material flow analysis specific targeting the meat sector (Amicarelli et al., 2021; Redlingshöfer et al., 2017, 2019; Xue et al., 2019) or general food categories, including meat (Beretta et al., 2013; Beretta & Hellweg, 2019; Caldeira et al., 2019; Östergren et al., 2014).

Overall, data quantity and quality for specific supply chains within the meat sector are insufficient (Amicarelli et al., 2021). Especially rare data or data with large variety exists for the whole farming management (animal production, stage 1, Figure 13), including the tracking of sick and death animals at the farms, during animal trade, transport and before slaughtering (Karwowska et al., 2021; Padalino et al., 2018). As well at the final consumption stage, data quality is lacking due to following reasons. Firstly, between the years 2010-2020 different methodologies were applied to measure food waste (OJEU, 2019). Secondly, studies often lack a representative number of households (Beretta et al., 2013; Quested, and Johnson, 2009). Thirdly, food waste among households was often measured via self-reporting food waste quantities, what can lead to an underestimation of the food wasted (Beretta et al., 2013). And finally, there is a lack of reliable data about the variation of household food waste quantities among different European countries, whereas consumer's waste behavior might be as well affected by inter-individual differences (e.g., country, age, gender, culture etc.).

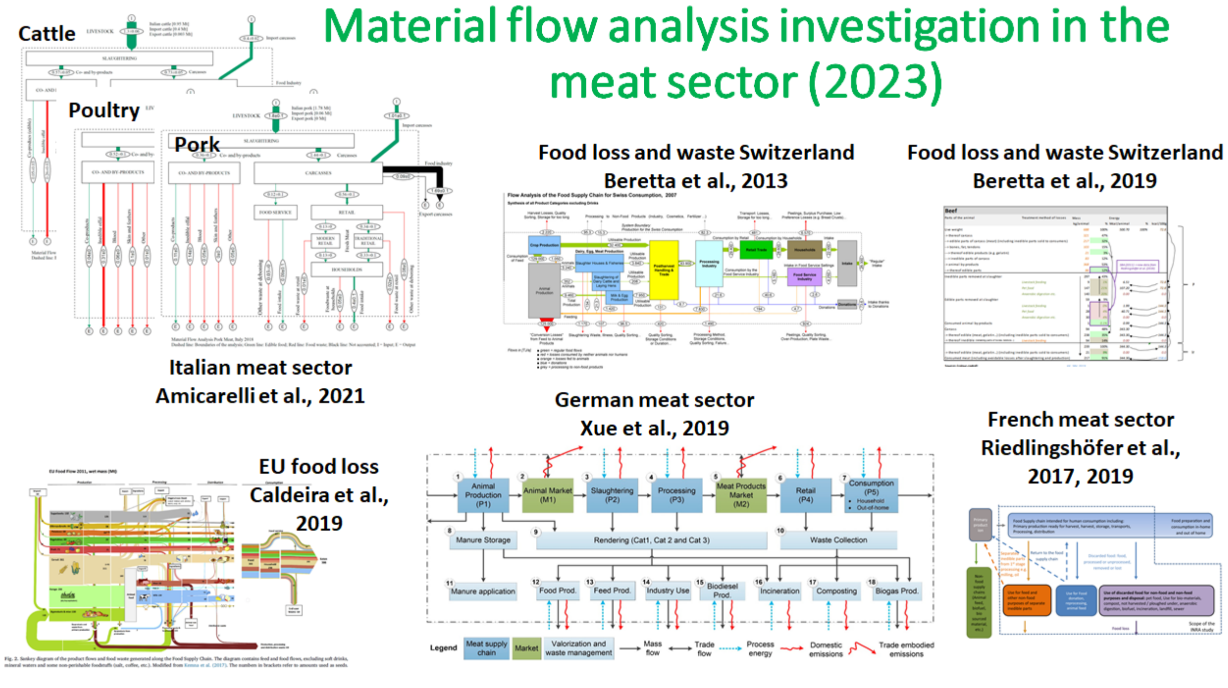

Figure 14 Frameworks that were integrated into the meat supply chain definition

Considering any meat supply chain, comparing data between studies and countries is difficult, as animals do have different characteristics (e.g., species, breeding techniques etc.) and slaughtering techniques. Moreover, as the analysis of different meat material flow analysis showed (Figure 13 and Table 9 in Appendix II), data are often old (might be due to confidentiality reasons on behalf of the industry) or not accessible or published.

To fill this gap, obtaining more detailed data about specific food supply chains from food production to consumption (on national and international trade [trade balance]), including their loss and waste

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management is of high relevance. For an improved meat framework, several points are considered to add:

- sources of disposal and quantity at each supply chain step (e.g., composting, incineration, biogas, biodiesel, industry use, animal feeding, food use) (Xue et al., 2019)
- spoilage during storage due to very short shelf-life and the condition of cold storage temperatures, or spoilage during distribution (Lipinski, 2020)
- production and loss of meat-based products.
- farm slaughter, pasture slaughter
- not legally defined waste: high-added value waste uncertain

Furthermore, to increase the data quality of household food waste, composition analysis instead of self-reported food waste is recommended (OJEU, 2019).

3.3.3 Framework of potato products and cereal products

Potato, a starchy tuber, is present in the market in both fresh and processed forms. De Laurentiis et al., (2021) have previously described the system boundaries for potato products supply chain as illustrated in Figure 15. A more comprehensive framework has been developed centered on the existing description which starts with the stage of potatoes leaving PP and involves the fresh potatoes distribution and manufacturing step. The proposed framework includes the possible reasons for FLW each stage of FLW and valorisation stages from harvesting to PHC.

As illustrated in figure 16, the specific activities in a potato product supply chain are defined as:

- Harvesting,
- Potato products: French fries, flake, granule, chips, and starch production,
- Distribution of potato products, starch,
- Public and household consumption of potato products and starch.

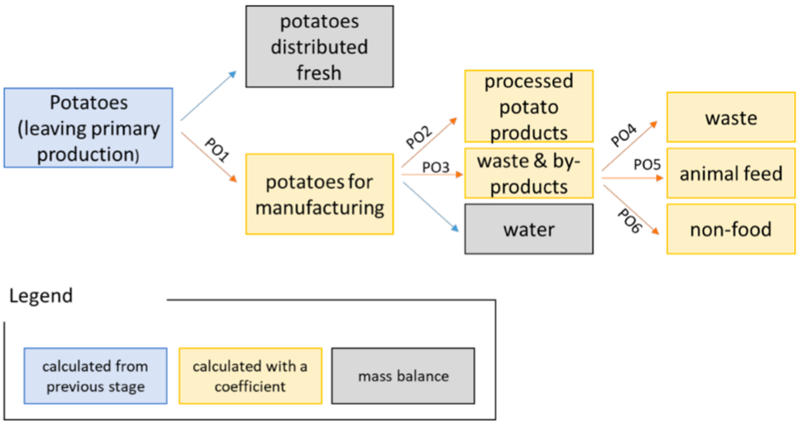

Figure 15 The potato products supply chain described by De Laurentiis et al., 2021.

Potato production involves cultivating suitable potato varieties based on factors such as climate, soil type, and market demand. Harvesting, either manual or mechanical, is applied after the potatoes reach maturity. Mechanical harvesters are commonly used to minimize damage to the tubers. Potato is supplied as fresh potato, or it is used as a raw material in certain products production such as French fries, flakes, granules, and chips. Due to its high starch content, potatoes are also utilized in starch production (Bhattacharya, 2023). Therefore, after harvesting, potato market includes both fresh potato or to be utilized in P&M. The primary sources of loss and waste in the fresh potato supply chain

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include field loss (1–2%), grading loss (3–13%), storage loss (3–5%), packing loss (20–25%), and retail waste (1.5–3%) (Terry et al.,2011). The low quality of potato, mechanical or harvest damage (affected by weather), grade-out, blight, greening, bruising, skin, fungal or pest damage are the reasons of food loss (WRAP, 2012).

According to a study determining the FLW along the potato products supply chain in Switzerland, approximately 53–55% of the initial fresh potato production and 41–46% of the initial processing potato production are ultimately lost across the entire potato value chain (Willersinn et al., 2015).This extensive study, incorporating field trials, diaries, interviews with processors, retailers, and consumers, as well as a literature review, revealed that losses during harvesting range from 15% to 24%, regardless of whether the potatoes are intended for fresh consumption or processing. The cultivation methods, site parameters, and quality parameters (degrees of infection with microorganisms, damage by slugs or wire worms, deformities, green tubers, rottenness, iron spots, and other damage) are determinant regarding FL at this stage (Keiser et al., 2007). At the P&M step, 19% of the delivered potatoes are lost with the largest portion (14%) attributed to peeling, 2% to storage and transportation, and 3% to quality issues.

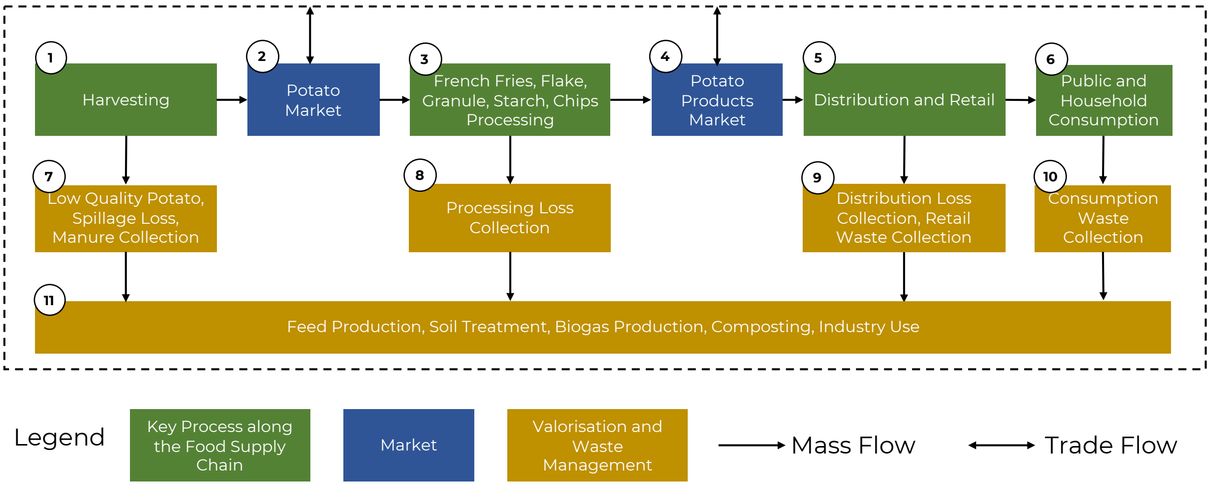

Figure 16 System definition of the potato products supply chain

Peeling losses depend greatly on the quality of the raw material. Losses within the processing industry exhibit significant variability, contingent on the specific products being manufactured. Throw-outs generated during French fries' production can be reused for the manufacturing of mashed potatoes. In contrast, specialized chip producers reported challenges in recycling losses (Willersinn et al., 2015). Losses at the retail stage of the potato supply chain are uncommon, particularly in the case of processed potato products. On the other hand, at public and household consumption stage, fresh potato waste and the peeling losses are also very common.

While there are studies measuring FLW at specific stages of potato products supply chain, there is a crucial need to collectively monitor and evaluate all stages. The existing databases provided in Table 11 (Appendix II) can be valuable for estimating FLW throughout the potato supply chain. European Statistical Office (Eurostat), (United States Department of Agriculture (USDA) and Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) collect statistics encompassing the harvested potato amount, both in the fresh and processed potato market, including import and export data. They also provide data on processing, distribution, and retail. EFSA provides databases on food consumption, and FAO has established a database on FLW at each stage of the potato supply chain. However, these datasets are limited to certain countries, lacking a comprehensive context across different nations. For instance, while the data by Willersinn et al. (2015) is valuable, it only covers the Swiss potato supply chain. Furthermore, the identification of the FSC stages to which data in databases corresponds is challenging due to the absence of common FSC boundaries and standardised terminology.

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Wheat, maize, rice, barley, rye, and oat are common cereal crops mostly consumed in the world. De Laurentiis et al. (2021) has been previously described the system boundaries for specific cereal products (common wheat, maize, rice, and barley) (Figure 17 illustrates the example of common wheat supply chain). They do not include the harvesting, PP stage, possible reasons or relevant stages for FLW and valorisation techniques in their models.

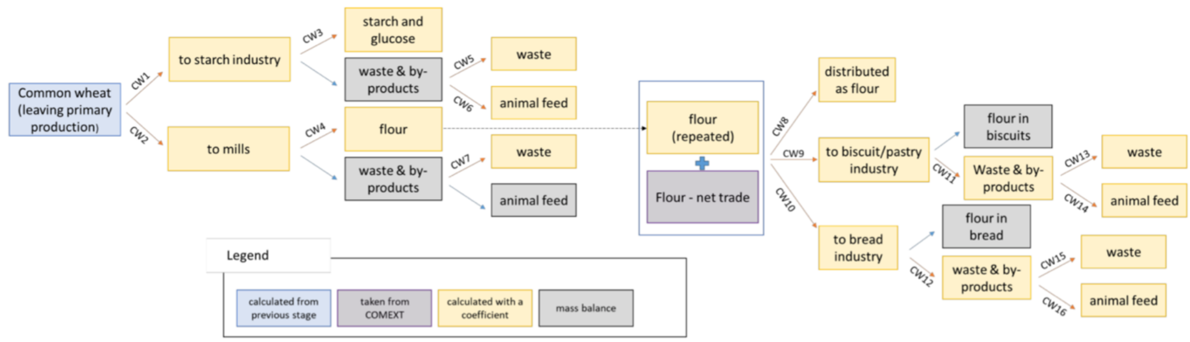

Figure 17 The cereal products (common wheat) supply chain described by De Laurentiis et al., 2021.

Although the processing of cereals somehow differs depending on crops, it is possible to establish a general framework by considering the key processes along the cereal products supply chain as follows

- Harvesting and subsequent primary production steps to obtain grains including threshing, cleaning, hulling, and drying,
- Milling, cereal products (bakery products, flakes, pasta, etc.) production, starch production, beer production,
- Distribution of cereal products, starch, and beer,
- Public and household consumption of cereal products, starch, beer.

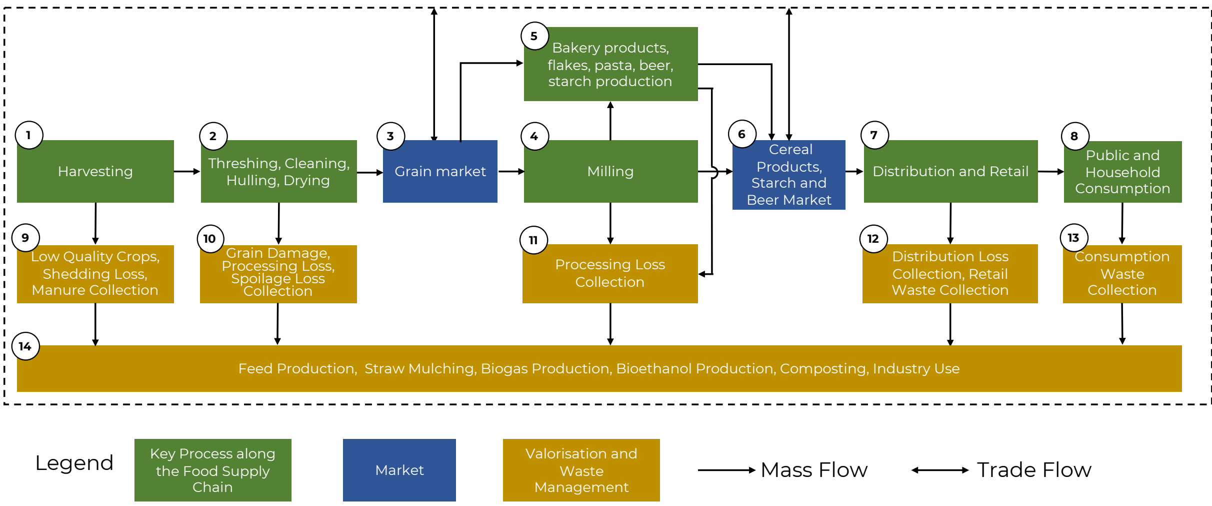

Figure 18 System definition of the cereal products supply chain

Harvesting is a critical stage where mature cereal crops are cut, collected, and prepared for further processing. The timing of harvesting is crucial to ensure optimal yield and quality. At this stage, losses are primarily caused by grain shedding, with the quantity of loss depending on the time of harvesting: if the harvesting procedure is completed late, shedding is often greater. The operation may be done manually or mechanically. When grain is harvested mechanically, its greater proportion may be damaged, resulting in increased losses (WRI, 2016). Quantitative and qualitative losses of cereals can stem from adverse weather conditions during plant growth and harvest, such as prolonged rain, floods, hail, drought, and frost. Additionally, diseases like fusariosis and pests such as insects, rodents, and

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birds, along with the improper use of plant protection products (pesticides) during cultivation or harvesting, can contribute to chemical contamination and pollution (Laba et al., 2022).

After harvesting, the next operational steps, including threshing, hulling, and cleaning, are applied to the crops to separate them from the rest of the plant. This process results in obtaining clean grains, which are then subjected to a drying process to prevent microbial damage to the crops (FAO, 2007). To ensure safe storage and decreases the related FL, it is necessary to dry grain to a moisture content of 10-15%. Grains containing damaged kernels should be stored at a moisture content 1-2% lower than the recommended levels (Reykdal,2017).

Grains could reach to the grain market, or they undergo various processing stages involves milling to remove fibrous bran fractions and/or secondary processing to produce cereal products. Secondary processing steps including fermentation, baking, puffing, flaking, frying, extrusion, starch or beer production, can differ depending on grain types (FAO, 2007). Wheat, rye, triticale, hulled barley, and hulled oats undergo milling processes to obtain flour with respective milling yields of 64%, 59%, 58.9%, 63%, 35.1%, respectively (Aprodu and Banu, 2017). However, milling yields vary highly depending on the milling method. Cereal milling is divided into two main categories: dry milling and wet milling. The dry milling process involves the removal of bran and germ, which are considered grain by-products. Dry milling further includes techniques like pearling, reduction, grinding, impact milling, and hammer milling. These abrasive methods gradually eliminate the seed coat, sub-aleurone, aleurone layers, and the germ to achieve polished grains, such as oat, rice, and barley. On the other hand, wet milling is employed for starch and gluten production, resulting in by-products like steep solids, germ, and bran (Balandrán-Quintana, 2018).

By-products generated in milling process, which are not used in human consumption, are mostly used as animal feed. In addition, cereal by-products are used as functional ingredients as they contain multiple benefits and health-promoting components such as dietary fibre, minerals, vitamins, polyphenols, and phytosterols (Luithui et al., 2019). After the milling process, wheat and maize are extensively distributed in the form of flour. Additionally, both serve as raw materials for starch production in the FSC. Rye, once milled, is predominantly utilized in the production of baking products while barley finds its primary use in the production of beer (De Laurentiis, 2021). On the other hand, unmilled rice, paddy rice, is typically de-husked or dehulled to obtain brown rice. When processing paddy, additional operations such as pre-cleaning, de-stoning, parboiling (pre-milling treatment), polishing, and glazing may also be necessary (WRI, 2016).
Assessing FLW within the cereal products supply chain considering the distinct operations involved in each stage of cereal production is crucial. Throughout these various operations, losses occur because of multiple factors including grain damage, the nature of various products, and their processing stages, packaging, and storage conditions. For instance, maize and its products have a relatively high lipid content and tend to go rancid quickly. Ground maize meal therefore has a short shelf life (FAO, 2007). Transportation is also reported as an important operation where FLW occur (Kumar and Kalita, 2017). As for FLW management, cereals of inferior quality were most often composted, used for processing into non-food products, animal feed, bioenergy purposes or enhancing soil fertility (Laba et al., 2022).

Table 12 (Appendix II) provides information on data availability and description of the cereal products supply chain. Eurostat publishes EU Total Cereals Balance Sheet, which covers durum wheat, soft wheat, maize, barley, triticale, oat, rye, sorghum, others. This sheet complies statistics on harvested area, production, yield, import and export, domestic uses of cereal products, FL (exclude harvesting). Additionally, FAOSTAT offers a database on the cereal and cereal products market including information on losses. Similar to potato products, FAO has developed a database on losses and waste -throughout the FSC for cereal products, and the consumption amount has been estimated by EFSA. Likewise, USDA gathers statistics on the cereal products supply chain for US countries. The African Postharvest Losses Information System (APHLIS), led by Natural Resources Institute, collects, analyses, and disseminates data on postharvest losses of cereal grains in sub-Saharan Africa. These data could prove invaluable for estimating FLW throughout the cereal products supply chain.

3.3.4 Framework of dairy products

According to Eurostat, dairy products are defined as processed products resulting from the processing of raw milk or from the further processing of such processed products[16]. Dairy products include fresh milk, cream, butter, yoghurt, cheese, whey, ice cream and sorbet. Generally, dairy products provide human with a multitude of nutrients, and consisted as an crucial component in the diet of 8 billion people (FAO, 2023). In the EU, the consumption of dairy products is high. For example, the consumption of fresh dairy products in milk solids exceeded 20 kg per capital between the year 2019 and 2021, much higher than the global average and is estimated to increase further by the year of 2031 (OECD & FAO, 2022). The production of dairy products generates a substantial amount of dairy wastewater, to nearly 200 million cubic meters annually (Stasinakis et al., 2022). Correspondingly, this study gave specific attention to the dairy products in the FLW measurement and monitoring framework development.

To establish the FLW measurement and monitoring framework of the dairy supply chain, the system boundaries for all food groups (except meat and fish) established by JRC (JRC, 2021) (see the figure 19), and FUSIONS definitional framework (FUSIONS, 2014) (See the section of "A Food Supply Chain" in figure 7) were adopted. Malliaroudaki et al. (2022) also proposes a specific dairy supply chain contains four sectors: farm, manufacturing, cold chain, consumer uses (Figure 21). Refresh (2017) identified dairy FW drivers along the supply chain by distinguishing the sectors as: primary production, processing & packaging, retail & logistics, and foodservice & household (in Figure 20). According to these studies, a dairy supply chain could be divided into four key sectors (in Figure 21):

- Milk production,
- Raw milk and non-milk dairy products processing,
- Distribution and retail,
- Public and household consumption.

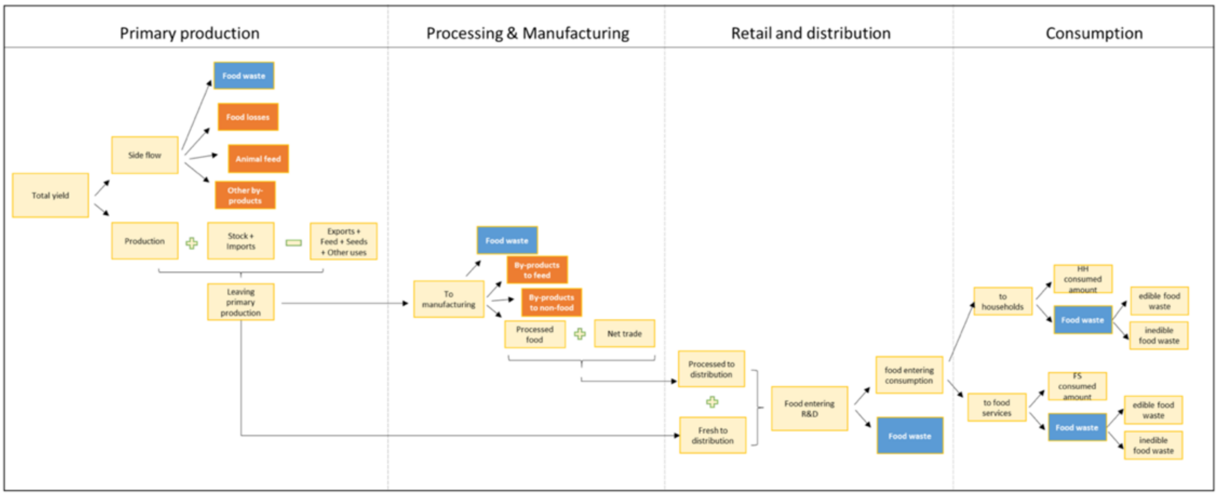

Figure 19 System definitions for all food groups except for meat and fish, proposed by JRC (2021).

Specifically, the milk production refers to the activities related to the raw milk production, includes livestock husbandry (Aan Den Toorn et al., 2020), milk animal feeding (Bartl et al., 2011; Berlin, 2002), milking handling (Saama et al., 1994), and milk storage. Potential FLW generated here includes manure collection, low quality mild, spillage loss (Martin et al., 2021), etc.

[16] Glossary: Dairy product. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Dairy_product

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At the processing sector (for both raw milk and non-milk dairy products), where the raw milk produced from the previous sector serves as the primary material input, generally consisted of two main subsections: raw milk processing, and non-milk products processing. The raw milk processing mainly involves processing activities like pasteurization (González-García et al., 2013), packaging (González-García et al., 2013), homogenization, cooling, etc. While the processing of non-milk products like cheese, yoghurt, butter mainly involves the processing activities like incubation, cream separation, concentration, cooling, package, etc. FLW generated here could be milk spillage during pasteurization and yogurt and cheese processing (Martin et al., 2021), product damage, storage and package loss, or caused by facility inefficiencies, and equipment failures. We noticed that some certain integrated dairy processing companies may have the capacitary to undertake a series of milk processing procedures, extending from raw milk processing to the final packaging of dairy products. This study distinguished these two subsectors in the dairy supply chain by taking into consideration of some specialized dairy producers. Those producers may focus on specific non-milk dairy products processing and require inputs (i.e., pasteurized milk) from other raw milk process factories.

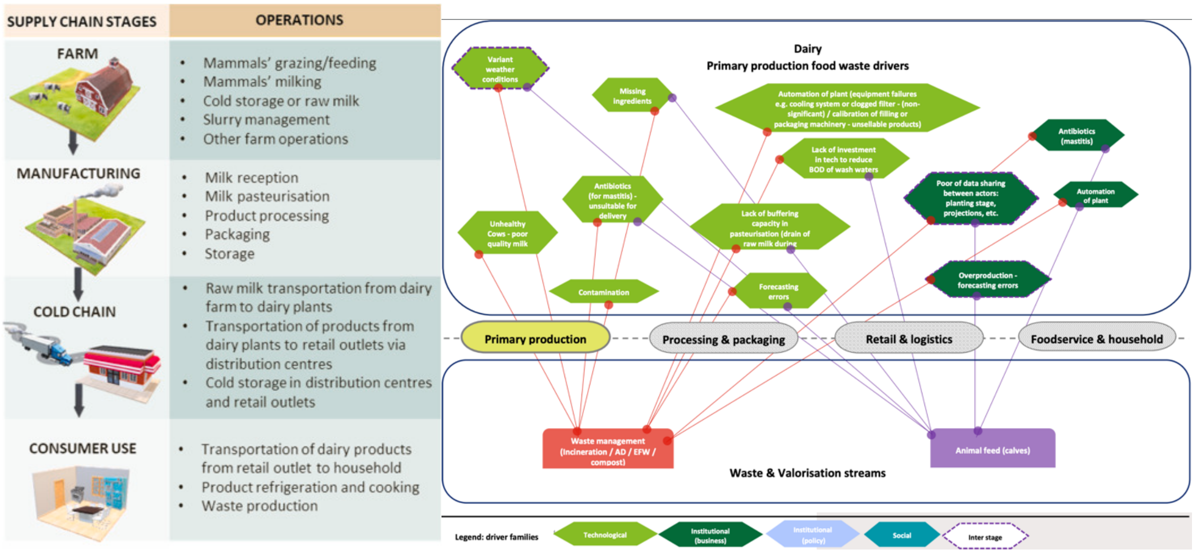

Figure 20 Dairy supply chain in Malliaroudaki et al. (2022) (left) and Refresh (2017) (right)

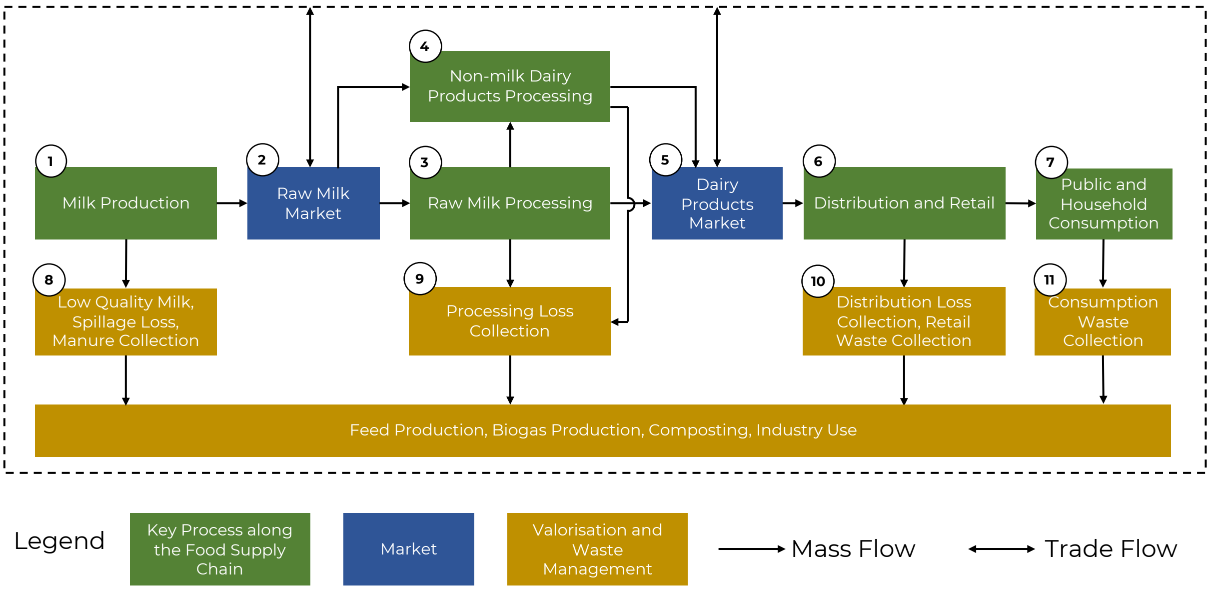

Figure 21 System Definition of the Dairy Products Supply Chain

After the processing sector, dairy products are distributed to retail and wholesale through various transportation methods in the distribution and retail sector. FLW may generate here due to damage

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during transportation or inventory storage, spoilage during shelf time by inefficient management, etc. Subsequently, the dairy products are consumed in either household settings, or in foodservices like restaurant, hotels, canteens, etc. FLW generation in these contexts are mainly driven by human behaviours including dietary patterns, shopping habits, food preparing approaches, etc.

Regarding the data availability in the dairy products supply chain (summarized in Table 13 in Appendix II), Eurostat provides detailed data like total raw cow's milk (also organic raw cow's milk) delivered to dairies that is valuable for the process sector 1. Specifically, all these data is available on a monthly base for each EU MS. The Eurostat database also provides information like raw cream delivered to dairies, drinking milk, skimmed milk powder, cheese from cow's milk, useful for process sector 3 and 4. Besides, Eurostat also provides milk products processed, and milk treated data, relevant to the process sectors 3 and 4 as well. Dairy products trade data is available in Eurostat for both national (within EU MSs) and international (with Non-EU countries like China and USA) exchanges. The European Food Safety Authority (EFSA) provides specific country-level data on the dairy products consumption (process sector 7). FAO food loss and waste database offers FLW rates for various dairy products by country, includes raw milk of cattle, cheese from whole cow milk, dairy products. Data for specific FSC sectors are available. However, FAO database encompasses a range of sources, including literature, and modelled estimation, the data quality may not be as robust as firsthand data sources.

3.3.5 A recommended framework for the food supply chain

Previous results showed that the key processes identified in those category-specific frameworks could be broadly assigned into production, processing, distribution, and consumption stages. Building on the frameworks established for specific food categories, this study further developed a harmonized framework for all the food types following this structure. At the meantime, literature review highlighted that the MFA framework developed by JRC could be a promising template (Caldeira et al., 2021) (Figure 22), especially considering its relevance in the context of EU countries. Consequently, this study segmented the general food supply chain into four stages: primary production, processing and manufacturing, distribution and retail, and public and household consumption (Figure 24). These four stages were further interpreted in the following:

- Primary and production: this stage refers to the production of raw food materials and products, includes agricultural cultivation, animal feeding, aquaculture and fishing, harvesting, etc.
- Processing and manufacturing: this stage refers to the processing of raw food materials and products, and manufacture them into edible forms, includes washing, cutting, slaughtering, pasteurizing, fermentation, mixing, as well as mixing, cooking, and packaging.
- Distribution and retail: this stage refers to the transportation of the processed food products to the retail and wholesale phases, includes legislation, cold chain management, inventory storage, and sales.
- Public and household consumption: this stage refers to the final consumption of the food products, includes, preparing, household storage, cooking, hospitality, and catering.

For each of these four stages, the FLW collection sector has been incorporated to account the potential FLW generated at each stage, mainly following the accounting approach recommended by Caldeira et al. (2019) (Figure 23) and food waste definitional framework in FUSIONS (2014) (Figure 7). The establishment of separate FLW collection sectors aim to emphasize the distinguished data collection methods required in these stages, and to assist the identification of varied causes of FLW as well as their reduction strategies. Recognizing the potential for food products trades at both primary production stage (i.e., fresh tomato, raw milk, etc.) and from processing and manufacturing stage (i.e., tomato sauce, cheese, etc.), we incorporated markets after both stages aligning with discussions in Caldeira et al. (2019, 2021) and (Dong et al., 2022).

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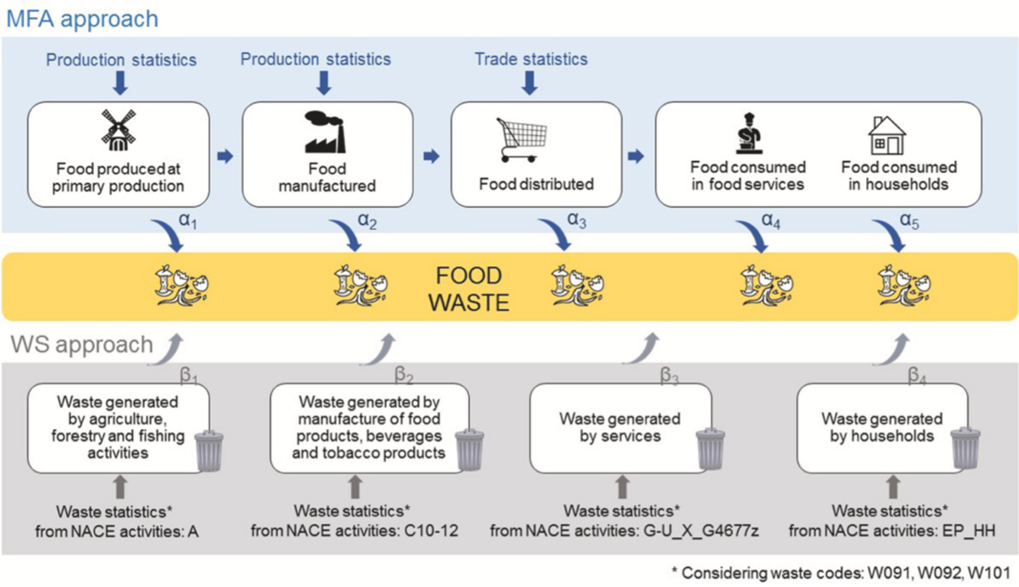

Figure 22 Food waste estimation framework building on MFA approach proposed by JRC (Caldeira et al., 2021)

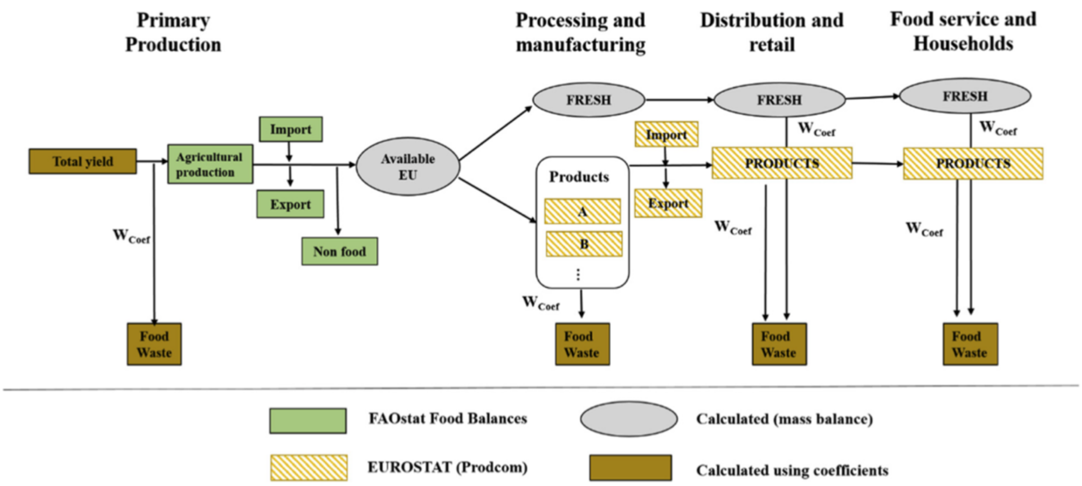

Figure 23 Food waste accounting approach proposed by JRC in Caldeira et al. (2019)

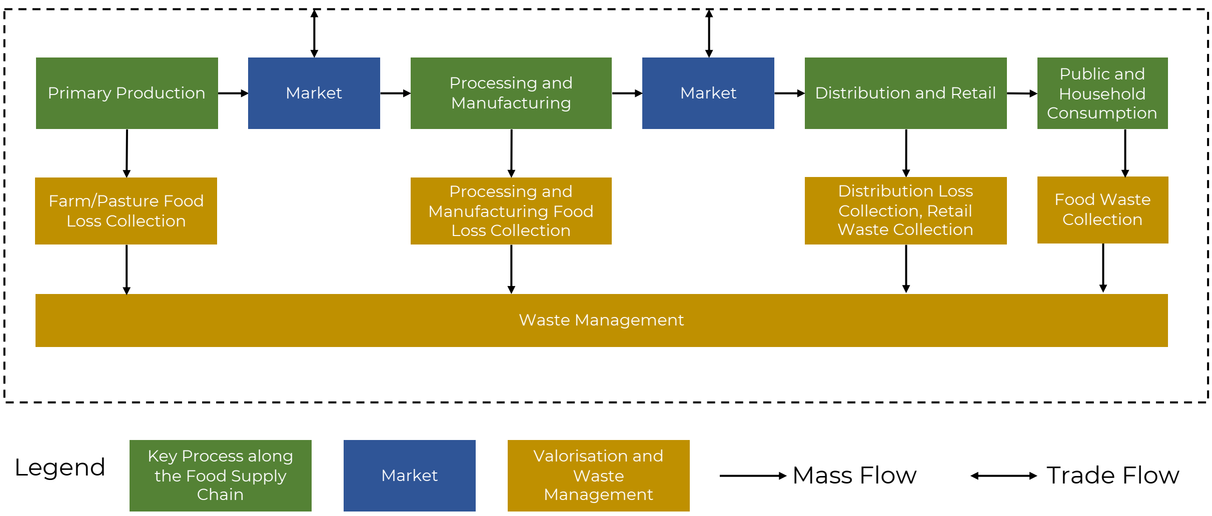

Figure 24 System Definition of the Food Supply Chain.

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3.4 Advancing framework harmonization: identifying key elements and best practices

As for data collection and reporting (Table 3), three key items emerged as top priorities with highest average scores: primary data, actual weighing, and distinguishing edible and inedible parts of food. This underscore, to develop a FLW measurement and monitoring framework, data accuracy is of critical importance. The lowest ranking of secondary data further evidenced this point. Furthermore, the minimal SDs for the top three items are the indicated a high level of experts' opinions on prioritizing actual data collection (reflected also by a more centralized scores distribution in Figure 25). While environmental, economic, and social metrics were similarly ranked in importance for data collection, the slightly higher emphasis on environmental and economic aspects suggested that addressing these impacts is currently attracted more attention in tackling FLW issues. It is worthy a notice that experts assigned a relatively low rank to the importance of real-time data collection, possibly due to its inherent complexity. Moreover, reporting the FLW destinations received a higher ranking than recording their valorisation approaches.

Table 3 Expert scores on specific framework items.

Framework items		mean	sd	min	max
Data Collection and Reporting	Actual Weighing	8.189	1.05	5	9
	Primary Data	8.324	0.784	7	9
	Secondary Data	6.73	1.521	3	9
	Real Time	6.919	1.785	3	9
	Edible/inedible	7.973	1.19	5	9
	Environmental Metrics	7.432	1.303	5	9
	Economic Metrics	7.405	1.499	3	9
	Social Metrics	7.162	1.302	5	9
	Destinations	7.865	1.512	3	9
	Valorisation	7.27	1.694	3	9
Monitoring and Evolution	Pilots	7.784	1.397	4	9
	Feedback	8.216	0.886	6	9
	Experts Consultation	7.243	1.362	4	9
	Challenge	7.73	1.217	5	9
Stakeholder Engagement	Primary Stakeholder	8.135	1.084	5	9
	Secondary Stakeholder	8.027	0.986	5	9
	Transparent Communication	8.351	0.949	5	9
	Organisation Type	7.568	1.119	5	9
Legislation	Voluntary Basis	6.297	1.998	2	9
	Compulsory Basis	7.757	1.588	2	9
	Food Loss	7.135	1.917	2	9

How to better promote framework monitoring and evolution, experts have provided clear guidance through their rankings. The collection of regular feedback from practitioners emerged as the top priority, evidenced by its highest rank average score and minimal SDs. Hence, effective communications with practitioners will benefit the FLW measurement data collection. Besides, experts emphasized the critical importance of pilot studies. However, in contrast, the rather lower average rating on expert consultation may indicate that a preference for practical experience from FSC practitioners over theoretical expert knowledge. As the importance of feedback acquisition from

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stakeholders was already evident from the previous questions, we could further find answers on how to engage stakeholders. First, both primary stakeholders (i.e., farmers, retailers, consumers) and secondary stakeholders (i.e., policy makers, NGOs, academy) are important in developing and enhancing the framework. Crucially, establishing transparent communications among all stakeholders should be the priority in stakeholder engagement.

Regarding the role of legislation development in the realm of FLW measurement framework, experts gave higher priority to compulsory legislation over voluntary approaches. This indicates that mandatory responsibilities are crucial for enhancing the FLW data collection and presentation. In addition, providing a clear definition of ''food loss'' is considered important.

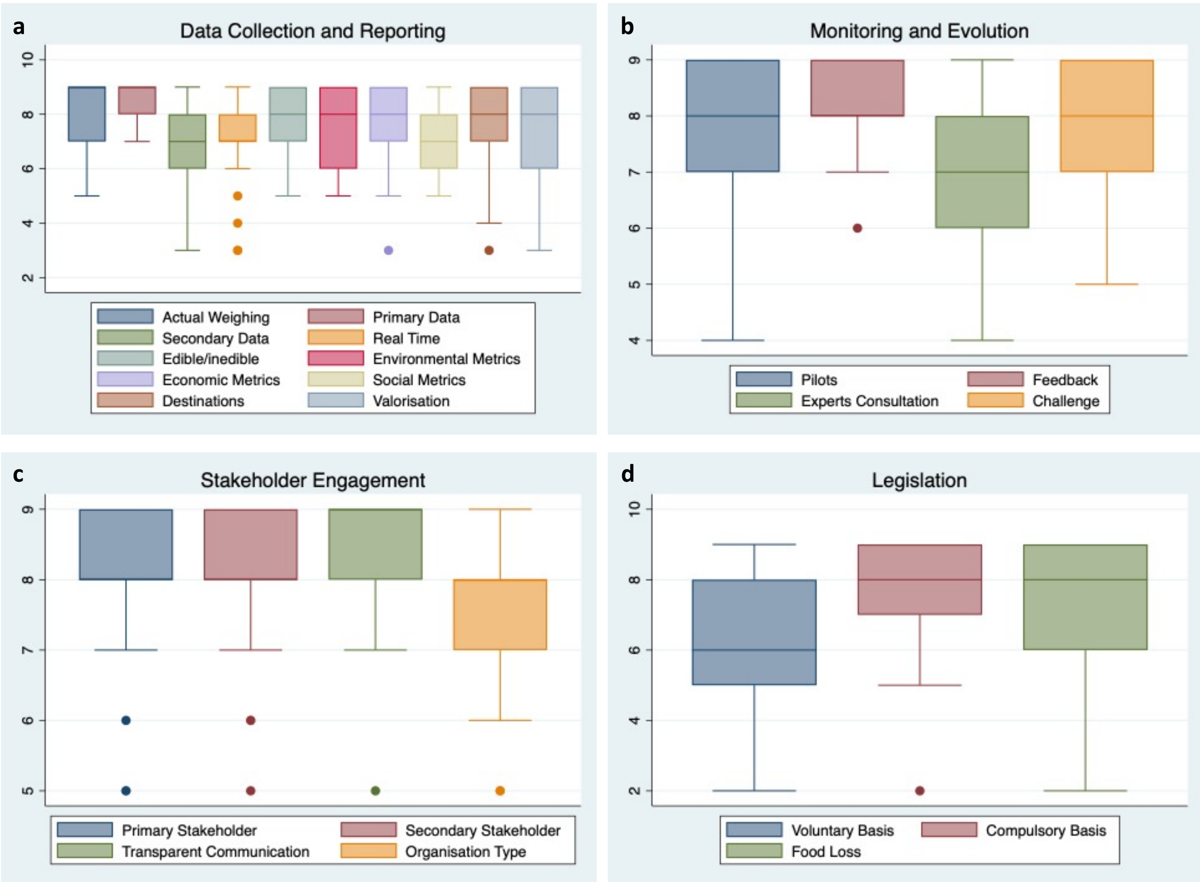

Figure 25 Expert survey statistical analysis results.
a) Data collection and Reporting. b) Monitoring and Evolution. c) Stakeholder Engagement. d) Legislation

From the D 1.1 FLW measurement practice inventory, this study first selected all those practices that applied those methods that need direct access to the FLW basing on FLWP (Hanson et al., 2016), but not using any "measurement or approximation" (for instance, mass balance, modeling, and proxy data). Results showed that 26 practices filtered. Among them, this study excluded two practices that used secondary data, and one practice that fail to state the FLW definitions it applied. Correspondingly, a total of 23 practices identified (Table 4). Notably, 8 of them only applied the more robust methods (direct weighing, counting, volume assessment, and waste composition analysis).

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Table 4 Best practices identification from D 1.1 practice inventory

Practices applying more robust methods were marked with an asterisk (*) for easy identification.

Practice number[17]	Practice title	Target FSC stages	Geographic scope	FLW measurement methods	Target food commodity
1*	Municipal Food Waste Measurement	Whole stage	National	Digital weighing	All food commodities
5	Household Budget Survey	Households	National	Surveys and interviews	All food commodities
6	Ministry of Agriculture and Foresty's Food Waste Survey	Households	National	Surveys and interviews	All food commodities
7*	Smart Scale System	Retail and wholesale, Food services	National	Digital weighing	All food commodities
9	Household food waste measurement	Households	National	Diaries	All food commodities
10	The generation of food waste and food loss in the Estonian food supply chain_Household	Households	National	Diaries	All food commodities
11	The generation of food waste and food loss in the Estonian food supply chain_Retail and wholesale	Retail and wholesale	National	Diaries	All food commodities
12	The generation of food waste and food loss in the Estonian food supply chain_SEI survey	Households	National	Digital weighing, Diaries, Surveys and interviews	All food commodities
14*	Digital weighing	Primary production, Handling and storage, Processing and manufacturing, Distribution and logistics	Regional	Digital weighing	Dairy
15*	Meals department Skövde municipality	Food services	Municipal	Digital weighing	All food commodities
16	Origins of Food waste in the food chain	Food services, Households	National	Surveys and interviews	All food commodities
17*	Waste composition analysis	Households	Municipal	Waste composition analysis	All food commodities
18*	collection green waste and composition analysis for food waste	Households	Case studies	Waste composition analysis	All food commodities
19	" Self reported Food waste frequency questionnaire on a weekly average"	Households	Regional	Diaries, Food waste frequency questionnaire	All food commodities

[17] The practice numbers correspond to those listed in Table 3 of Deliverable 1.1 (D1.1) for alignment and reference.

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22	self-reported amount of food waste	Households	National	Surveys and interviews	All food commodities
24*	Generation and Treatment of Municipal Solid Waste	Whole stage	Municipal	Digital weighing	All food commodities
27	Food Waste Behavior among Romanian Consumers: A Cluster Analysis	Households, Different consumers groups	National	Surveys and interviews	Fruit, Vegetables, Meat, Dairy, Fish and fish products, Bakery products, Cereals
33	WASTESTIMATOR	Food services, Households	National	Digital weighing, Surveys and interviews, Waste Manager application	All food commodities
34	The statistical survey on food waste	Households	National	Digital weighing, Diaries	All food commodities
35	The statistical survey on food waste	Primary production, Processing and manufacturing, Distribution and logistics, Retail and wholesale, Food services	National	Surveys and interviews	All food commodities
37*	Factsheet on food waste by consumers 2013	Whole stage	National	Waste Composition anlaysis	All food commodities
39	Analysing household food waste in the Maltese islands	Households	National	Surveys and interviews	Fruit, Vegetables, Bakery products
40	"The Italy case" Report by Waste Watcher International	Households	National	Surveys and interviews	Fruit, Vegetables, Bakery products

3.5 Advancing framework harmonization: identifying drivers and barriers

Experts guided the harmonised FLW measurement and monitoring framework with drivers' identification. Drivers refers to the factors that could lead to the development, improvement, and evolution of a harmonised framework. Drivers were grouped into five categories: benefits, awareness, data collection and analysis, governance, legislation. Table 5 presents the list of drivers together with their distributions among various experts' professional roles.

The driver category of benefits refers to the advantages or positive outcomes that result from the FLW measurement and monitoring framework. Experts identified seven specific benefits of a harmonised framework that could foster its development: knowledge, health, food security, legal, environmental, economic, and social benefits. This indicates that a harmonised framework will yield significant advantages in these areas. Notably, the benefits most frequently mentioned were economic, social, environmental, and food security. Knowledge benefits from a harmonised FLW framework include enhanced understanding of FLW hotspots, causes, and potential solutions. Public health will benefit from the framework. Food security could be enhanced by addressing food scarcity and stabilizing food price. Environment impacts could be witnessed in the reduction of greenhouse gas emissions. Economically, a harmonised framework can lead to cost savings, lower waste fees, and potentially reduce tax. Company's sustainable reputation as well as personal social responsibility improving could be the social benefits.

Table 5 Identified drivers from expert survey and their distribution.

Drivers		RE	NR	PG	FP
Benefits	Knowledge benefits	1	0	0	0
	Health benefits	2	0	0	0
	Food security benefits	4	0	1	0
	Legal benefit	1	0	0	0
	Environmental benefits	3	1	1	0
	Economic benefits	8	3	0	1
	Social benefits	4	1	0	1
Awareness	Public awareness	3	0	0	1
Data collection and analysis	Comparable dataset	2	0	1	0
	Tailored methods	1	0	0	0
	Digitalization	1	0	0	0
Governance	Better monitoring	0	0	0	1
	Research investment	1	0	0	0
	Innovative technology	1	0	0	0
Legislation	Existing EU legislations	6	2	0	1
	FLW management responsibility	1	1	0	0
	Tax on FLW	1	0	0	0

Table legend.
RE: Researcher. NR: NPO/NGO Representative. PG: Policy Maker/Government Official. FG: FSC Practitioner.

The driver category of awareness refers to the perception or recognition of the FLW issues, from various levels like individual, industrial, and governmental. Various aspects of public awareness could be leveraged during the framework harmonisation, by involving all key stakeholders and decision-makers. Public interest in sustainability issues, commitments like SDS 12.3, as well as other voluntary agreement could serve as the driving forces behind a harmonised framework.

The driver category of data issues refers to the factors that influence the data collection and analysis of FLW measurement. Enhanced data collection could facilitate the framework harmonisation. Establishing clear baseline data to build comparable dataset is crucial. Tailoring data collection methods to suit varied national contexts could work as well.

The driver category of governance refers to the aspects of governance that involve strategic planning, investment allocation, technology promotion, and supervision of the harmonized framework. Better monitoring and supervising the framework, investing in research, and applying new technologies could be the specific governance drivers.

The driver category of legislation refers to the legislative factor that will influence, promote, or even impede the FLW measurement and monitoring framework harmonization. Experts frequently mentioned legislative drivers as key to promote the harmonisation of FLW measurement framework.

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Existing EU legislations, integrating taxation policies, and mandating compulsory reporting of FLW data were specific drivers.

Deliverable D 1.1 once conducted SWOT analysis specifically focused on FLW measurement practices and legislation actions. Key findings from the SWOT analysis also confirmed that multiple of FLW measurement benefits, high governing awareness, improved data collection method, strong legislative base with wide coverage these strengths and opportunities could be potential drivers for the framework harmonization. In addition, wide practice coverage in terms of geography and food commodities of existing FLW measurement practices, knowledge sharing practices among projects, sufficient funds in promoting FLW measurement practices and research, innovative technologies could be leveraged but not mentioned by the expert survey.

Experts identified a total of 26 barriers that might challenges to the harmonisation of FLW measurement and monitoring framework (Table 6). These barriers were categorized into five groups:

1) Knowledge deficiency
2) Low awareness
3) Inefficient management
4) Data issues
5) Absence of a well-defined framework

Among these barriers, financial constraints were the most frequently cited, with over 17 experts raising this barrier. In contrast, the majority of the other barriers were mentioned by only one expert each. This underscores the significance of financial constraints as a primary obstacle.

The barrier categorize of knowledge deficiency refers to the absence or insufficient level of specific FLW knowledge. Specific knowledge includes but not limited to the understanding of FLW issues, multiple FLW impacts, as well as the monitoring methods.

The barrier category of low awareness refers to the low level of perception or recognition of FLW issues and the lack of attention towards them. Individual concerns about FLW data reporting, potential conflicts between addressing FLW and pursuing business goals, business confidentiality issues, and marker regulations like product return policy all could reduce the awareness. Individual's resistance to the potential changes caused by FLW data collection or reduction strategies. Other drivers of low awareness include the perceived limited benefits of FLW management, possible reputation risks caused by FLW data reporting, lack of leadership awareness, insufficient individual awareness, and the lack of motivations to address FLW issues.

The barrier category of inefficient management refers to the less efficiency in handling FLW measurement and monitoring. Specific barriers include varied FLW management systems among MSs, inadequate legislative support, inefficient internal coordination and communications, the lack of human resources, time-intensive nature of FLW data collection, and the financial issues (costly data collection methods and limited financial budgets).

The barrier category of data issues refers to the challenges in the process of data collection, analysis, and comparison, which might lead to a low efficient FLW measurement. Potential barriers caused by data issues include inconsistent data collection (which may lead to incomparability of data), the lack of comprehensive data management system, the absence of dedicated database for regular data recording and analysis, data sharing obstacles among MSs and stakeholders. In addition, technological issues were raised by many experts, as the inefficient data collection technologies may challenge the FLW measurement framework harmonisation.

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The barrier category of absence of a well-defined framework refers to the inadequacies within the framework itself or the lack of key components. Several specific barriers may pose additionally challenges to the harmonised framework. The absence of well-defined management solutions, lack of guidance, not clearly defined FLW. Furthermore, conflicts with other waste issues (like plastic waste collection), the lack of specific Key Performance Indicators (KPIs), and inadequate defined scaling methods in FLW measurement data collection exemplifies the barriers.

Table 6 Identified barriers from expert survey and their distribution.

Barriers		RE	NR	PG	FP
Knowledge deficiency	Lack of knowledge on FLW impacts	2	0	0	0
	Lack of knowledge on monitoring	1	0	0	0
Low awareness	Individual concern	1	0	0	0
	Conflicts with business goals	2	1	1	0
	Resistance to change	1	0	0	0
	Low FLW reduction benefits	1	1	0	0
	Bad reputation for reporting FLW	1	0	0	0
	Lack of leading awareness	1	0	0	0
	Low individual awareness	1	0	0	0
	Low motivation	1	0	0	1
Inefficient management	No common FLW management system	0	0	1	0
	Legal issues	1	1	1	2
	Inefficient internal coordination	2	1	0	0
	Human resource issues	2	0	0	0
	Time issues	3	0	1	1
	Financial constraints	15	1	0	1
Data issues	Inconsistent data collection	0	0	1	0
	No data management system	1	0	0	0
	No FLW database	1	0	0	0
	Data sharing issues	1	0	0	0
	Technological issues	7	1	1	0
Absence of a well-defined framework	Weak FLW management solutions	1	0	0	0
	Lack of guidance	1	0	0	0
	No clear definition on the FLW	1	1	0	0
	Conflicts with other waste issues	0	1	0	0
	Specific indicators and scaling system	1	0	0	0

Table legend.
RE: Researcher. NR: NPO/NGO Representative. PG: Policy Maker/Government Official. FG: FSC Practitioner.

Focusing on weakness and threats, Deliverable D 1.1 SWOT analysis identified that the absence of a harmonized framework, inconsistent and weak data collection, limited information dissemination among FSC actors and nations, legislation gaps on FLW measurement and reduction and data reporting, disparities in legislation development across countries/regions, potential conflicts with existing legislations, less stakeholder engagement. All those weaknesses and threats that were reflected in the specific barrier points raised by experts. Besides, incompatible data, the absence of standardized food categories, the overlook of ethical impacts, inefficient FLW measurement practice management and monitoring, all these barriers were missed in the expert survey that also required special attention when promote the framework harmonization.

3.6 Advancing framework harmonization: identifying solutions

Experts proposed 32 solutions to facilitate the harmonization of a FLW measurement and monitoring framework (Table 7). These solutions were categorized into the following seven groups:

1) Research investment.
- Research could focus on FLW measurement issues.

2) Cooperation with market and business.
- Specific assistants to business, especially small and medium-sized ones.
- Creating new business models and initiate collaboration actors.
- Justification with market failure that needs to be corrected. Revise food products return policy.

3) Stakeholders Motivation.
- Provide recognition for those being transparent–- acknowledge their efforts. Emphasize the influence of the individual.
- Education campaigns to alleviate apathy to FLW issues and raise public awareness.
- Emphasize the value of wasted food itself, and the benefits of FW reduction, especially on the economic benefits.
- Motivate stakeholder in a right way.
- Aligning the FLW measurement with individual/business own interests.
- Increase public awareness with campaigns.

4) Knowledge and skills enhancement.
- Trainings on data collections.
- Sharing/exchanging knowledge that could enhance the understanding on FLW and their collection methods.
- Dissemination of best and successful practices.

5) Effective framework implementation.
- Enhancing FLW measurement date collections.
- Developing well-defined indicator systems.
- Defining food loss and waste clearly.
- Cooperate with non-food sector, like plastic waste collection.
- Providing with tailored materials and resources.

6) Governance improvement.
- Setting clear FLW reduction directions.
- Increasing investments in FLW management.
- Proving financial incentives like tax reduction or rewarding for reporting FLW data.
- Increasing budgets and fundings.
- Improving legislations.
- Proving government support in mandatory measurement.
- Increasing governance awareness like prioritizing the FLW management.

7) Data collection improvement.
- Promoting low-cost measurement methods.
- Streamlining and analysing data collection methods across MS.
- Centralizing data process.

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- Proving efficient measurement tools.
- Promoting technologies in data collection.
- Better not using 'top-down' exercise in data collection.
- Adopting proper methods to all contexts.

Table 7 Identified solutions from expert survey and their distribution.

Solutions		RE	NR	PG	FP
Research	Research investment	1	0	0	0
Cooperation with market and business	Business assistant tools	1	0	0	0
	Collaborative business models	1	0	0	0
	Correct market failure	1	0	1	0
Stakeholders motivation	Acknowledge effort / influence	1	1	0	0
	Education campaigns	2	0	0	0
	Emphasize benefits	5	0	0	1
	Motivations alignment	1	0	0	0
	Aligning measurement with own interests	1	0	0	0
	Increase public awareness	3	0	0	0
Knowledge and skills enhancement	Training	2	0	0	0
	Knowledge sharing	2	0	0	0
	Best practices sharing	2	0	0	1
Effective framework implementation	Supervision	0	0	0	1
	Indicators development	0	0	0	1
	Clear FLW definition	1	1	0	0
	Cooperate with non-food actors	1	0	0	0
	Material/resources support	2	0	0	0
Governance improvement	Clear targets	0	1	0	0
	Increase invests	0	1	0	0
	Financial incentives	5	0	0	0
	Increase budget	2	0	0	0
	Improve legislation	1	3	0	1
	Provision of government support	1	0	0	0
	Increase governance awareness	2	1	0	0
Data collection improvement	Low costs measurement	1	0	0	0
	Comprehensive method analysis across MSs	0	0	1	0
	Data process centralization	1	0	0	0
	Proper measurement tools	2	0	0	0
	Innovative technologies	1	0	0	1
	No "top-dow" measurement	1	0	0	0
	Proper data collection methods	1	1	0	0

Table legend.
RE: Researcher. NR: NPO/NGO Representative. PG: Policy Maker/Government Official. FG: FSC Practitioner.

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4. Conclusion

Building on a mixed of methodologies, this report proposed recommendations on the FLW measurement and monitoring framework harmonization. Specifically, this report reviewed literature about FLW-related frameworks, as well as FLW definitions. Key findings from the literature review were integrated into the development of four food categories supply chain system definitions and then informed the general food supply chain framework recommendation. Expert survey enriched the framework harmonization with key elements, drivers, and barriers identification, solutions to address those barriers were proposed as well.

Specific attentions were given to four food categories when developing the framework, they were namely, fruits vegetables and fruit juices, meat products, potato products and cereal products, dairy products. While the system definitions for these four food categories exhibited slight variations, they all adhered to a similar conceptual structure. Correspondingly, this study recommended a general FLW measurement and monitoring framework which consisted of primary production (PP), processing and manufacturing (P&M), retail and distribution (R&D), and public and household consumption (PHC), four key process sectors. At each sector, FLW should be collected and measured respectively. Followed by both PP and P&M sectors, markets were added to account for intra-EU and international food products trades.

Main findings from the expert survey highlighted that framework benefits (i.e., economic benefits of FLW reduction), public interests and awareness in FLW issues, enhanced data collection and analysis methods, good governess, and related legislations could be the driving forces behind the harmonization of FLW measurement framework. And various existing barriers need to be better addressed, including Knowledge deficiency, Low awareness, Inefficient management, Data issues, Absence of a well-defined framework. To better measure FLW, this study integrated expert's insights and WRI protocol into the identification of best practices, 23 practices from the inventory established in Deliverable D 1.1 were filtered. A total of 32 solution proposals were categorized into seven domains that could be applied for the framework harmonization: 1) Research investment. 2) Cooperation with market and business. 3) Stakeholder motivation. 4) Knowledge and skill enhancement. 5) Effective framework implementation. 6) Governance improvement. 7) Data collection improvement.

For the future studies on FLW measurement and monitoring, this report recommends following the next steps to develop a harmonized framework. First, this study provided a general system definition along with four specific ones about different food categories, all these system definitions will help to develop system boundaries when collecting FLW data. Second, multiple FLW definitions were reviewed and compared building on the criteria centering with the FLW protocol, this can inform future studies in defining FLW according on their own objectives. Third, practical FLW data collections could be conducted by taking the experts' insights into consideration, which contains various key elements when collecting FLW data. The process of data collection could be further enriched by using best practices identified from the D 1.1 inventory. Finally, drivers of the harmonized framework should be better leveraged, combing with the solutions to address barriers that might hinder the framework development.

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5. Bibliography

Aan Den Toorn, S. I., Worrell, E., & Van Den Broek, M. A. (2020). Meat, dairy, and more: Analysis of material, energy, and greenhouse gas flows of the meat and dairy supply chains in the EU28 for 2016. Journal of Industrial Ecology, 24(3), 601–614. https://doi.org/10.1111/jiec.12950

Amicarelli, V., Rana, R., Lombardi, M., & Bux, C. (2021). Material flow analysis and sustainability of the Italian meat industry. Journal of Cleaner Production, 299, 126902. https://doi.org/10.1016/j.jclepro.2021.126902

Aprodu, I., Banu, I. (2017) Milling functional and thermo-mechanical properties of wheat, rye, triticale, barley and oat, Journal of Cereal Science 77, 42-48. https://doi.org/10.1016/j.jcs.2017.07.009

Balandrán-Quintana R. R. (2018) Recovery of proteins from cereal processing by-products, Sustainable Recovery and Reutilization of Cereal Processing By-Products. In Woodhead Publishing Series in Food Science, Technology and Nutrition, pp: 125-157. https://doi.org/10.1016/B978-0-08-102162-0.00005-8

Bartl, K., Gómez, C. A., & Nemecek, T. (2011). Life cycle assessment of milk produced in two smallholder dairy systems in the highlands and the coast of Peru. Journal of Cleaner Production, 19(13), 1494–1505. https://doi.org/10.1016/j.jclepro.2011.04.010

Belitz, H.-D., Grosch, W., & Schieberle, P. (2008). Lehbuch der Lebensmittelchemie. https://doi.org/10.1007/978-3-540-73202-0

Beretta, C., & Hellweg, S. (2019). LEBENSMITTELVERLUSTE IN DER SCHWEIZ: UMWELTBELASTUNG UND VERMEIDUNGSPOTENZIAL.

Beretta, C., Stoessel, F., Baier, U., & Hellweg, S. (2013). Quantifying food losses and the potential for reduction in Switzerland. Waste Management (New York, N.Y.), 33(3), 764–773. https://doi.org/10.1016/j.wasman.2012.11.007

Berlin, J. (2002). Environmental life cycle assessment (LCA) of Swedish semi-hard cheese. International Dairy Journal, 12(11), 939–953. https://doi.org/10.1016/S0958-6946(02)00112-7

Bhattacharya, S. (2023). Root and tuber crops, in Snack Foods, Academic Press, pp.75-93. https://doi.org/10.1016/B978-0-12-819759-2.00015-X

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

Caldeira, C., De Laurentiis, V., Ghose, A., Corrado, S., & Sala, S. (2021). Grown and thrown: Exploring approaches to estimate food waste in EU countries. Resources, Conservation and Recycling, 168, 105426. https://doi.org/10.1016/j.resconrec.2021.105426

Caldeira, C., Sara, C., & Serenella, S. (2017). Food waste accounting methodologies, challenges and opportunities. Publications Office of the European Union JRC109202, https://doi.org/10.2760/54845

Cerri M., & Reale L. (2020) Anatomical traits of the principal fruits: An overview. Scientia Horticulturae, 270, 109390. https://doi.org/10.1016/j.scienta.2020.109390

Codex Alimentarius Commission. 2013. Codex Alimentarius Commission, Procedural Manual, 21st edition. Rome, Italy: Food and Agriculture Organization of the United Nations and World Health Organization.

Cooreman-Algoed, M., Boone, L., Taelman, S. E., Van Hemelryck, S., Brunson, A., & Dewulf, J. (2022). Impact of consumer behaviour on the environmental sustainability profile of food production and consumption chains – a case study on chicken meat. Resources, Conservation and Recycling, 178, 106089. https://doi.org/10.1016/j.resconrec.2021.106089

De Laurentiis V., Caldeira C., Biganzoli F., & Sala S. (2021) Building a balancing system for food waste accounting at national level – Model updates version 2.0. Publications Office of the European Union, JRC124446. https://doi.org/10.2760/316306

Dong, W., Armstrong, K., Jin, M., Nimbalkar, S., Guo, W., Zhuang, J., & Cresko, J. (2022). A framework to quantify mass flow and assess food loss and waste in the US food supply chain. Communications Earth & Environment, 3(1), 83. https://doi.org/10.1038/s43247-022-00414-9

Dulo B., Githalga J., Raes K., & De Meester S. (2022) Material Flow Analysis and Resource Recovery Potential Analysis of Selected Fruit, Vegetable and Nut Waste in Kenya. Waste and Biomass Valorization, 13,3671-3687. https://doi.org/10.1007/s12649-022-01751-8

Eriksson, M., Persson Osowski, C., Björkman, J., Hansson, E., Malefors, C., Eriksson, E., & Ghosh, R. (2018). The tree structure—A general framework for food waste quantification in food services. Resources, Conservation and Recycling, 130, 140–151. https://doi.org/10.1016/j.resconrec.2017.11.030

EU. (2019). The European Green Deal.

EU. (2020a). Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions. A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system (COM/2020/381 final). EUR-Lex

EU. (2020b). Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions. A new Circular Economy Action Plan For a cleaner and more competitive Europe (COM/2020/98 final). EUR-Lex

EUROPEAN COMMISSION. (2023). Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2008/98/EC on waste. Publications Office.

European Parliament and Council. (2008). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives. In Official Journal of the European Union. https://doi.org/2008/98/EC.; 32008L0098

European Union (2023). Proposal for a Directive of the European Parliament and of the Council amending Directive 2008/98/EC on waste (COM/2023/420 final). EUR-Lex.

FAO. (1993) Codex Alimentarius Volume 2 – Pesticides residues in food Second Edition. Section 2 Classification of Foods and Animal Feeds.

FAO. (2011). Global food losses and food waste: Extent, causes and prevention. Food and Agriculture Organization of the United Nations.

FAO. (2007) Post-Harvesting Processing. Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-au104e.pdf

FAO. (2013). Food wastage footprint: Impacts on natural resources summary report. https://www.fao.org/3/i3347e/i3347e.pdf

FAO. (2015). Global Initiative on Food Loss and Waste Reduction.

FAO. (2019). The State of Food and Agriculture 2019: Moving forward on food loss and waste reduction. FAO. https://doi.org/10.4060/CA6030EN

FAO. (2023). Food safety is everyone's business in the primary production of milk.

FUSIONS. (2014a). Definitional Framework for Food Waste.

FUSIONS. (2014b). Drivers of current food waste generation threats of future increase and opportunities for reduction.

Galanakis, C. (2020). Food waste valorization opportunities for different food industries (S. 341–422). https://doi.org/10.1016/B978-0-12-816449-5.00011-4

Gallagher R, Raimondo M., & Caracciolo F. (2022) Eating the "inedible": How to improve the consumption of the perceived inedible parts of fruits and vegetables in Ireland and Italy? Food Quality and Preference, 99, 104548. https://doi.org/10.1016/j.foodqual.2022.104548 (get rights and content)

Gustavsson, J., Cederberg, C., Sonesson, U., Otterdijk, R. V., & Meybeck, A. (2011). Global food losses and food waste: Extent, causes and prevention. https://www.semanticscholar.org/paper/Global-food-losses-and-food-waste%3A-extent%2C-causes-Gustavsson-Cederberg/19c0065b1ad3f83f5ce7b0b16742d137d0f2125e

Hanson, C., Lipinski, B., Robertson, K., Dias, D., Gavilan, I., Gréverath, P., Ritter, S., Fonseca, J., van Otterdijk, R., Timmermans, T., Lomax, J., O'Connor, C., Dawe, A., Swannell, R., Berger, V., Reddy, M., Somogyi, D., Tran, B., Leach, B., & Quested, T. (2016). FLW Protocol Food Loss and Waste Accounting and Reporting Standard.

Hebrok, M., & Boks, C. (2017). Household food waste: Drivers and potential intervention points for design – An extensive review. Journal of Cleaner Production, 151, 380–392. https://doi.org/10.1016/j.jclepro.2017.03.069

HLPE. (2014). Food losses and waste in the context of sustainable food systems. https://www.fao.org/3/i3901e/i3901e.pdf

Hoehn D., Vázquez-Rowe I., Kahhat R., Margallo M., Laso J., Fernández-Ríos A., Ruiz-Salmón I., & Aldaco R. (2023) A critical review on food loss and waste quantification approaches: Is there a need to develop alternatives beyond the currently widespread pathways? Resources, Conservation & Recycling, 188, 106671. https://doi.org/10.1016/j.resconrec.2022.106671

IARC (2003) Fruit and Vegetables. IARC Handbooks of Cancer Prevention Volume 8. https://publications.iarc.fr/Book-And-Report-Series/Iarc-Handbooks-Of-Cancer-Prevention/Fruit-And-Vegetables-2003

Ingrao, C., Faccilongo, N., Di Gioia, L., & Messineo, A. (2018). Food waste recovery into energy in a circular economy perspective: A comprehensive review of aspects related to plant operation and environmental assessment. Journal of Cleaner Production, 184, 869–892. https://doi.org/10.1016/j.jclepro.2018.02.267

Ishangulyyev, R., Kim, S., & Lee, S. (2019). Understanding Food Loss and Waste—Why Are We Losing and Wasting Food? Foods, 8(8), 297. https://doi.org/10.3390/foods8080297

JRC. (2021). Building a balancing system for food waste accounting at National Level. EUR 30685 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-37275-2, doi:10.2760/316306, JRC124446.

JRC. (2023). Building a balancing system for food waste accounting at National Level. Model updates version 2.0, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/374244, JRC133379.

Karwowska, M., Łaba, S., & Szczepański, K. (2021). Food Loss and Waste in Meat Sector—Why the Consumption Stage Generates the Most Losses? Sustainability, 13(11), Article 11. https://doi.org/10.3390/su13116227

Keiser, A., Häberli, M., Schnyder, E., Berchier, P., (2007). Einfluss des Anbausystems, der Anbautechnik und des Standorts auf die Kartoffelqualität in der Schweiz. Schweizerische Hochschule für Landwirtschaft (SHL), CH-3052 Zollikofen.

Kuckartz, U., & Rädiker, S. (2019). Analyzing qualitative data with MAXQDA (pp. 1-290). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-15671-8

Kumar D, Kalita P. (2017) Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food

Security in Developing Countries. Foods. 6(1):8. https://doi.org/10.3390/foods6010008

Łaba S, Cacak-Pietrzak G, Łaba R, Sułek A, Szczepański K. (2022) Food Losses in Consumer Cereal Production in Poland in the Context of Food Security and Environmental Impact. Agriculture 12(5), 665. https://doi.org/10.3390/agriculture12050665

Lipinski, B. (2020). Why Does Animal-Based Food Loss and Waste Matter? Animal Frontiers: The Review Magazine of Animal Agriculture, 10(4), 48–52. https://doi.org/10.1093/af/vfaa039

Lombardi, M., & Costantino, M. (2020). A Social Innovation Model for Reducing Food Waste: The Case Study of an Italian Non-Profit Organization. Administrative Sciences, 10(3), Article 3. https://doi.org/10.3390/admsci10030045

Luithui Y, Baghya Nisha R, Meera M.S. (2019) Cereal by-products as an important functional ingredient: effect of processing. Journal of Food Science and Technology 56(1), 1-11. https://doi.org/10.1007/s13197-018-3461-y

Majerska J., Michalska A., & Figiel A. (2019) A review of new directions in managing fruit and vegetable processing byproducts. Trends in Food Science & Technology, 88, 207-219. https://doi.org/10.1016/j.tifs.2019.03.021 (get rights and content)

Malliaroudaki, M. I., Watson, N. J., Ferrari, R., Nchari, L. N., & Gomes, R. L. (2022). Energy management for a net zero dairy supply chain under climate change. Trends in Food Science & Technology, 126, 153–167. https://doi.org/10.1016/j.tifs.2022.01.015

Martin, N. H., Torres-Frenzel, P., & Wiedmann, M. (2021). Invited review: Controlling dairy product spoilage to reduce food loss and waste. Journal of Dairy Science, 104(2), 1251–1261. https://doi.org/10.3168/jds.2020-19130

Mendelson E., Zumajo-Cardona C., & Ambrose B. (2020) What Is a Fruit? Front. Young Minds, 8, 27. https://doi.org/10.3389/frym.2020.00027

Miljøstyrelsen. (2021). Madaffald fra primærproduktion samt forarbejdnings- og fremstillingssektoren 2018. Miljøstyrelsen.

Monier, V. (2011). Preparatory study on food waste across EU 27. European Commission.

OECD & FAO. (2022). OECD-FAO Agricultural Outlook 2022-2031. OECD. https://doi.org/10.1787/f1b0b29c-en

OJEU. (2019). Commission Delegated Decision (EU) 2019/1597 of 3 May 2019 supplementing Directive 2008/98/EC of the European Parliament and of the Council as regards a common methodology and minimum quality requirements for the uniform measurement of levels of food waste (Text with EEA relevance.)—Publications Office of the EU. https://op.europa.eu/en/publication-detail/-/publication/241cf6a4-e103-11e9-9c4e-01aa75ed71a1/language-en/format-HTML/source-117095121

Östergren, K., Gustavsson, J., Bos-Brouwers, H., Timmermans, T., Hansen, O.-J., Møller, H., Anderson, G., O'Connor, C., Soethoudt, H., Netherlands, T., Quested, T., Easteal, S., Politano, A., Bellettato, C., Canali, M., Falasconi, L., Gaiani, S., Vittuari, M., Schneider, F., & Redlingshöfer, B. (2014). FUSIONS definitional framework for food waste. Full report.

Padalino, B., Tullio, D., Cannone, S., & Bozzo, G. (2018). Road Transport of Farm Animals: Mortality, Morbidity, Species and Country of Origin at a Southern Italian Control Post. Animals : an Open Access Journal from MDPI, 8(9), 155. https://doi.org/10.3390/ani8090155

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 of London. Series B, Biological Sciences, 365(1554), 3065–3081. https://doi.org/10.1098/rstb.2010.0126

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: Quantification

This project has received funding from the European Union's Horizon Research and Innovation Action (HORIZON-CL6-2022-FARM2FORK-01) under Grant Agreement No. 101084222

and potential for change to 2050. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 365(1554), 3065–3081. https://doi.org/10.1098/rstb.2010.0126

Quested, Johnson, T., Hannah. (2009). Household Food and Drink Waste in the UK 2009. WRAP. https://wrap.org.uk/resources/report/household-food-and-drink-waste-uk-2009

Redlingshöfer, B., COUDURIER, B., & Bareille, N. (2019). État des lieux des pertes alimentaires et potentiel d'utilisation des sous-produits animaux par les filières animales. INRA Productions Animales, 32, 67–84. https://doi.org/10.20870/productions-animales.2019.32.1.2454

Redlingshöfer, B., Coudurier, B., & Georget, M. (2017). Quantifying food loss during primary production and processing in France. Journal of Cleaner Production, 164, 703–714. https://doi.org/10.1016/j.jclepro.2017.06.173

Refresh. (2017). Systems maps and analytical framework. Mapping food waste drivers across the food supply chain.

Refresh. (2019). Integration of LCC and LCA results to higher system levels: The German meat and EU tomato cases.

Reykdal, O. (2017) Drying and Storage of Harvested Grain A Review of Methods. Northern Periphery and Arctic Programme Northern Cereals – New Markets for a Changing Environment. https://cereal.interreg-npa.eu/subsites/CEREAL/Grain_Drying-Method_Review-Report-NPA-Cereal-DT221.pdf

Saama, P. M., Koenig, B. E., Koenig, H. E., & Anderson, J. H. (1994). Analytical Tools for Material and Energy Balance, Cash Flow, and Environmental Loads in a Dairy Cattle Enterprise. Journal of Dairy Science, 77(4), 994–1002. https://doi.org/10.3168/jds.S0022-0302(94)77035-1

Silvennoinen, K., Hartikainen, H., Katajajuuri, J.-M., Nisonen, S., Pietiläinen, O., & Timonen, K. (2019). WASTESTIMATOR : Ruokahävikin päivitetyt mittaustulokset ja ruokahävikin seurantatyökalun kehittäminen: Kotitaloudet ja ravitsemispalvelut.

Spang, E. S., Moreno, L. C., Pace, S. A., Achmon, Y., Donis-Gonzalez, I., Gosliner, W., Jablonski-Sheffield, M. P., Momin, M. A., Quested, T., Winans, K. S., & Tomich, T. P. (2019). Food Loss and Waste: Measurement, Drivers, and Solutions (SSRN Scholarly Paper 3472227). https://doi.org/10.1146/annurev-environ-101718-033228

Stasinakis, A. S., Charalambous, P., & Vyrides, I. (2022). Dairy wastewater management in EU: Produced amounts, existing legislation, applied treatment processes and future challenges. Journal of Environmental Management, 303, 114152. https://doi.org/10.1016/j.jenvman.2021.114152

STREFOWA. (2016). REPORT ON STATUS QUO OF FOOD WASTE PREVENTION AND MANAGEMENT.pdf.

Terry, L.A.; Mena, C.; Williams, A.; Jenney, N.; Whitehead, P. (2011). Fruit and Vegetable Resource Maps: Mapping Fruit and Vegetable Waste through the Wholesale Supply Chain, RSC008; WRAP: Oxon, UK

UN. (2015). UN SDGs TRANSFORMING OUR WORLD- THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT.pdf.

UNEP (2021) Food Waste Index Report 2021. Nairobi. https://www.unep.org/resources/report/unep-food-waste-index-report-2021

USDA. (2014). The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.2501659

Vittuari, M., Garcia Herrero, L., Masotti, M., Iori, E., Caldeira, C., Qian, Z., Bruns, H., Van Herpen, E., Obersteiner, G., Kaptan, G., Liu, G., Mikkelsen, B. E., Swannell, R., Kasza, G., Nohlen, H., & Sala, S. (2023). How to reduce consumer food waste at household level: A literature review on drivers and levers for behavioural change. Sustainable Production and Consumption, 38, 104–114. https://doi.org/10.1016/j.spc.2023.03.023

This project has received funding from the European Union's Horizon Research and Innovation Action (HORIZON-CL6-2022-FARM2FORK-01) under Grant Agreement No. 101084222

Willersinn, C., Mack, G., Mouron, P., Keiser, A., & Siegrist, M. (2015). Quantity and quality of food losses along the Swiss potato supply chain: Stepwise investigation and the influence of quality standards on losses. Waste Management, 46, 120–132. https://doi.org/10.1016/j.wasman.2015.08.033

WRAP. (2012) Reducing Supply Chain and Consumer Potato Waste Case Study. Available online: https://wrap.org.uk/resources/case-study/reducing-supply-chain-and-consumer-potato-waste-case-study

WRAP. (2020). UK food surplus and waste measurement and reporting guidelines.

WRI. (2013). Working Pape Reducing Food Loss and Waste.

WRI. (2016). Guidance on FLW Quantification Methods https://flwprotocol.org/wp-content/uploads/2016/05/FLW_Protocol_Guidance_on_FLW_Quantification_Methods.pdf

Xue, L., Cao, Z., Scherhaufer, S., Östergren, K., Cheng, S., & Liu, G. (2021). Mapping the EU tomato supply chain from farm to fork for greenhouse gas emission mitigation strategies. Journal of Industrial Ecology, 25(2), 377–389. https://doi.org/10.1111/jiec.13080

Xue, L., Prass, N., Gollnow, S., Davis, J., Scherhaufer, S., Östergren, K., Cheng, S., & Liu, G. (2019). Efficiency and Carbon Footprint of the German Meat Supply Chain. Environmental Science & Technology, 53(9), 5133–5142. https://doi.org/10.1021/acs.est.8b06079

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6. Annexes

Appendix I Expert online survey questionnaire

Expert Consultation on Building the Food Loss and Waste Measurement Framework

WASTELESS - Waste Quantification Solutions to Limit Environmental Stress (https://wastelesseu.com/) is funded by the European Union's Horizon Europe Research and Innovation programme under Grant Agreement n° 101084222. This project aims to develop tools and recommendations for measuring and monitoring food loss and waste (FLW) which will ultimately contribute to its reduction by at least 20% annually.
This survey seeks expert insights to pinpoint the crucial elements of the FLW measurement framework. Once you've successfully submitted your responses, you're welcome to request the survey results and participate in the subsequent discussion on framework building.
This survey is divided into five sections. Each section comprises multiple questions, with the majority seeking your evaluation on the importance of framework components.
Please consider sharing this survey with colleagues or any experts who might have an interest in this topic.
Thank you for your invaluable contributions!

Please provide your name
We deeply value your privacy. Please be assured that your personal information will remain confidential and will not be shared or used beyond the purpose of this survey.

Please provide your email address
We deeply value your privacy. Please be assured that your personal information will remain confidential and will not be shared or used beyond the purpose of this survey.

What is your primary job profession or role?
- Researchers
- Policy Makers & Government
- Non-Profit/NGO Representatives
- Food Loss and Waste Auditors
- Waste Management & Recycling
- Technology Professionals
- Food & Agriculture Practitioners (Farmers and Ranchers, Meat & Dairy Processors, Distributors & Retailers, Chefs, etc.)
- Other...

Would you be interested in participating in future discussions regarding the development of a food loss and waste framework?
If you select 'yes', we will stay in contact and update you on upcoming discussions.
Yes
No

Food loss and waste measurement - **Data Collection and Reporting**

How important is it to have **actual weighing** in food loss and waste measurement?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to use **primary data** (using methods like digital weighing, survey, diary, etc.)

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to use **secondary data** (literature data, proxy data, etc.)

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is to collect food loss and waste data **in real-time**?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to **distinguis**h food loss and waste between **edible and inedible parts**?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

Which classification system would you suggest for **categorizing food** to measure food loss and waste?

How important is it to include **environment metrics** (like carbon footprint) in data collection?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to include **economic metrics** (like monetary value) in data collection?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to include **social metrics** (like food insecurity) in data collection?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to identify the food loss and waste **destinations** (e.g., landfill, animal feed, not harvested) during data collection?

	1	2	3	4	5	6	7	8	9	

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Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to define the food loss and waste **valorization** (e.g., molecules recovery, energy production) during data collection?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

Food loss and waste measurement - **Monitoring and Evolution**

How important is it have **pilot studies** for a food loss and waste measurement framework before actual implementation?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to **regularly gather implementation feedback** from practitioners?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to have **external experts to monitor and evaluate** food loss and waste measurement and prevention practices?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How challenging is to **implement the framework across Europe or globally**?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How could be best solved the problem with **underreporting food waste** among consumers at **household level**?

____

How could be best solved the problem with **underreporting food loss and waste** among food business operators, such as those in **production, retail, and foodservice**?

____

Food loss and waste measurement - **Stakeholder Engagement**

How important is it to engage **the primary stakeholders** (like famers, retailers, consumers, etc.) in food loss and waste measurement?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to engage **the secondary stakeholders** (like policy-makers, NGSs, academy, etc.) in the food loss and waste measurement?

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	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is to **transparent communication among stakeholders** in food loss and waste measurement and management?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to detail the **organisation type** in the food supply chain (e.g., apple farmer, cow milk processor, vegetable retailer)?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How do you recommend **engaging a wide range of stakeholders**?

____

Food loss and waste measurement – **Legislation**

How important is it to have legislations on **voluntary basis** to measure and prevent food loss and waste?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to have legislations on **compulsory basis** to measure and prevent food loss and waste??

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

How important is it to **distinguish between 'food loss' and 'food waste' at regulatory level**?

	1	2	3	4	5	6	7	8	9	
Extremely Unimportant	O	O	O	O	O	O	O	O	O	Extremely Important

What is your definition of '**food loss**'?

____

Are there any **legislative gaps** concerning food loss and waste measurement?
If so, could you please identify them?

____
____
____
____
____

Drivers and **barriers** for harmonised food loss and waste measuring & monitoring framework

What could be the **drivers** for food loss and waste measuring & monitoring framework?

____
____

What potential **barriers (such as legal, economic, or technological)** might hinder the measurement and monitoring framework for food loss and waste?

What could be the **solutions** to overcome these barriers?

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Appendix II Data exanimation for the specific frameworks of different food categorize.

Table 8 Data availability and description of the fruits, fruit juices, and vegetables supply chain

Process number	Data Base	Country	Data Description	Data Sources	Data Quality
1	Eurostat	EU Countries	Fresh vegetables (including melons)	https://ec.europa.eu/eurostat/databrowser/view/apro_cpsh1/default/table?lang=en	High
1,4	FAOSTAT	Global countries	Production (crops and livestocks products)	https://www.fao.org/faostat/en/#data/QCL	High
2,3,5	FAOSTAT	Global countries	Trade (crops and livestocks products)	https://www.fao.org/faostat/en/#data/TCL	High
2,3,5	FAOSTAT	Global countries	Detailed trade matrix	https://www.fao.org/faostat/en/#data/TM	High
2	Eurostat	EU Countries	Fruit and vegetable trades among EU countries and third countries	https://agridata.ec.europa.eu/extensions/DataPortal/fruit-and-vegetables.html	High
3	Eurostat	EU Countries	Sold production, exports and imports	https://ec.europa.eu/eurostat/databrowser/view/ds-056120/legacyMultiFreq/table?lang=en	High
6	Eurostat	EU Countries	Turnover and volume of sales in wholesale and retail trade - monthly data (Retail and wholesale of food and beverages)	https://ec.europa.eu/eurostat/databrowser/view/sts_trtu_m/default/table?lang=en	Low
7	Eurostat	EU Countries	Frequency of fruit and vegetables consumption by sex, age and educational attainment level (fruit, vegetables)	https://ec.europa.eu/eurostat/databrowser/view/hlth_ehis_fv1e/default/table?lang=en	High
7	EFSA	EU Countries	EFSA Comprehensive European Food Consumption Database (fruit and fruit products, vegetables and vegetable products)	https://www.efsa.europa.eu/en/microstrategy/foodex2-level-1	High
8,9,10,11	JRC	EU Countries	Building a balancing system for food waste accounting at national level - Model updates version 2.0 (annexes)	https://data.jrc.ec.europa.eu/dataset/a86ae681-f051-4809-85f3-5fa0ad7b25ee	High
8,9,10,11	JRC	EU Countries	EU Bioeconomy Monitoring System dashboards	https://knowledge4policy.ec.europa.eu/bioeconomy/monitoring_en	High
8,9,10,11	FAO	Global Countries	Food Loss and Waste Database	https://www.fao.org/platform-food-loss-waste/flw-data/en	Middle

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1,2,3,4, 5,8,9,10 ,11	FAOSTAT	Global countries	Food Balances	https://www.fao.org/faostat/en/#data/FBS	High
1,2,3,4, 5,8,9,10 ,11	JRC	EU Countries	EU estimated agricultural balance sheets at Member State level (only for some fruits)	https://datam.jrc.ec.europa.eu/datam/mashup/EU_ESTIMATED_AGRICULTURAL_BALANCE_SHEETS/	High

Table 9 Data availability and description of the meat products supply chain

Process number	Data	Country	Description	Sources	Quality
1	ISMEA	Italy	Beef, cattle breeding	https://it.readkong.com/page/allevamento-bovino-da-carne-scheda-di-settore-3932826	high
1	ISMEA	Italy	Pig breeding	https://www.ismea.it/flex/files/D.b3aef742c589d5fca4f6/report_suino.pdf	high
7	Expert interview 2011	Switzerland	Animal losses due to illnesses	Tannenhof, 2011. Personal Communication with Farmer Hans Metzger. Hans Metzger, Tannenhof, 4313 Möhlin.	low
2	FAO trade statistics	EU region	FAO trade statistics, crops & livestock, extra-EU imports and exports	http://www.fao.org/ faostat/en/#data/TP	high
3	I.Stat	Italy	Monthly slaughter of red and white meat cattle	https://www.istat.it/it/archivio/200942	high
3	I.Stat	Italy	Red meat, annual data	http://dati.istat.it/index.aspx?queryid=34786	high
3	I.Stat	Italy	White meat, annual data	http://dati.istat.it/index.aspx?queryid=34786	high
3	ISMEA	Italy	Pork meat and saussages	https://www.ismeamercati.it/carni/carne-suina-salumi	High
3, 8	Expert interview 2011	Switzerland	Meat loss during production	SBA. 2011. Personal communication with Joachim Messner, manager. Schlachtbetrieb Basel AG (SBA), Postfach 422, 4012 Basel. SBV. 2009.	Low
3, 8	Expert interview 2011	Switzerland	Meat loss during production	Aviforum, 2011. Personal Communication with Andreas Gloor. Aviforum, Burgerweg 22, 3052 Zollikofen	Low
3, 8	Literature	France	Food gradually discarded at meat production and processing/packing	https://www.sciencedirect.com/science/article/pii/S0959652617313434#ec1	Low
3	SIFCO	France	national union of animal rendering industries, SIFCO.	https://www.sifco.fr/wp-content/uploads/2019/01/Rapport-activite%CC%81-SIFCO-2014-11-06-15-BD.pdf	High

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8	FranceAgriMer	France	Valorisation of sheep (ovine) meat	https://www.franceagrimer.fr/content/download/9839/64442/file/06-Abats-Ovins-30-11-11.pdf	High
8	FranceAgriMer	France	Valorisation of beef, sheep and pork meat	https://www.franceagrimer.fr/content/download/24724/205306/file/ETU-VIA-2013-Valorisationdu5%e8quartier(version%20longue)-Bl%e9zat.pdf	High
3	Literature	-	Poultry processing	https://www.sciencedirect.com/science/article/pii/S0260877404000561	Low
1, 3, 8	FAO Commodity Balance Sheets (CBS),	EU region	production, stocks, supply and non-food uses of food per product category	https://www.fao.org/faostat/en/#data/CB http://www.fao.org/faostat/en/#data/BL	High
4	Eurostat (Prodcome)	EU region	trade and production of manufactured products	https://ec.europa.eu/eurostat/web/prodcom/database	High
5,6,10	Swiss confederation	Switzerland	Food losses in the retail trade and in the catering trade in Switzerland	https://www.parlament.ch/centers/eparl/curia/2012/20123907/Bericht%20BR%20D.pdf	High
5,6,10	Environmental working groups	USA	Meat losses at retail and households	https://static.ewg.org/reports/2011/meateaters/pdf/report_ewg_meat_eaters_guide_to_health_and_climate_2011.pdf	Low
6	Swiss farmers' association	Switzerland	Consumption data Swiss households 2008	https://www.sbv-usp.ch/fileadmin/sbvuspch/04_Medien/Publikationen/SES/Archiv/SES_2008-85.pdf	Low
6,10	Department for Environment Food and Rural Affairs	United Kingdom	Household Food and Drink Waste linked to Food and Drink Purchases	https://assets.publishing.service.gov.uk/media/5a79ff75ed915d6d99f5c689/defra-stats-foodfarm-food-foodwastepurchases-100727.pdf	High
6,10	Wrap	United Kingdom	Household Food and Drink Waste in the UK	https://wrap.org.uk/sites/default/files/2020-12/Household-Food-and-Drink-Waste-in-the-UK-2009.pdf	High
6	Statista	EU region	Per capita meat consumption forecast in the big five European countries	https://www.statista.com/forecasts/679528/per-capita-meat-consumption-european-union-eu	High
6	European Environment Agency	EU region	EU consumption	https://www.eea.europa.eu/publications/food-in-a-green-light	High
1-6	ISMEA	Italy	Poultry	https://www.ismeamercati.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/4355	High

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Table 10 Missing data of the meats supply chain

Process number	Country	Missing data description
7,8	EU region	Missing data about animal death on farm due to sickness (including slaughtering healthy animals on farms), transport and before slaughtering
3	EU region	Data whole supply chain for other animal species than beef, pig and poultry (e.g., horses, rabbits, wild animals)
9	EU region	Data about losses due to spoilage and lack of appropriate storage
4	EU region	Data whole supply chain for meat based products (sausages, etc., not fresh meat)
6,10	EU region	High quality data on consumer food waste, especially in households
8	EU region	Lack of valorisation data and if the products were consumed according to their intention

Table 11 Data availability and description of the potato products supply chain

Process number	Data Base	Country	Data Description	Data Sources	Data Quality
1,2,3,4	Eurostat	EU Countries	Harvested crop, fresh potato and products market	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=The_EU_potato_sector_-_statistics_on_production,_prices_and_trade	High
2	Euromonitor	18 Countries	Fresh potato market	https://www.euromonitor.com/starchy-roots	High
1,2	LUKE	Finland	Food potato storage on farms and market	https://statdb.luke.fi/PxWeb/pxweb/en/LUKE/LUKE__02%20Maatalous__04%20Tuotanto__30%20Ruokaperunan%20varastotilasto/01_Ruokaperunan_varastot_maatiloilla.px/table/tableViewLayout2/?rxid=dc711a9e-de6d-454b-82c2-74ff79a3a5e0	High
2,3,4,8,9, 10,11	FAOSTAT	181 Countries	Food Balance Sheet (2010-) for potato and potato products and sweet potato	https://www.fao.org/faostat/en/#data/FBS	
1,2,3,4	USDA	US Countries	National planted, harvested, production, yield statistics for potato	https://www.nass.usda.gov/Statistics_by_Subject/index.php?sector=CROPS	High
2,3,4,5	USDA	US Countries	USDA, Economic Research Service (ERS) Food Availability (per capita) Data System for Potato	https://www.ers.usda.gov/data-products/food-availability-per-capita-data-system/	High
6	EFSA	EU Countries	Food Composition data	https://www.efsa.europa.eu/en/data-report/food-composition-data	High
7,8,9,10	FAO	Global Countries	Food Loss and Waste Database	https://www.fao.org/platform-food-loss-waste/flw-data/en	High
1,2,3,4,5,6, 7,8,9,10,11	Literature	Swiss	This paper quantified FLW along the Swiss	Willersinn et al. (2015):	

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			potato supply chain by collecting data from field trials, from structured interviews with wholesalers, processors and retailers, and from consumer surveys.	https://doi.org/10.1016/j.wasman.2015.08.033	
7	Literature	Austria and Germany	This study presented a methodological approach for the on-site quantification of food losses in primary production of potato harvest.	https://doi.org/10.1016/j.wasman.2019.01.020	

Table 12 Data availability and description of the cereal products supply chain

Process number	Data Base	Country	Data Description	Data Sources	Data Quality
1	Eurostat	EU Countries	Cereals- Gross production by all crops (durum wheat, maize, barley, triticale, oat, rye, sorghum, others)	https://agridata.ec.europa.eu/extensions/DashboardCereals/CerealsProduction.html	High
3	Eurostat	EU Countries	Monthly EU Trade (Export and Import), Quantity in tones (grain equivalent	https://agridata.ec.europa.eu/extensions/DashboardCereals/CerealsTrade.html	High
3	Eurostat	EU Countries, Turkey, UK	Cereal balance items for the main cereals	https://ec.europa.eu/eurostat/databrowser/view/apro_cbs_cer/default/table?lang=en	High
4	Literature	-	This study published the milling yields for wheat, rye, triticale, hulled barley, hulled oat.	Aprodu et al. (2017): https://doi.org/10.1016/j.jcs.2017.07.009	
1,2,3,4	LUKE	Finland	The Cereals Balance Sheet-Domestic production and use, changes in stocks, imports and exports of Finland's major cereal crops (wheat, rye, oats and barley).	https://statdb.luke.fi/PxWeb/pxweb/en/LUKE/LUKE__02%20Maatalous__04%20Tuotanto__32%20Viljatase/01_Viljatase.px/table/tableViewLayout2/?rxid=dc711a9e-de6d-454b-82c2-74ff79a3a5e0	High
1,2,3,4, 5, 10,11,14	Eurostat	EU Countries	EU Total Cereals Balance Sheet (durum wheat, soft wheat, maize, barley, triticale, oat, rye, sorghum, others)	https://agridata.ec.europa.eu/extensions/DashboardSTO/STO_Cereals.html	High

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3, 6, 11,12, 13,14,	FAOSTAT	181 Countries	Food Balance Sheet (2010-) for cereals (wheat, rice, barley, maize, rye, millet, sorghum, oats) and their products	https://www.fao.org/faostat/en/#data/FBS	
1,2,3,4, 5	USDA	US Countries	National planted, harvested, production, yield statistics for cereals (wheat, barley, oat, corn, rice, sorghum, rye)	https://www.nass.usda.gov/Statistics_by_Subject/index.php?sector=CROPS	High
3,4,7,8, 1213	USDA	US Countries	USDA, Economic Research Service (ERS) Food Availability (per capita) Data System for Grains	https://www.ers.usda.gov/data-products/food-availability-per-capita-data-system/	High
7,8,9,10 , 11	FAO	Global Countries	Food Loss and Waste Database	https://www.fao.org/platform-food-loss-waste/flw-data/en	High
8	EFSA	EU Countries	Food Composition data	https://www.efsa.europa.eu/en/data-report/food-composition-data	High
10,11,12,13	APHLIS	Sub-Saharan Countries	The African Postharvest Losses Information System (APHLIS)	https://www.aphlis.net/en/data/tables/overview/XAF/all-crops/all-years	
1,3,4,6, 7, 8,9,10,11, 12,13	Literature	US	This study developed a framework to quantify mass flow and assess food loss and waste in the US food supply chains for food 10 food commodities including grains.	Dong et al., (2022): https://doi.org/10.1038/s43247-022-00414-9	
9,11,12, 13,14	Literature	Italy	This study quantified FLW along the pasta supply chain, emphasizing FLW valorization.	https://doi.org/10.1016/j.resconrec.2019.01.025	
1,2,9,10	Literature	Tanzania	This study assessed the harvest/post-harvest handling processing and food losses in maize and sorghum.	Abbas et al. (2014): https://doi.org/10.1016/j.jspr.2013.12.004	Low

Table 13 Data availability and description of the dairy supply chain

Process number	Data Base	Country	Data Description	Data Sources	Data Quality
1	Eurostat	EU Countries	Total raw cow's milk delivered to dairies	https://agridata.ec.europa.eu/extensions/DashboardDairy/DairyProduction.html	High

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2	Eurostat	EU Countries	Milk and dairy products: Intra-EU trade (EU and Member States)	https://agriculture.ec.europa.eu/data-and-analysis/markets/trade-data/trade-sector/milk-and-dairy-products_en	High
2	Eurostat	EU Countries	Fresh milk trades among EU countries and third countries	https://agridata.ec.europa.eu/extensions/DashboardDairy/DairyTrade.html	High
3	Eurostat	EU Countries	Milk treated - Distribution of enterprises by volume of annual production	https://ec.europa.eu/eurostat/web/agriculture/data/database	High
4	Eurostat	EU Countries	Milk products processed	https://ec.europa.eu/eurostat/web/agriculture/data/database	High
5	Eurostat	EU Countries	Milk and dairy products: Intra-EU trade (EU and Member States)	https://agriculture.ec.europa.eu/data-and-analysis/markets/trade-data/trade-sector/milk-and-dairy-products_en	High
5	Eurostat	EU Countries	Milk and milk products (butter, cheese, etc.) trades among EU countries and third countries	https://agridata.ec.europa.eu/extensions/DashboardDairy/DairyTrade.html	High
7	EFSA	EU Countries	Food Composition data	https://www.efsa.europa.eu/en/data-report/food-composition-data	High
8,9,10,11	FAO	Global Countries	Food Loss and Waste Database	https://www.fao.org/platform-food-loss-waste/flw-data/en	Range
9	Literature	Hungary	This study determined the extent of milk loss at the company level, supplemented with loss values by each dairy product, at the processing stage	Tóth et al., (2021): https://doi.org/10.3390/foods10020229	Low

Table 14 Missing data of the dairy supply chain

Process number	Country	Data Description
6	EU countries	Milk and milk products distribution data

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