FOLOU

D5.1 – Product Category Rules for the assessment of sustainability burdens of food losses

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Abbreviations

ALCA: Attributional LCA

CBS: Commodity balance sheet

CF: Characterization factor

CLCA: Consequential LCA

CO2: carbon dioxide

CPI: Consumer Price Index

CSS: Country Specific Sector

DSQ: domestic supply quantity

EC: European Commission.

FAO: Food and Agriculture organization

FBS: Food balance sheet

FL: Food Losses

FSC: Food Supply Chain

FU: Functional unit

GHG: Green House Gases

H: number of heads of animal species

JRC: Joint Research Center

LCA: Life Cycle Assessment

LCC: Life Cycle Cost

LCSA: Life Cycle Sustainability Assessment

LW: live weight

MRIO: Multi-Regional Input-Output

MS: Membre state

MVC: Monetary valuation coefficients

N2O: nitrous oxide

NH4: methane

OC: Oil crop

P: total production

PCR: Product Category Rules

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Pf: production of food

PL: production losses

PP: Primary production

PSILCA: Product-specific Supply and Use Input-Output Life Cycle Assessment

RTf: root tubes fraction

SCL: Substitution, Consequential, Long-term

SDGs: Sustainable Development Goals

Sf: share of feed

SL: side losses

SLCA: Social Life Cycle Assessment

So: share of other by-products

Ss: share of seed

TEA: Techno-economic analysis

Ty: Total yield.

WP: Work package

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Table 1-Glossary

Fraction	*Definition*	*Source*
Commodity Balance Sheet (CBS)	*A commodity balance sheet is a financial statement that provides a summary of the supply and demand for a particular commodity over a specific period. It is a tool commonly used in the field of economics and agriculture to analyse the production, consumption, and overall availability of a specific commodity within a given market or region.*	*Eurostat*
Food Balance Sheet (FBS)	*FBS present a comprehensive picture of the agrifood situation of a country in a specified reference period, showing the pattern of a country's food supply and utilizations.*	*FAO*
Commodity primary equivalent	*the amount of primary commodity input that would be required to produce a given amount of derived product output*	*(GSARS, 2017)*
Domestic supply quantity	*The domestic supply quantity (DSQ) is calculated as production plus imports plus stock variation minus exports*	*CBS (calculated)*
Stock variation	*Stock variation, also known as inventory variation, refers to the change in the quantity of food held in stock between two distinct points in time.*	*CBS*
Production (P)	*Refers to the total quantity of a specific commodity that is produced within a given region or country during a particular time period. It represents the output of that commodity from various sources, such as farms, mines, factories, or other production facilities*	*CBS*
Food production (Pf)	*Production in terms of crops, livestock and fishery destined for human consumption*	*CBC (calculated)*
Side flow	*Side flows represent the share of the total crop ready for harvest that is either wasted, lost, transformed in animal feed or in other by-products.*	*Hartikainen et al., (2018)*
Total yield (Ty)	*Total yield refers to the overall quantity or output of food products produced in a specific region or country during a particular period. It is a measure of the total agricultural production and is often expressed in physical units depending on the type of crops or commodities being considered.*	*CBC (calculated)*
Food losses (FL)	*Food loss is any harvest-mature plant, animal or living being (including inedible parts) that is not successfully harvested, as well as food removed from the supply chain during post-harvest phase that does not become animal feed, by-product or food waste*	*FOLOU project*
Side losses (PL)	*Side losses refers to the losses that occur during the production of crops, livestock or fishery bearing in mind the total production given by CBC/FBC accounting for food intended for human consumption, seeds production, feed productions and other by-products from the same crop, livestock, or fishery*	*FOLOU project*

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Executive Summary

The present document will be used as a methodological compass for the development of the Life Cycle Sustainability Assessment (LCSA). That is to serve as a solid baseline for the decision-making during the next years and the execution of FOLOU LCSA.

LCSA is formed by the assessment of the three pillars of sustainability:

1. Life Cycle Assessment (LCA) assesses environmental aspects.

2. Life Cycle Cost (LCC) or Techno-economic analysis (TEA) to evaluate the economic performance

3. Social Life Cycle Assessment (Social-LCA) to ensure the social dimension

For the development of this deliverable, at first, the quantification of food loss and side loss were described. The production and consumption of food products are extracted from CBS and FBS to be used to calculate side flows of the production of each product per commodity group and country. This step requires a collection of side flows coefficient that represents the share and the destination of the fractions that were discarded from food supply chain. The coefficients will be used to calculate the amount of food loss per product, commodity at country and EU level. Likewise, side losses was determined using the total production of food and the corresponding coefficient of side flows from the total production.

Due to the lack of standardized definition and methodology of measurement of food loss, many variations in terms of impact assessment were found for LCA and LCC. However, no relevant studies regarding SLCA were reported up to the day of the present deliverable.

In this sense, comprehensive methodologies for the quantification of food losses at primary production stage, quantification of side losses at primary production stage, quantification of environmental, economic and social impacts associated with these fractions of food/side losses at primary production stage, will be developed to cover the existing gap on the sustainability assessment of food losses at primary production stage.

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I- Framework of the FOLOU

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1. Introduction

In a world where the challenges of food security, resource conservation, and sustainability intersect, it is imperative to address the issue of food losses comprehensively. Food loss is a serious worldwide issue that negatively affects the environment, economy, and society. The food supply chain is a multi-stage process that involves production, harvesting, transportation, storage, and consumption and the food losses arise at various stages. In the present work, the focus will be on the fraction of food losses generated at the primary production stage of five food commodity groups:

1- Grain and pulses,
2- Fruits and vegetables,
3- Root tubers and oil crops,
4- Meat and animal derived products,
5- Fish.

The goal of this task is to establish a robust framework for evaluating the environmental, economic, and social impacts of food losses incurred during primary production stage for the abovementioned food commodities. The framework will be presented by means of a tailored methodology for each commodity group known as "**Product Category Rules**" for the assessment of sustainability burdens of food losses.

Product Category Rules (PCR) are the product category-specific requirements for conducting life cycle assessment (LCA) studies in order to achieve comparability in results between different producers of the same product.

The PCR will provide guidance on the methods and models to be used for data collection and Sustainability Life Cycle Assessment. It will include Life Cycle Assessment (LCA), Life Cycle Cost (LCC) and Social Life Cycle Assessment (SLCA). They assess, respectively, the environmental, economic, and social aspects of food losses at primary production stage with a holistic perspective.

However, in this task, the aim is to highlight the burdens associated with food losses instead of assessing the sustainability performance of a given food product.

By developing precise rules and methodologies for impacts assessment, thus identification of the most relevant processes/operations that burden the primary production, we are empowering stakeholders across the food supply chain to make informed decisions, optimize resource use, and mitigate the far-reaching impacts of food losses.

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2. Goal and scope of the deliverable

The current deliverable intends to establish overarching methodology on how to perform the LCA, LCC and SLCA of food losses at primary production stage. This deliverable is the outcome of the first task « **Definition of the Framework** » of work package 5 of the FOLOU project. The methodology will be presented by means of a Product Category Rules of the impacts associated to food losses at primary production stage. The PCR forms the foundation of WP5, and spans from M6 to M12 consisting of five main segments:

1- Methodology of quantification of food losses and side losses at primary production stage:

It will cover the quantification of food losses at primary production stage for five main commodities, namely: 1) Fruits and vegetables, 2) Root and pulses, 3) crops and oil seeds, 3) fishery and aquaculture, 5) Meat and dairy products. The type of data used for the quantification will be provided and the conceptual systems adapted for each commodity will be defined. The fraction of FL will be given per each product and commodity at MS and aggregated EU level. This methodology will be the cornerstone for subsequent assessments and analyses.

2- Methodology for the environmental impact assessment of food losses at primary production stage:

This task encompasses a comprehensive approach on how to quantify the environmental impacts of FL at primary production stage per each of the five commodities. Defining as first step the system boundaries for each commodity while identifying the impacts to be considered for the assessment along with the assumptions made for each of them. Afterward, the PCR will entail the adequate approach to quantify each of the selected impacts for each commodity. This comprehensive analysis ensures that we capture the full spectrum of consequences (environmental, economic, and social) resulting from the reduction of FL at primary production stage.

3- Methodology for the economic impact assessment associated to FL at primary production stage:

In this section, the system boundary established for each commodity in the previous step will be conserved (same system boundary as the environmental impacts assessment). The environmental impacts are associated with an economic burden that represents the costs of operations, maintenance, end-of-life and financing. The economic models to be developed will differentiate

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between the fixed and variable costs from one hand while considering two types of cut-off approaches: Environmental and semi-financial ones.

4- Methodology for the social impact assessment associated to FL at primary production stage:

The main objective of this section is to provide a rigorous and adaptable methodology for conducting a comprehensive and insightful social impacts assessment within the food supply chain at primary production stage. First relevant social indicators from Product Social Impact Life Cycle Assessment (PSILCA) database will be selected to assess the social footprint of EU food losses by means of life cycle inventory. The obtained results will address social sustainability impacts of food losses, but also supporting the tracking of progress towards the Sustainable Development Goals (SDGs).

5- Methodology for quantifying environmental and economic savings resulting from the reduction of food losses for each commodity:

The last objective of this deliverable consists of calculating the net environmental and economic savings resulting from the reduction of food losses at primary production stage. The results obtained via environmental and economic assessments will be the basis for this analysis. Once we fix the percentage of reduction to be considered, the avoided impacts will be considered to finalize the balance and quantify the savings resulting from food losses reduction at primary stage of each commodity.

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3. An overall vision of FOLOU objective

3.1. Scope of sustainability assessment within FOLOU

The primary objective of FOLOU is to rigorously quantify **FL** occurring at the primary production stage and to analyze the associated environmental, economic and social burdens. In undertaking this assessment, FOLOU focuses exclusively on the fraction of food that departs from the food supply chain during the primary production of food intended for human consumption (**Pf**). By narrowing the scope to this critical stage, the methodology aims to provide a detailed understanding of the impacts linked to FL, enabling stakeholders to develop targeted strategies for mitigation s and fostering more sustainable practices in the early stages of the food supply chain. In addition to the primary objective of quantifying FL, the FOLOU project extends its analysis to encompass other side flows occurring at the primary production stage of food, such as food waste and fractions directed toward animal feed. Although not included in FOLOU scope, this comprehensive approach aims to provide a broader context for understanding the magnitude of FL in relation to the overall primary production and associated side flows. By quantifying these additional elements, the study seeks to offer a holistic perspective on the efficiency and sustainability of food production systems.

Furthermore, the FOLOU project will go a step further by quantifying total side losses (**SL**) at the primary production stage and its associated impacts. This comprehensive assessment will encompass integral losses for both food production intended for human consumption and other outputs not designated for human use. Termed as "side losses," this inclusive measure will provide a holistic understanding of the overall efficiency and sustainability of primary production processes. By accounting for all losses, regardless of their intended destination, the study aims to offer a nuanced perspective on resource utilization and environmental impacts across diverse production pathways.

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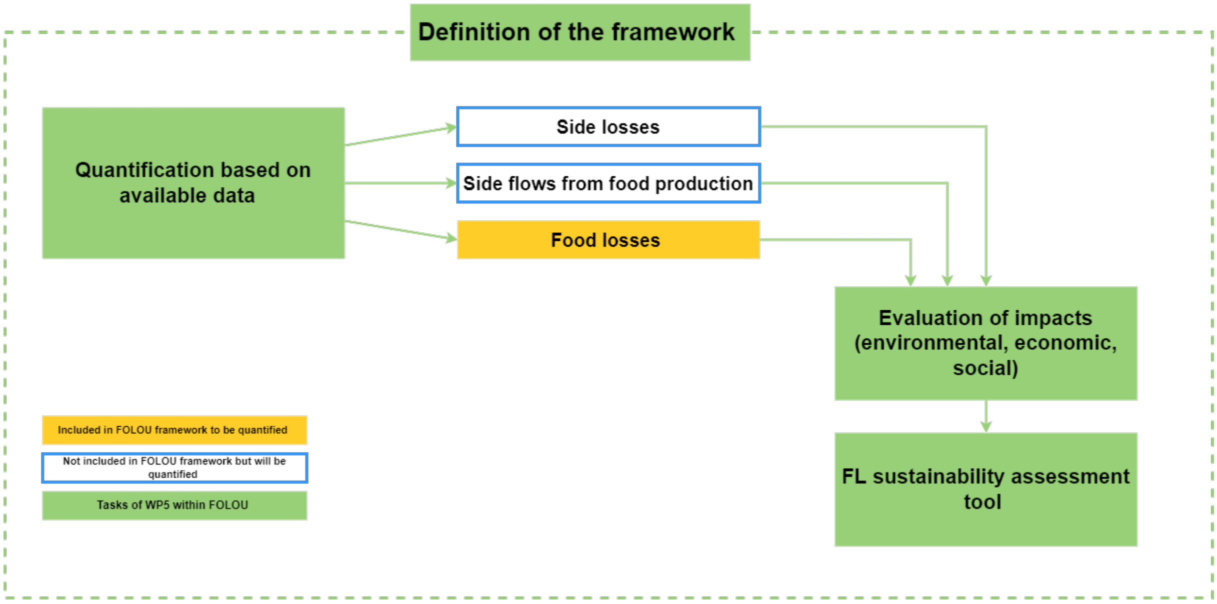

Figure 1- General scope of sustainability assessment within FOLOU framework.

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3.2. Objectives of WP5: sustainability assessment

Assessing sustainability is becoming common practice in the context of product and territorial policies. Sustainability Science (SS) is considered an emerging discipline, applicative and solution-oriented whose aim is to manage environmental, social and economic issues in light of cultural, historic and institutional perspectives. The challenges of the discipline are not only related to better identifying the problems affecting sustainability but to the actual transition towards solutions adopting an integrated, comprehensive, and participatory approach (Sala et al., 2013 a, b).

WP5 of the FOLOU project is tackling the sustainability assessment of FL at primary production stage. Firstly, it aims to gauge and estimate the extent of food losses occurring during the initial stages of production at both the national and European Union levels. Its second goal is to evaluate the adverse sustainability impacts associated with these losses, encompassing environmental, economic, and social dimensions. Lastly, the WP endeavors to construct a tool for sustainability assessment, equipping administrators, and researchers with the means to monitor the progress of implemented reduction strategies and to evaluate potential advantages stemming from envisioned strategies to minimize food losses.

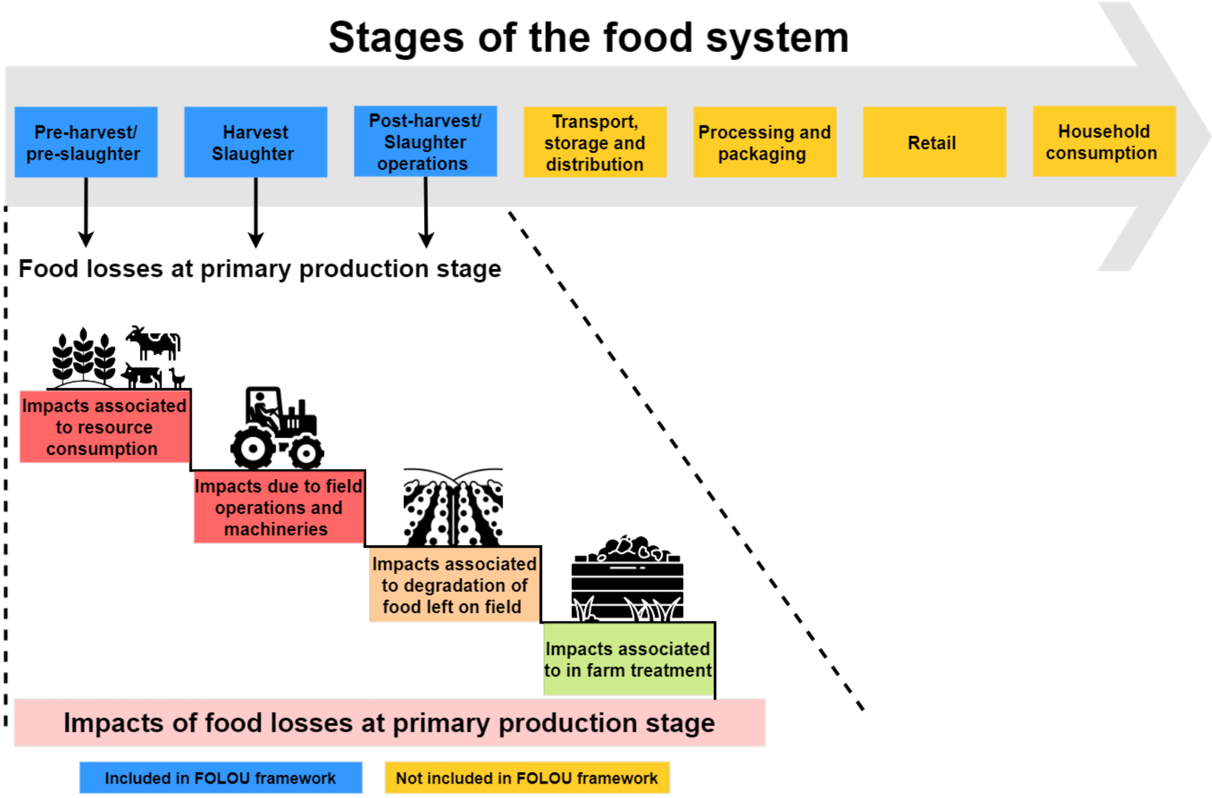

Figure 2- Objectives of WP5 of FOLOU project in terms of impacts assessment

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3.3. Relation with other deliverables and tasks

In Work Package 5 (WP5), our focus is on assessing the sustainability of FL at primary production (PP) stage of five food commodities and several key deliverables are interlinked to ensure a seamless progression.

The initial task (T5.1) involves developing a PCR where a comprehensive methodology is provided to conduct sustainability assessment of FL at PP. The second task (T5.2) involves conducting a thorough screening of the available data to gather relevant inputs for our quantifying the magnitude of FL based on available data. The findings from this task will directly inform the subsequent deliverable (D5.2), which is the formulation of our database about the inputs of food productions and losses for five commodities at regional and EU level. As we move forward, the evaluation of LCA, LCC and SLCA (T5.3) will be tightly linked to the FL database created in (T5.2), ensuring that our approach aligns with the project's objectives.

Simultaneously, the creation of a sustainability tool (T5.4) is contingent upon finalizing the sustainability assessment, and any adjustments to the latter will be reflected in the former. By establishing these linkages, we aim to maintain a cohesive and logical progression within WP5, fostering efficient collaboration among team members and maximizing the effectiveness of our efforts.

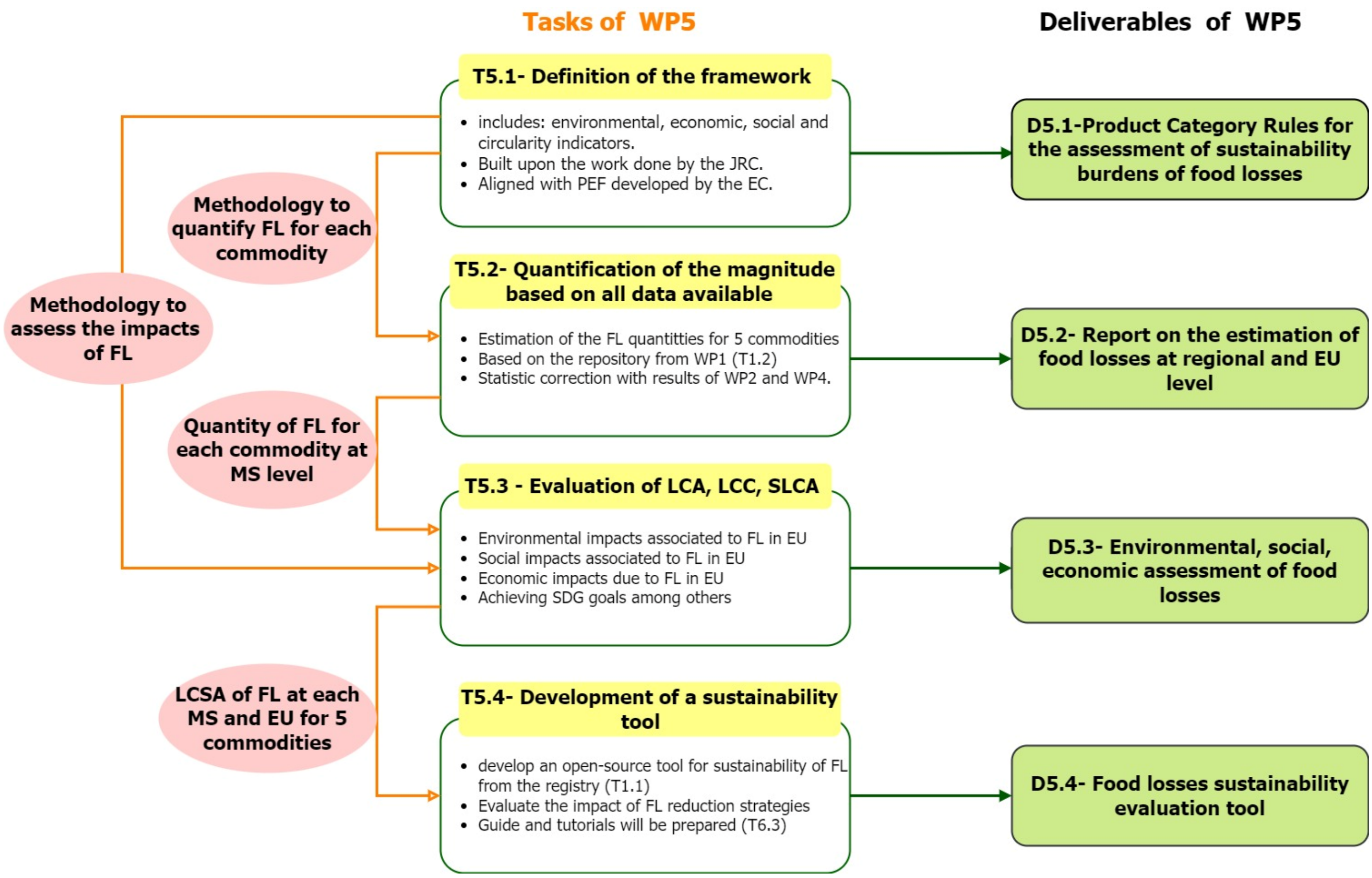

Figure 3- Linkage between Tasks and Deliverables of WP5 within FOLOU project

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4. Life cycle sustainability assessment: a framework for different commodities

4.1 Goal and scope

The developed framework will play a major role in WP5, it is the pilar to the sustainability assessment of the food losses at primary production stage for five commodity groups at each MS and at EU level. The sustainability assessment will allow us to reflect the magnitude of the decisions made regarding a significant fraction of food that has been removed from its supply chain on the environment, on the economy and on society. Thus, help identify areas where improvement can be made and foster innovation and sustainability in food production.

The outcomes of the sustainability assessment will be the database to an interactive sustainable tool that will allow users to uncover the environmental burdens associated with food losses across the EU. The tool will be useful for decision-entities that will take charge of improving and mitigating the food losses, to identify the risks and propose solutions, optimization of the resource efficiency and also unify the point of views and avoid conflicts while taking actions from the stakeholders.

By mapping all the food losses quantities along with the corresponding environmental, social and economic impact of each country, we can easily trace the good practices and adapt them for each country, commodity and product. This way we can achieve a more sustainable food supply chain for the EU and be a reference to the rest of the world.

4.2 Limitations for life cycle sustainability assessment

Performing life cycle sustainability assessment is a comprehensive approach to evaluate the environmental, economic, and social impacts of a product or system throughout its entire life cycle. However, like any assessment methodology, LCSA has its limitations and challenges. In line with the objective of the sustainability assessment to be performed within FOLOU project, some key limitations can be summarized as follows:

- **Data availability and quality:** due to the lack of a law of regulation in the EU for quantifying food losses at primary production stage, there is a huge lack of repositories reporting the quantity of FL at each MS for all commodities and products. The assessment will be based on the available data that can be found on national statistics, technical reports, case studies, and potential surveys. The various and diverse sources of data for each country and for each commodity will be a challenge when it comes to the quantification of food losses in Task 5.2 and the available data within the system boundary of each commodity. The data used for the sustainability assessment will be

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statistically corrected using the results obtained by technical WPs throughout FOLOU project.

- **Scope and system boundaries:** the definition of food losses at EU level is not standardized up to today, various definitions of FL have been established by different entities, namely: EC, FAO, FUSION… The definition used in this framework is the one developed by FOLOU project and that is a combination of many existing ones additional to further aspects that haven't been considered: ***Food loss is any harvest-mature plant, animal or living being (including inedible parts) that is not successfully harvested, as well as food removed from the supply chain during post-harvest phase that does not become animal feed, by-product or food waste***. The scope of the systems to be evaluated by the means of sustainability assessment will be subjected to assumptions and hypothesizes to be able to conduct the assessment for the different commodities and keep the same boundaries and approaches for all MS.
- **Subjectivity and stakeholder engagement:** LCSA often involves subjective judgments and assumptions, especially in the evaluation of social and economic impacts. Engaging stakeholders and considering diverse perspectives can be challenging but is essential for a comprehensive assessment. As mentioned previously, the definition of food losses itself is the foundation for this challenge, as for example, when it comes to reporting the amount of food lost at primary production stage, the farmers do not consider any loss if the destination of the fraction is a valorization or is does not represent an economic loss. Thus, to harmonize the point of view of the different stakeholders at all member states, it is a hindrance that will affect the sustainability assessment.
- **Temporal aspects:** This limitation is also linked to the type of data available for the sustainability assessment. The source of data to be used performing the LCSA in FOLOU project will be different for each MS and product, this also means that the temporal aspect of the data will be different for each case study and different sources of national, or EU average. The purpose is to focus the temporal coverage to the last five years, however, there is no available data for the majority of the EU countries for that period of time.
- **Geographic variations:** For many EU countries, data reporting FL at primary production for either the products or the commodities is available. Consequently, the EU averages shall be considered in this case for conducting the LCSA.
- **Lack of standardized methodologies:** food loss is not considered as a product as is the case of food waste. Therefore, there is a lack of methodologies and models to quantify the impact of this fraction that is leaving the food supply chain, and at the moment the environmental impacts for example are allocated to the commercialized product. In order to assess the sustainability of FL, there is an absence of any framework or guideline to follow for the assessment.

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II- Quantification of food losses and side losses

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5. Quantification of food losses at primary production stage

The quantification of FL per commodity and country will be reported in this work package. As no empiric data is available at the moment for most products and countries (due to the absence of national registries and law obliging MS to report the FL at primary production stage), secondary data will be used to quantify the amount of FL of five defined commodities at country and EU level. A major challenge is arising also by using secondary data, that there are many definitions of FL and thus the data that can be found may have a larger scope than the one we are condition with FOLOU project, which leads us to make assumptions on the numbers to be used to the quantification. Another hindrance is that the FL of products that are representing a commodity are few compared to the total production, which will make the total amount of FL per country far from reality. In the following sections an elaborate part will be dedicated to explaining the assumptions and the type of data to be used for each commodity.

In this section, many definitions for the different fractions derived from food production are being used. The following table represents a brief explanation of each term, the equation used to calculate it and the source of data to be used in the calculation.

One of the main objectives of WP5 in FOLOU project is to be aligned with the work that has been done by the JRC regarding food waste, for this purpose, the quantification of food losses at primary production stage presented in the following sections, is an adapted approach of the one developed by the JRC in the report "***Building a balancing system for food waste accounting at National Level***", conserving the same boundaries, same abbreviations, approaches and assumptions. The quantification of food losses in this WP will be performed using two different boundaries, the first one is the calculation the fraction of food losses related to the harvested products destinated to food production, and the second one is in relation to the total production including the total yield and the sum of all side flows, which will be called in the rest of the deliverable **"Side Losses"**.

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5.1. Grain and pulses,

To calculate the food losses at primary production stage of grain and pulses, a multi-step approach was followed. These steps include: 1) the calculation of the amount of each crop produced in the last five years for each product representing a commodity in each country of the EU. 2) the calculation of the fraction of food losses associated with each amount of production calculated in the previous step (see figure 4). A detailed explanation of each step follows.

Step I: Calculate the production amount of the products representing each commodity at country level.

CBS and the FBS supply data on crop supply and uses represented in commodity primary equivalents, or the quantity of primary commodities needed for producing a certain volume of derived products (GSARS, 2017). The domestic supply quantity (DSQ) is calculated as production plus imports plus stock variation minus export. Following that, the DSQ is allocated to the following uses: feed, seeds, losses, processing, food supply amount, and other uses (Figure 4). The Figure below was adapted from the definition of DSQ by the JRC in the report "***Building a balancing system for food waste accounting at National Level***" the elements Losses and waste here refers to the fractions of FL and FW. For a comprehensive description of the components of the FBS/CBS, the reader is directed to FAO, (2001). For the purpose of quantifying the food production for each product and commodity at MS and EU level, the following amounts were extracted from the CBS and the FBS: Production amount, stock fluctuation, domestic supply quantity, feed, seeds, and other uses.

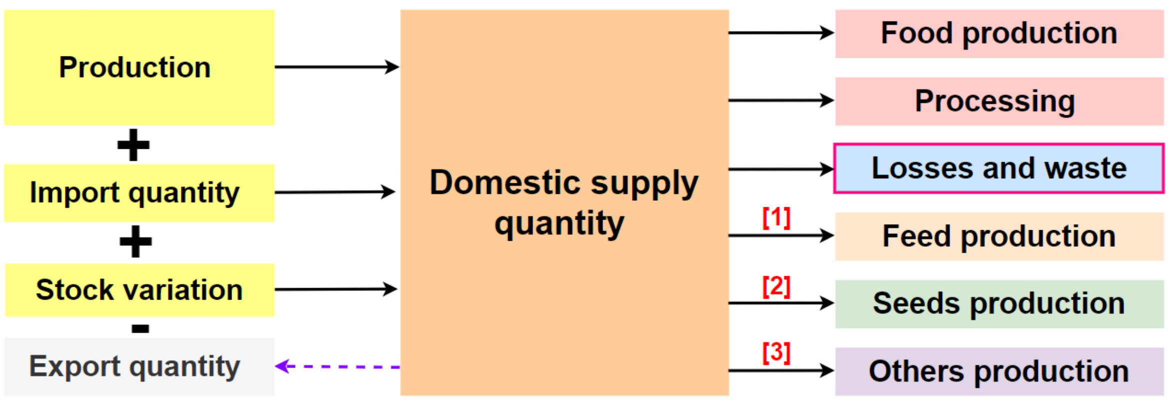

Figure 4- Visual representation of the calculation procedure followed to derive the amount of feed, seed and others from DSQ.

For the calculation of the food production destined to human consumption, the fractions of feed, seeds and other uses are to be subtracted from the production amount. The share of feed, seeds and other uses are calculated according to the following equations:

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$$Sf = \frac{\text{Feed}}{\text{DSQ}} \quad (\%)$$ [1]

$$Ss = \frac{\text{Seeds}}{\text{DSQ}} \quad (\%)$$ [2]

$$So = \frac{Other\ uses}{\text{DSQ}} \quad (\%)$$ [3]

As abovementioned, the work to be done within WP5 of FOLOU project, is aiming to be aligned with the work previously done the JRC in "*Building a balancing system for food waste accounting at National Level*" about food waste and to respect the same boundaries. According to the definition of food waste, the estimated amount of food waste generated at primary production stage should only take into account the fraction of harvested crops intended for human consumption. Therefore, the quantity of food produced was calculated as follows:

$$Pf = \mathrm{P} - (\mathrm{P} * \mathrm{Sf} + \mathrm{P} * \mathrm{Ss} + \mathrm{P} * \mathrm{So})$$ [4]

Where P is the production from CBS/FBS, and Sf, Ss and So represents the shares of feed, seeds, and other uses, calculated by the mean of the equations 1, 2 and 3, respectively.

The assumptions made for this calculation are being conserved from the ones made in "*Building a balancing system for food waste accounting at National Level*" by the JRC.

Since the reason behind calculating the food production intended for human consumption is to calculate in the end the fraction of food losses generated at primary production stage, the elements "losses" and "processing" are part the food supply chain, hence is not necessary to subtract their quantities from the total production.

Step II: Calculation of food losses generated at primary production stage.

According to the definition of food losses developed with WP4 of FOLOU project "***Food loss is any harvest-mature plant, animal or living being (including inedible parts) that is not successfully harvested, as well as food removed from the supply chain during post-harvest phase that does not become animal feed, by-product or food waste***.", the amount of food that has been lost at primary production is occurring along with other side flows in the process of producing food (Figure 5).

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The element “Feed production (Pfeed)” derived from total production refers to the fraction of feed that was intended to be commercialized from the start, however the fraction “Animal feed” derived from side flows refers to the fraction of agricultural surplus that was converted into animal feed after the valorization of crops (See Figure 5).

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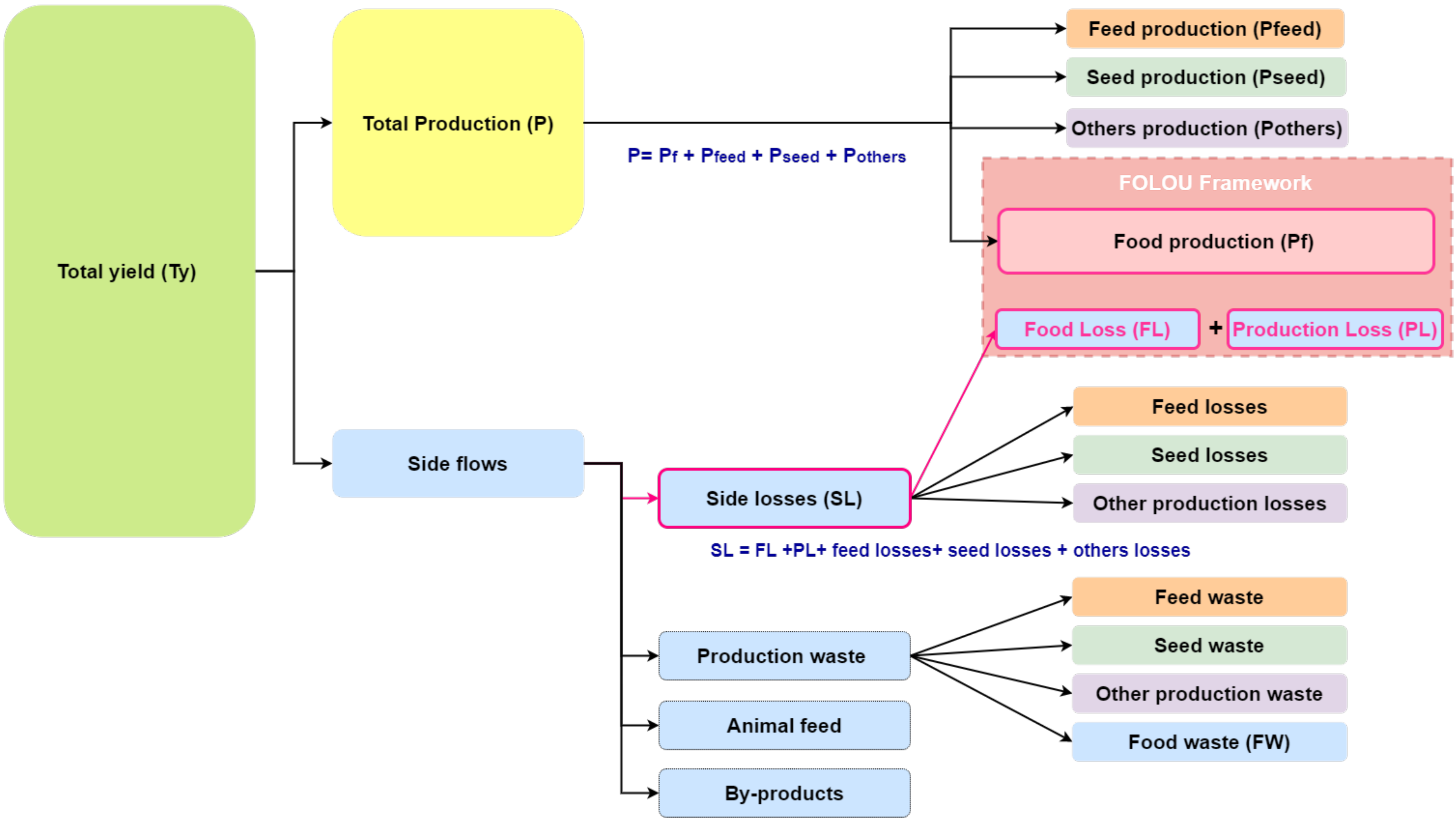

Figure 5- Distribution of food production and side flows elements used in the calculation for plant-based food commodities (framed in red).

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In this work, the quantities of the elements "food waste", "Animal feed", "by-products" will be quantified as well besides the amount of food losses. Since waste and losses at primary production are not included in the production amount extracted from the FBS/CBS, the "total yield" (i.e., the entirety of a crop ready for harvest) is determined from the produced amount (Pf) by applying a coefficient (PP01), as shown in equation 5 and Figure 6. The percentage of the overall crop that is ready for harvest that is either wasted, lost, converted into animal feed, or turned into other byproducts is represented by this coefficient, known as the "side flow coefficient" (Hartikainen et al., 2018). The fraction of FL corresponding to the production of food intended for human consumption is calculated following equation 8 as illustrated in Figure 6.

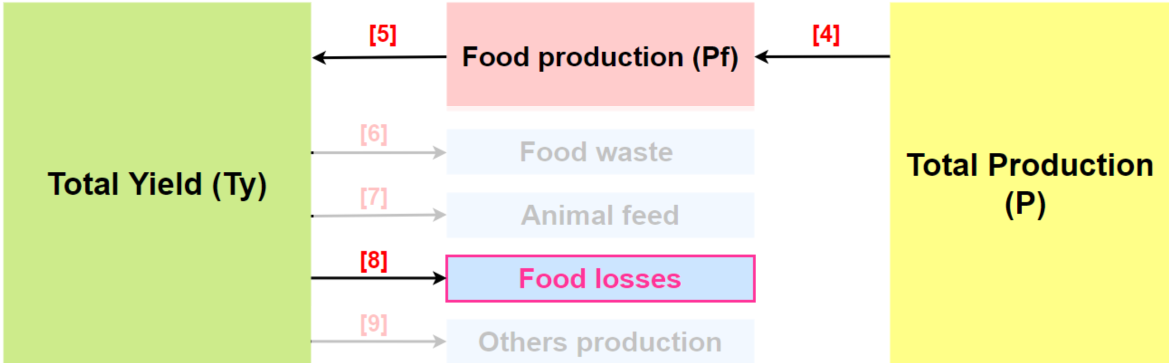

Figure 6- Visual representation of the calculation procedure followed to calculate food production (Pf) and food losses for plant-based food commodities.

Following equations 6 to 9, each component (food waste, food losses, animal feed, and other by-products) is subsequently derived from the total yield using coefficients taken from the literature as illustrated in Figure 7.

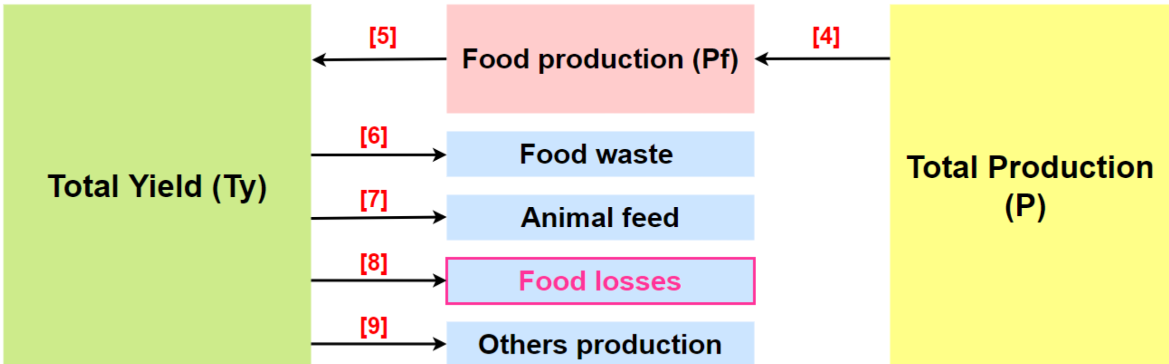

Figure 7- Visual representation of the calculation procedure followed to calculate food production (Pf) and derived side flows for plant-based food commodities.

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$$\text{Total yield} = \frac{Pf}{(1 - PP01)} \quad [5]$$

$$\text{Food waste} = \frac{Pf}{(1 - PP01)} * PP02 \quad [6]$$

$$\text{Animal feed} = \frac{Pf}{(1 - PP01)} * PP03 \quad [7]$$

$$\text{Food losses} = \frac{Pf}{(1 - PP01)} * PP04' \quad [8]$$

$$\text{Other by} - \text{product} = \frac{Pf}{(1 - PP01)} * PP05 \quad [9]$$

Where:

PP01: side flow coefficient, equal to PP02+PP03+PP04'+PP05

PP02: food waste coefficient

PP03: animal feed coefficient

PP04': food loss coefficient

PP05: other by-products coefficient

The coefficient PP04' used in the calculation of food losses at primary production stage is modified from the one used by the JRC in their work "Building a balancing system for food waste accounting at National Level". The new coefficient is based on the previous one updated with percentages of food losses collected from different national repositories, case studies, new statistic reports for different products from each commodity group at country and EU levels.

The approach provided above, also includes the calculation of food waste, animal feed and other by-products derived from the side flows. The quantification of the later terms is carried out in order to assess the total mass balance for food products from total production, despite not being included in the FOLOU framework.

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5.2. Fruits and vegetables,

The quantification approach adapted for the commodity of fruits and vegetables are identical to the one considered for grains and pulses. The two steps are being conserved keeping the same order of equations.

5.3. Root tubers and oil crops,

The first step was modified in the case of oil crops and root tubers to account for the non-food uses destined for the commodity. The modification will affect the first step of the previous versions for the commodities of "fruits and vegetables" and "grain and pulses". The new version of "Step I" will be segmented into "Step IA" for the quantification of crop oil production intended for food purposes, and "Step IB" for the quantification of root tubers intended for food purposes. The calculation is presented below:

Step I-A: calculation of the amount of oil crops produced for food purposes:

Generally, the production of oil crops is intended for two main destinations, namely, food production and biofuels production. The first step is to determine the share of each share of the previous elements, thus extracting the amount of oil crops intended for human consumption from the share used for the production of biofuels in the last five years. Transport and environment (2020) provide data on the share of oil crops entering in the production of oils for the year 2020 for the following vegetables oils: soybean oil, rapeseed oil, sunflower oil, palm oil, and generic vegetable oil. This data will be used to estimate the remaining fraction destinated for human consumption.

Based on these shares the estimated food production (OCi) for the commodity oil crops is calculated by adaption equation [4] as follows:

$$Pf = \sum_{i=0}^{5} [\mathrm{Pi} - (\mathrm{Pi} * \mathrm{Sfi} + \mathrm{Pi} * \mathrm{Ss} + \mathrm{Pi} * \mathrm{Soi})] * (OC1i) \qquad [10]$$

Step I-B: calculation of the amount of root tubers produced for food purposes:

Generally, the production of root tubers crops is used mainly for human food, animal feed and for manufacturing starch, alcohol, and fermented beverages including beers. As the objective of this exercise is resulting in the quantification of food losses, the fraction of animal feed has to be subtracted from the total amount produced. The elements "starch", "alcohol" and "fermented beverages" are not necessary to be eliminated as their end use is human consumption even if they enter another commodity group. The production of root tubers intended for human consumption is calculated following the equation [11] as follows:

$$Pf = \sum_{i=0}^{3} [\mathrm{Pi} - (\mathrm{Pi} * \mathrm{Sfi} + \mathrm{Pi} * \mathrm{Ss} + \mathrm{Pi} * \mathrm{Soi})] * (RTfi) \qquad [11]$$

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<u>Step II: calculation of food losses generated at primary production stage for oil crop commodity:</u>

Food losses, food waste, animal feed and other by-products are calculated from the food production calculated by equations 10 and 11, using the coefficients PP01, PP02, PP03, PP04 and PP05 by the mean of equations 5 to 9.

5.4. Meat and animal derived products,

The quantification of food losses for the commodity "Meat and animal derived products" will be segmented into two categories, the first one corresponding to animal derived products, and the second one corresponding to meat. The calculation steps follow the same approach as presented for crops in sections 5.1, 5.2 and 5.3.

<u>Step I-A: calculation of the amount of animal derived products intended for food purposes:</u>

The first step is being subjected to some consideration as shown in Figure 6. In case of milk, the element "seeds" is equal to zero, meanwhile it accounts for eggs used for hatching in case of eggs. The element "feed" for eggs is equal to zero. The modifications for calculating food production are shown as follows in the equations:

$$Pf(milk) = \mathrm{P} - (\mathrm{P} * \mathrm{Sf} + \mathrm{P} * \mathrm{So}) \qquad [12]$$

$$Pf(eggs) = \mathrm{P} - (\mathrm{P} * \mathrm{Ss} + \mathrm{P} * \mathrm{So}) \qquad [13]$$

<u>Step I-B: calculation of the amount of meat products intended for food purposes:</u>

The approach for meat products at primary production stage presents substantial differences in comparison to the abovementioned food commodities. As specified in the definition of food losses for meat commodity group developed under the FOLOU project, "***Food loss is any harvest-mature plant, animal or living being (including inedible parts) that is not successfully harvested, as well as food removed from the supply chain during post-harvest phase that does not become animal feed, by-product or food waste***.", primary production of meat supply chain includes the activities taking place up to slaughter, the latter being excluded. Given that live animals are not regarded as food under EU law (European Parliament and Council, 2002), there is now no food waste at primary production of meat supply chain. However, there are losses brought on by animal deaths during transportation to the butcher and by rejections at the slaughterhouse, which are here measured and categorized as food losses (Figure 8).

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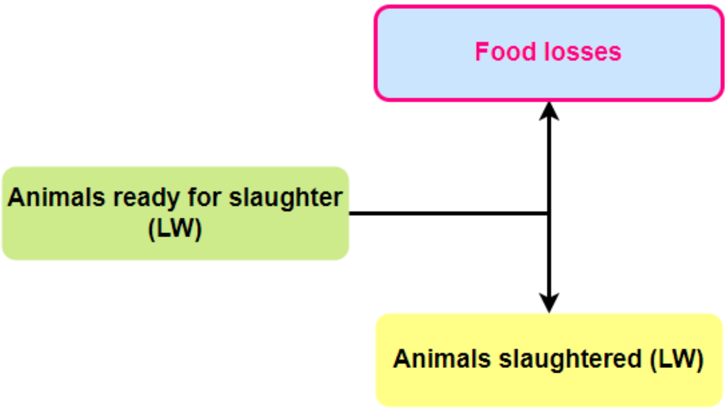

Figure 8- Production and side flows illustration for meat commodity.

The food production (Pf) for meat is equivalent to the live weight of livestock slaughtered in each country (LW). It is calculated from the number of animals slaughtered (Hi) that is extracted from FAOSTAT livestock primary database, and the average weight of each species at slaughter that will be given the notation (PP06) and will be determined for each country as reported in GLEAMI website. The calculation of food production for food commodity is then described in the following equation:

$$Pf(meat) = \sum_{i}^{n} Hi * PP06\, i \qquad [14]$$

Where:

Hi are the number of heads of each species (i) slaughtered in the country considered.

PP06i is the average weight at slaughter of species (i) in the country considered.

Step II: calculation of food losses generated at primary production stage meat and animal derived product commodity:

As described in the previous step, only food loss is being accounted for as a side flow for meat commodity. The calculation of food losses is done following equation [8] in section 5.1, considering the coefficient of side flows PP01 equal to PP04'. The new coefficient used in this exercise is based on the previous one (used by JRC) updated with percentages of food losses collected from different national repositories, case studies, new statistic reports for different products from each commodity group at country and EU levels. The calculation of food losses for meat commodity is described by the following equation:

$$\text{Food losses (meat)} = \frac{Pf}{(1 - PP04)} * PP04' \qquad [15]$$

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In case of animal derived products, the quantity of food losses at primary production stage is determined following the same approach as plant-based commodities, where a food losses coefficient PP04' corresponding to the food group will be defined combining different sources as adapted for meat (see above paragraph).

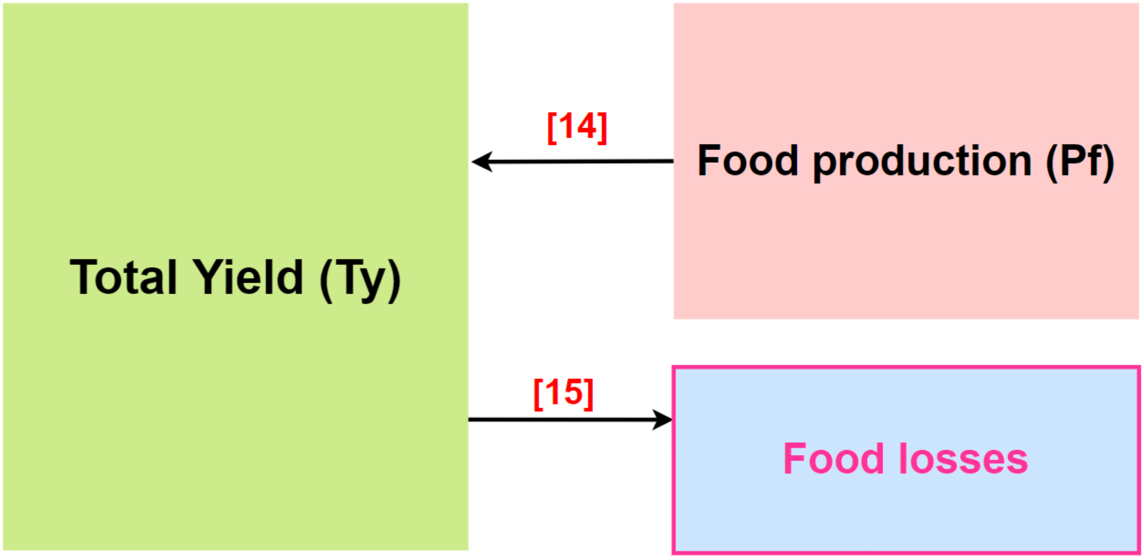

Figure 9-Visual representation of the calculation procedure followed to calculate food production (Pf) and production side flows for meat commodity.

5.5. Fish.

Step I: calculation of food production from fish commodity at primary production:

Information on the supply and usage of fish represented in live weight equivalent is provided by CBS and the FBS. The FBS/CBS is used to extract the following data: production, imports, exports, animal feed, and other uses of fish production. The quantity of fish produced for food purposes (Pf) is then determined using equation [4] in the same way that was done for the fruits and vegetables commodity (step I).

Step II: calculation of food losses generated at primary production stage of fish commodity:

Subsequently a differentiation is made between farmed fish and fish that was captured in the wild, as shown by Figure 10. This is so that wild fish and farmed fish can have their respective food waste/loss coefficients at primary production from the literature research that was consulted. Since FAOSTAT does not provide this information, the distinction is created based on the breakdown of wild and farmed fish for fish caught in the EU by species type as reported by EUMOFA (2018).

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$$\text{Food losses (fish)} = \frac{Pf}{(1 - PP01)} * PP06 \qquad [16]$$

Where:

PP06 is the coefficient of PP06 for fish.

Food waste and by-products (in this case only animal feed) generated at primary production (i.e., fishing of wild and farmed fish) are then calculated by applying coefficients taken from the literature to the Pf, as illustrated in equations 5, 6, 7 and 8, following step 2 of the procedure presented for plant-based food groups. it is important to distinguish the differences between side flows fraction between fish commodity from the previous commodities, as according to (ADEME, 2016), the entire side flow generated from wild fish is wasted (by-catches thrown back in sea), while the entire side flow generated from farmed fish is used as animal feed (PP01 and PP02 only for wild fish, and PP01 and PP03 only for farmed fish).

To be aligned with the abovementioned study by the JRC, in case of fish commodity, fish losses at primary production stage will be equal to zero and only food waste from wild fishing will be counted for in the quantification of food waste.

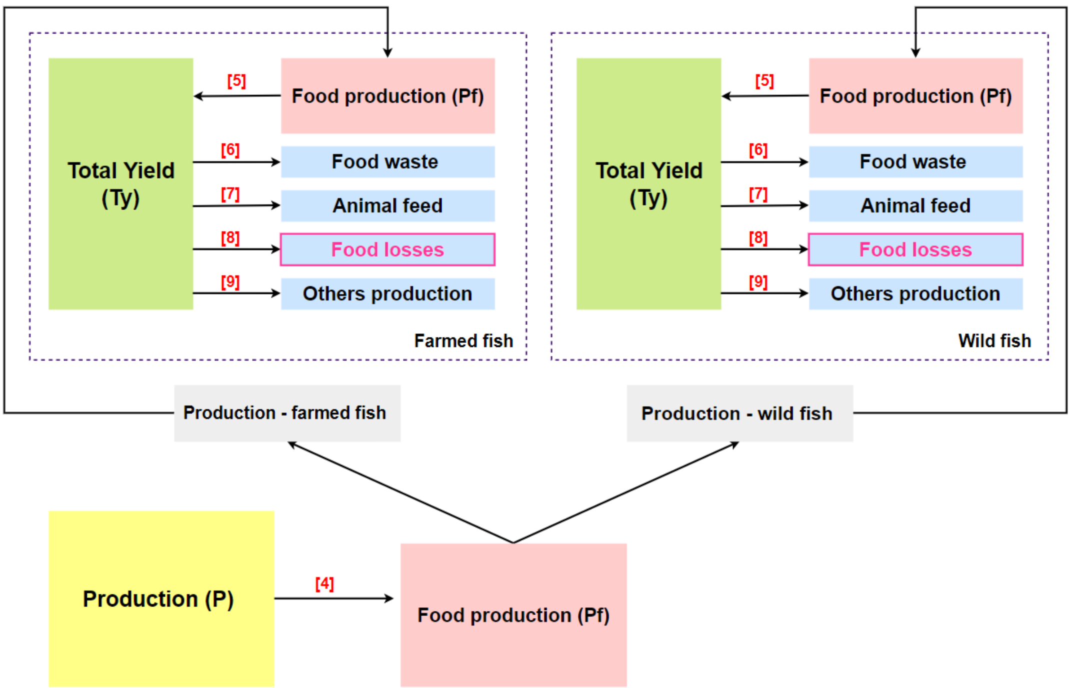

Figure 10-Visual representation of the calculation procedure followed to calculate food production (Pf) and production side flows for fish commodity.

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6. Quantification of side losses

Food losses and side losses are related concepts in the context of agriculture and food supply chains and refer to the same stages and aspects of the process. The quantification of FL based on the definition that has been developed in the framework of FOLOU project (elaborated in Section 5) refers to the losses occurring the primary production of a food supply chain considering the production of food intended for human consumption.

Side losses in this section refers to the losses that occur during the production of crops, livestock or fishery bearing in mind the total production given by CBC/FBC accounting for food intended for human consumption, seeds production, feed productions and other by-products from the same crop, livestock, or fishery. Figure 11 illustrate the framework used to calculate total side losses.

The quantification approach adapted in this section consists only of a single step compared to quantifying FL. The coefficient of side flows will be calculated from the total production available in CBS and FBS without subtracting the fractions of seed production, feed production and other by-products. In the following sections, a detailed description of how to quantify side losses (SL) at primary production stage for the five commodities will be elaborated. Two steps approach will be also followed to keep the same structure as FL quantification to facilitate understanding the approach and distinguishing between the two concepts.

6.1 Grain and pulses

Step I: calculation of crops production from grain and pulses commodity at primary production:

FBS/CBS provides information about the availability, consumption, and utilization of food commodities within a country. It typically includes information on the supply of various food items, production, imports, exports, and per capita food consumption. In this case FBS/CBS is used to extract grain and pulses production per commodity within MS.

Step II: calculation of side losses from grain and pulses commodity at primary production:

In this exercise, the quantities of the elements "food waste", "Animal feed", "by-products" will be quantified as well besides the amount of side losses. Since the elements "waste" and "losses" at primary production are not included in the production amount extracted from the FBS/CBS, the "total yield" (i.e., the entirety of a crop ready for harvest) is determined from the produced amount (P) by applying a coefficient (PP01), as shown in equation 17 and Figure 12. The approach is equivalent to the one used for quantifying FL substituting Pf by the total production of the crop in question (P).

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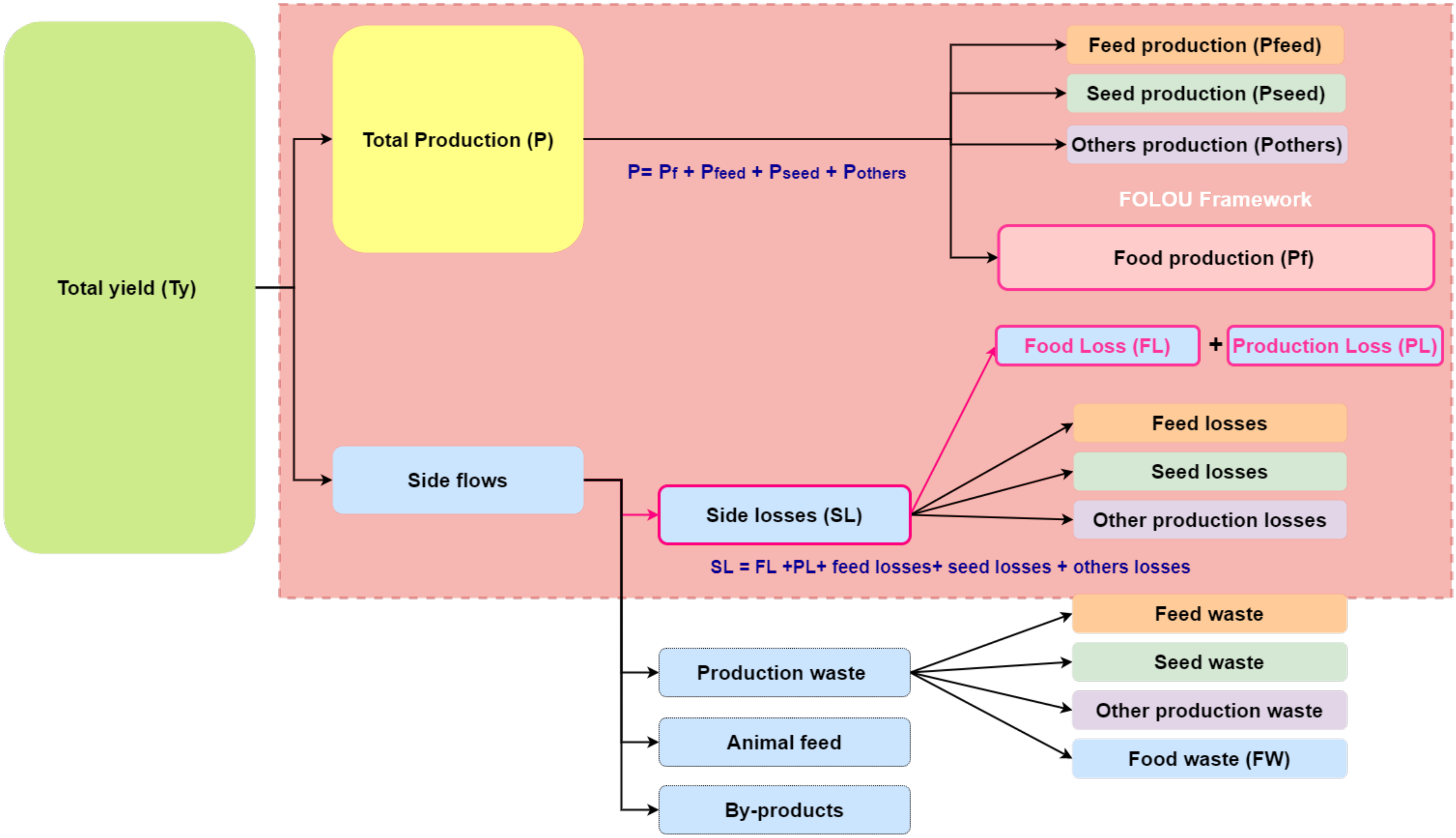

Figure 11- Distribution of total production and side flows elements used in the calculation (framed in red).

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Analogously to calculating FL, the percentage of the overall crop that is ready for harvest that is either wasted, lost, converted into animal feed, or turned into other byproducts is represented by this coefficient, known as the "side flow coefficient" (Hartikainen et al., 2018). Following equations 17 to 21, each component (food waste, food losses, animal feed, and other by-products) is subsequently derived from the total yield using coefficients taken from the literature.

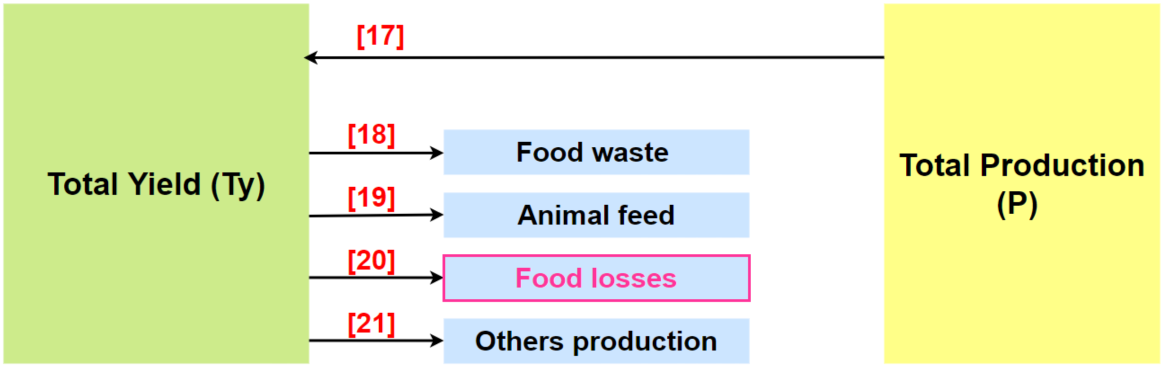

Figure 12-Visual representation of the calculation procedure followed to calculate total production (P) and production side flows for plant-based commodities.

$$\text{Total yield} = \frac{P}{(1 - PP01')} \qquad [17]$$

$$\text{Production waste} = \frac{P}{(1 - PP01')} * PP02' \qquad [18]$$

$$\text{Animal feed} = \frac{P}{(1 - PP01')} * PP03' \qquad [19]$$

$$\text{Side losses} = \frac{P}{(1 - PP01')} * PP04' \qquad [20]$$

$$\text{Other by} - \text{product} = \frac{P}{(1 - PP01')} * PP05' \qquad [21]$$

Where:

PP01´: side flow coefficient, equal to PP02´+PP03´+PP04'+PP05´

PP02´: production waste coefficient

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PP03´: animal feed coefficient

PP04´: side loss coefficient

PP05´: other by-products coefficient

The coefficient PP02´, PP03´, PP04', PP05´ used in the calculation of side losses at primary production stage is based on percentages of side losses collected from different national repositories, case studies, new statistic reports for different products from each commodity group at country and EU levels.

6.2. Fruits and vegetables,

The quantification approach adapted for the commodity of fruits and vegetables are identical to the one considered for grains and pulses. The two steps are being conserved keeping the same order of equations. The data is obtained from FBS and CBS.

6.3. Root tubers and oil crops,

Contrary to Section 5.3 where the fraction of non-food uses of oil crops and tubers was subtracted from the total production, inhere the whole amount will be considered for calculating side losses.

Step I: calculation of the amount of root tubers produced at primary production:

Generally, the production of root tubers crops is used mainly for human food, animal feed and for manufacturing starch, alcohol, and fermented beverages including beers. The amount to be used in this exercise includes all the previous elements for the various uses. The total production of root tubers as well as oil crops is extracted from FBS and CBS.

Step II: calculation of side losses generated at primary production stage for oil crop commodity:

Food losses, food waste, animal feed and other by-products are calculated from the food production calculated by equations 10 and 11, using the coefficients PP01, PP02´, PP03´, PP04´ and PP05´ by the mean of equations 18 to 21 elaborated in Section 6.1 for grains and pulses commodity. This approach is used for the whole commodity, namely, root tubers and oil crops, altering the coefficient corresponding to each one in equations 18 to 21.

6.4. Meat and animal derived products,

The quantification of side losses for the commodity "Meat and animal derived products" will also be segmented into two categories, the first one corresponding to animal derived products, and the second one corresponding to meat. The calculation steps are following the same approach as presented for crops in sections "6.1, 6.2 and 6.3".

Step I-A: calculation of the amount of animal derived products produced:

The total production of animal derived products will be represented mostly by milk and eggs (more intensive products in terms of production). The total production will be extracted from the FBS/CBS for each MS. The elements "feed" and "seed" and "others" will be kept in this exercise.

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Step I-B: calculation of the amount of meat products intended for food purposes:

In case of total production for meat products, it is equivalent to the production of meat intended for food purposes (as the only purpose behind producing meat is for food purposes). Thus, the total production will be same as represented in section 5.4 by the means of equation 14.

Step II: calculation of side losses generated at primary production stage of meat and animal derived product commodity:

As described previously in Section 5.4, only food loss is being accounted for as a side flow for meat commodity. The calculation of side losses is done following the same approach adapted for food losses for meat commodity, equation [8] in section 5.1, considering the coefficient of side flows PP01´ equal to PP04'. The coefficient used in this exercise is based on data collected from different national repositories, case studies, and new statistical reports for different products from each commodity group at country and EU levels. The calculation of side losses for meat commodity is described by the following equation:

$$\text{Side losses (meat)} = \frac{P}{(1 - PP04')} * PP04' \qquad [22]$$

In case of animal derived products, the quantity of side losses at primary production stage is determined following the same approach as plant-based commodities, where a food losses coefficient PP04'' corresponding to the food group will be defined combining different sources as adapted for meat (see above paragraph).

6.5. Fish,

Step I: calculation of total production of fish commodity at primary production:

Information on the supply and usage of fish represented in live weight equivalent is provided by CBS and the FBS. The FBS/CBS is used to extract the following data: production and other uses of fish production. Thus, the total production of fish per country is extracted directly from CBS and FBS.

Step II: calculation of side losses generated at primary production stage of fish commodity:

A differentiation is made between farmed fish and fish that was captured in the wild. This step is following the same approach as Step II from Section 5.5 where the side flows generated for both farmed fish and wild fish are collected from case studies and consulted sources. The side flow of side losses is calculated by the means of equations16, substituting Pf intended for human consumption by P representing the total production.

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III- Product Category Rules for the assessment of sustainability burdens of food losses

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7. Life cycle assessment (LCA)

7.1 Introduction to LCA

To quantify the environmental impacts associated with FL at primary production stage, the first step is to quantify the amount of FL generated. For the sustainability assessment of FOLOU project to be performed in T5.3 will use the results obtained in T5.2 for the quantification of FL and SL at primary production stage.

7.1.1 Definitions of LCA

LCA stands for "Life Cycle Assessment." It is a systematic and comprehensive methodology for evaluating the environmental impacts of a product, process, or service throughout its entire life cycle, from the extraction of raw materials to production, use, and disposal. LCA takes into account factors such as resource consumption, emissions, energy use, and other environmental indicators to assess the sustainability and environmental performance of the subject in question. It is a valuable tool for making informed decisions and improving the environmental sustainability of various products and activities.

LCA assesses a wide range of environmental impacts, including energy consumption, greenhouse gas emissions, water usage, air pollution, and the depletion of natural resources. The goal of LCA is to provide a holistic view of the environmental consequences associated with a product or process, helping stakeholders make informed decisions and identify opportunities for improvement.

7.1.2 Types of LCA

Depending on the specific focus and scope of the assessment There are several types or variations of Life Cycle Assessment (LCA) that can be defined. The main types of LCA include:

- **Attributional LCA (ALCA):** This is the most common type of LCA and focuses on the current or historical environmental impacts associated with a product or process. It quantifies the environmental inputs and outputs at each stage of the life cycle. ALCA is used for assessing existing systems and identifying areas for improvement.

- **Consequential LCA (CLCA):** CLCA looks at the potential consequences of changes in a product system. It assesses the impacts of decisions and actions, taking into account the broader effects that changes in one part of the life cycle might have on other parts. It is often used for evaluating the effects of policy changes, new technologies, or shifts in consumer behavior.

Within the FOLOU project, an hybrid LCA will be performed, combining elements of both ALCA and CLCA to provide a more comprehensive view of FL at PP per each MS. It considers the direct environmental impacts from ALCA to reflect the magnitude of the impacts associated to FL per different commodities, as well as the potential indirect and long-term consequences from CLCA to forecast the changes that will occur in the food supply chain if FL was reduced.

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7.1.3 Assessment framework

LCA will allow the identification of environmental hotspots and areas of inefficiency in the primary production stage. It will help pinpoint stages of the production process where significant environmental impacts occur, providing insights for targeted improvements. The assessment will allow stakeholders to prioritize actions based on the magnitude of environmental impacts obtained for the studies commodities. It will help answer questions about where efforts should be concentrated to achieve the most significant reductions in environmental footprints associated with food loss. The results will be reported separately based on the impact associated with A1-A2, B and C for each commodity. The below steps will be followed for the LCA assessment for FL at PP:

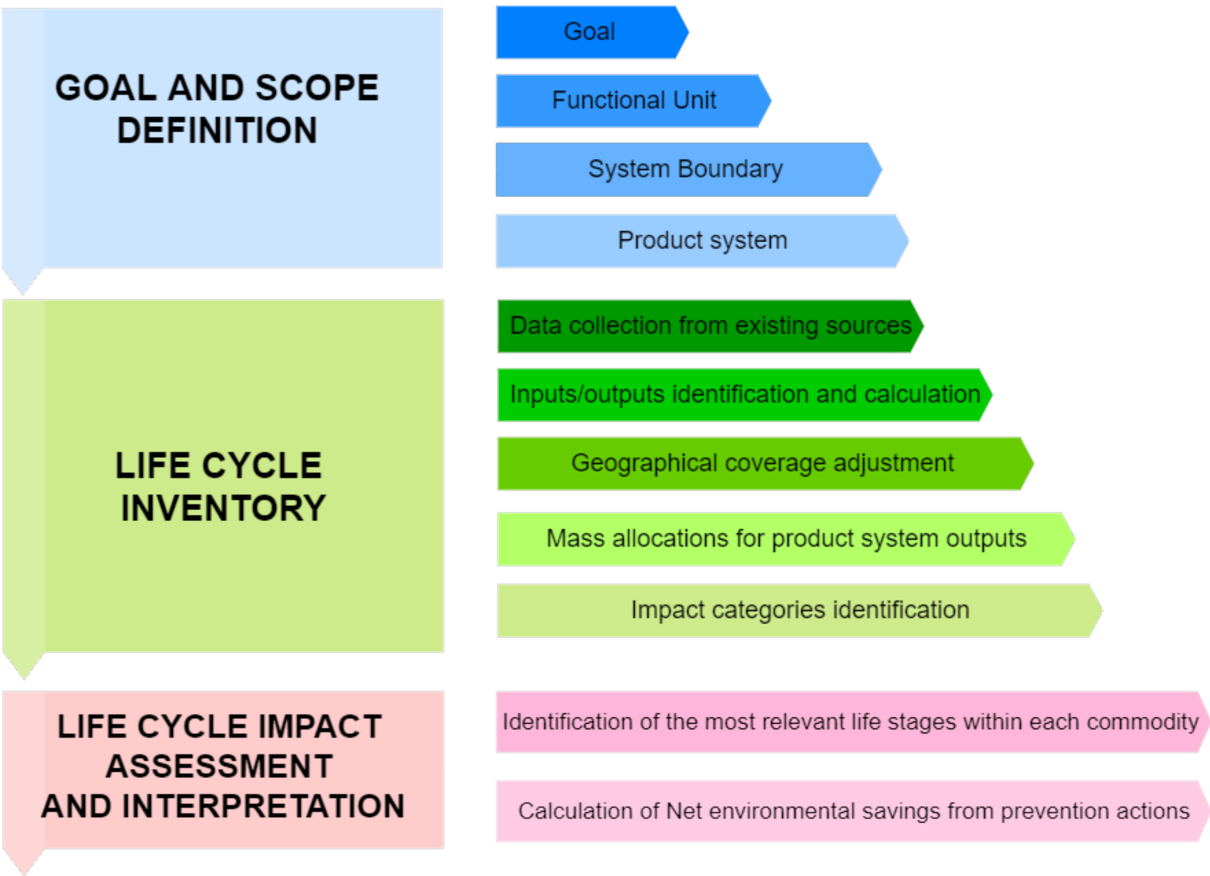

Figure 13- Steps to follow for LCA assessment of food/side losses at primary production stage.

7.2 Goal and scope

7.2.1 Goal and scope

The goal of the LCA study for FOLOU is to assess and understand the environmental impacts associated with food losses that occur at the primary production stage for five food commodities at each MS and quantify an EU average. The primary objective is to quantify and evaluate the environmental consequences of these losses depending on losses factors that will be defined and discussed. Among the impacts considered for each commodity, hotspots impacts will be defined for each MS in order to carry out a holistic comparison aiming to implement improvement

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at PP of the food supply chain. As mentioned in the introduction of this section, two types of LCA will be performed for FL at PP stage. First an understanding of the environmental impacts will be obtained through ALCA where the consequences of the fraction of FL will be reported for several products for each commodity, at country level, meaning to set the magnitude of these impacts based on available data. Afterward, some reduction scenarios in terms of FL will be defined to perform a consequential analysis aiming to analyze the probable influence that may affect food market from one side, and other connected markets using FL as a resource for production of goods and services.

	Attributional LCA	Consequential LCA
OBJECTIVES	Depict potential environmental impacts of FL at primary production stage of 5 commodities	Identify the consequences that defined decisions has on other systems, outise of the ALCA boundaries
MODELLING	• Use of historical, average, measurable data of food production and FL • Assess the stage included in the life cycle of food products and FL • Analyse the system as it is (or forcasted to be)	• Modelling driven by market mechanisms and potential trades of food products • Assess the product system around consequences, as hypothecal, generic supply chain • Medelling driven by consumer behaviour change.

Figure 14- Attributional and consequential LCA framework regarding food loss.

7.2.2 Functional unit

The Functional Unit (FU) is a fundamental concept that serves as a reference unit for quantifying the environmental impacts of a product, process, or service. The functional unit defines the specific function or performance of the system being assessed, and it is used to compare and evaluate different alternatives. For FL, the functional unit will be expressed as a specific quantity or weight of food. Depending on the commodity under study, the FU can be 1kg of fruit or 1kg of live weight in case of meat and fish. The discussion of the LCA results will be comparing results also as FL/ha in case of plant-based products to refer to the yield at country level and discuss about the hotspots impacts.

7.2.3 System boundaries

Defining system boundaries is a crucial step in conducting an LCA, it determines what processes and activities will be included in the assessment and what will be omitted. First, identify the stages of the food product life cycle that will be included in the assessment, namely, the activities that take place at primary production before leaving the farm. These typically encompass raw material and resource uses, production, internal transportation, and end-of-life stages. Temporal and spatial boundaries are to be considered as well, a cradle-to-gate approach to be followed for the food products at national level. Following, a separated description of the system boundary of each commodity group highlighting the environmental impacts to be considered in the LCA.

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- **Plant based products:**

The system boundary for assessing the environmental impacts of grain and pulses, Fruits and vegetables, Root tubers and oil crops in a LCA typically includes several key components, from the production of the food product to its end-of-life stage. The purpose of WP5 within FOLOU project, however, is to assess the environmental impacts of the fraction of food loss instead of food. The key components to be considered are similar to ones of the "food product" beside the impacts associated with fraction of FL left on the field and does not have a defined destination and the impacts associated with the treatment of the FL on-farm (Figure 14). To sum-up the impacts to be considered in LCA assessment for this food group are defined as follows:

A1- Impacts associated with resource consumption.

A2- Impacts due to machinery and field operations - On-farm handling.

B- Impacts associated with on-farm treatments for the fraction of FL.

C- Emissions due to degradation of food on the field (fraction left on the field).

The above impacts are defined taking into account FL definition developed within FOLOU project, also after confirmation with databases developers that the impacts available in databases do not account for this fraction, these impacts are illustrated in Figure 15. Potentially, the results obtained from T5.3 "Evaluation of LCA, LCC and SLCA" will be useful to estimate the total impact of a given marketable product without allocating all the impacts to the reference product but also accounting for the impacts of FL generated during its production.

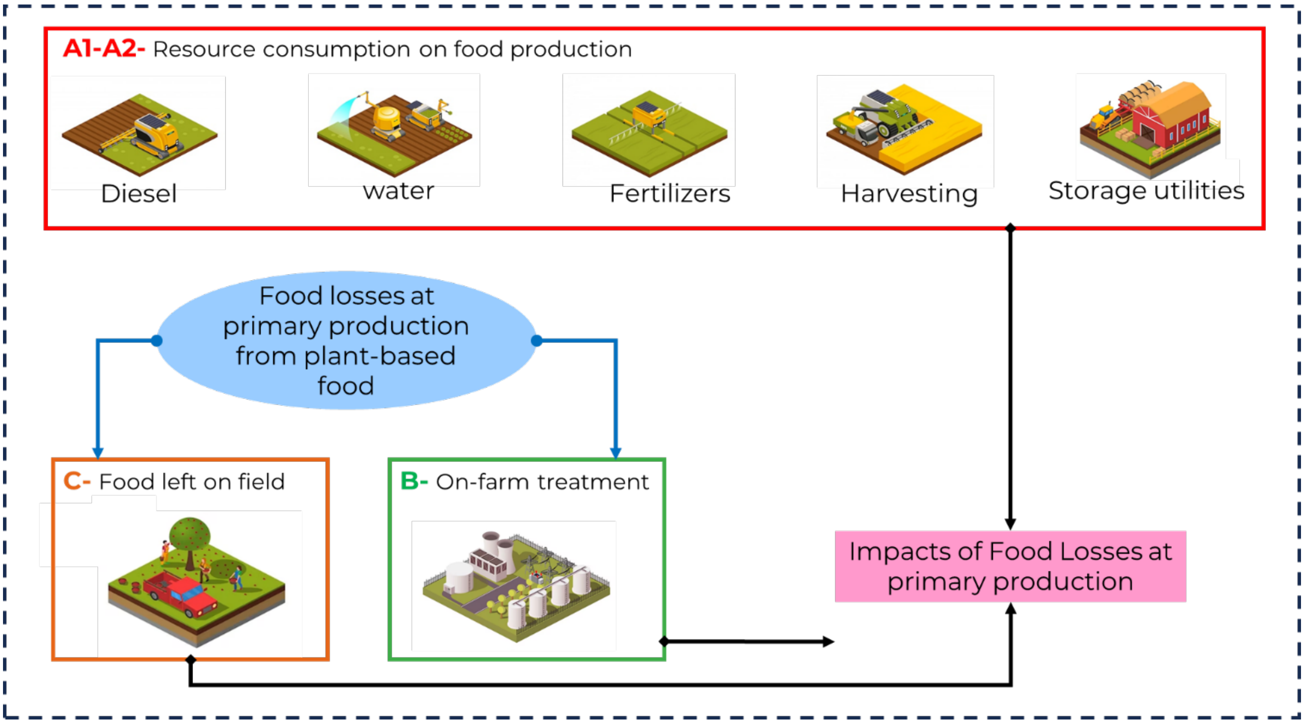

Figure 15- System boundaries for plant-based food commodities and impacts to be considered at primary production.

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- **Meat and animal derived products:**

The system boundaries for this commodity will be break down into three segments, meat products, and two most produced animal derived products, namely, milk and eggs.

Meat:

The system boundary for assessing the environmental impacts of meat loss in a LCA assessment includes the following components:

A1- Impacts associated to resource consumption for meat production.

A2- Impacts due to machinery and farm operations.

B- Impacts associated with the treatments of dead animals.

C- Livestock emissions (enteric fermentation, manure management...).

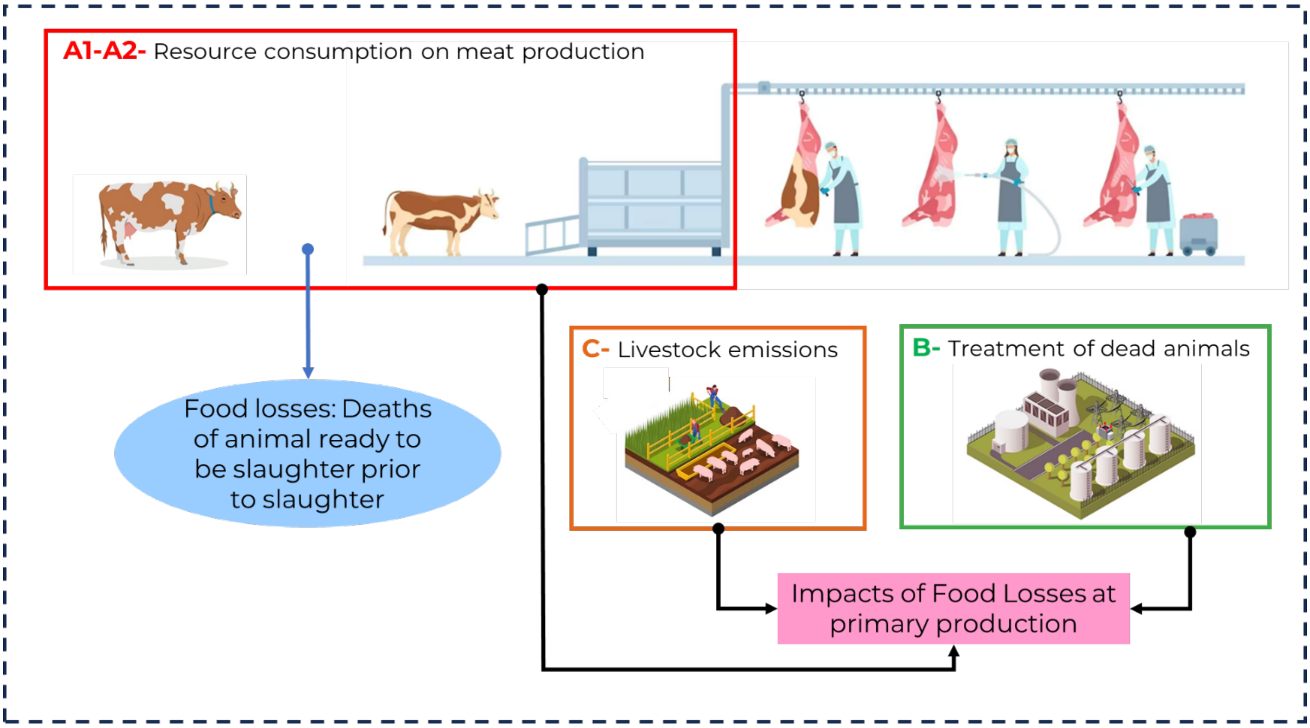

Figure 16-System boundaries for meat commodity and impacts to be considered at primary production.

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Milk:

Milk production is associated with the release of greenhouse gases, primarily methane (CH4) and nitrous oxide (N2O). Methane is produced during enteric fermentation in the digestive systems of cows, and nitrous oxide is released from manure management and the application of fertilizers. These gases contribute to global warming and climate change. The system boundary for assessing the environmental impacts of milk loss in a LCA assessment includes the following components:

A1- Impacts associated to resource consumption for meat production.

A2- Impacts due to machinery and farm operations.

B- Impacts associated with the treatments of dead animals.

C- Livestock emissions (enteric fermentation, manure management…).

Part of the impacts will be representing the phase of milk production, from resource consumption to operations, the treatment of lost milk if not counted as waste, moreover, a fraction of enteric fermentation corresponding the amount of milk loss at primary production. The impacts associated to the treatment of egg FL, is accounted when the treatment is not licensed as waste treatment within the production site.

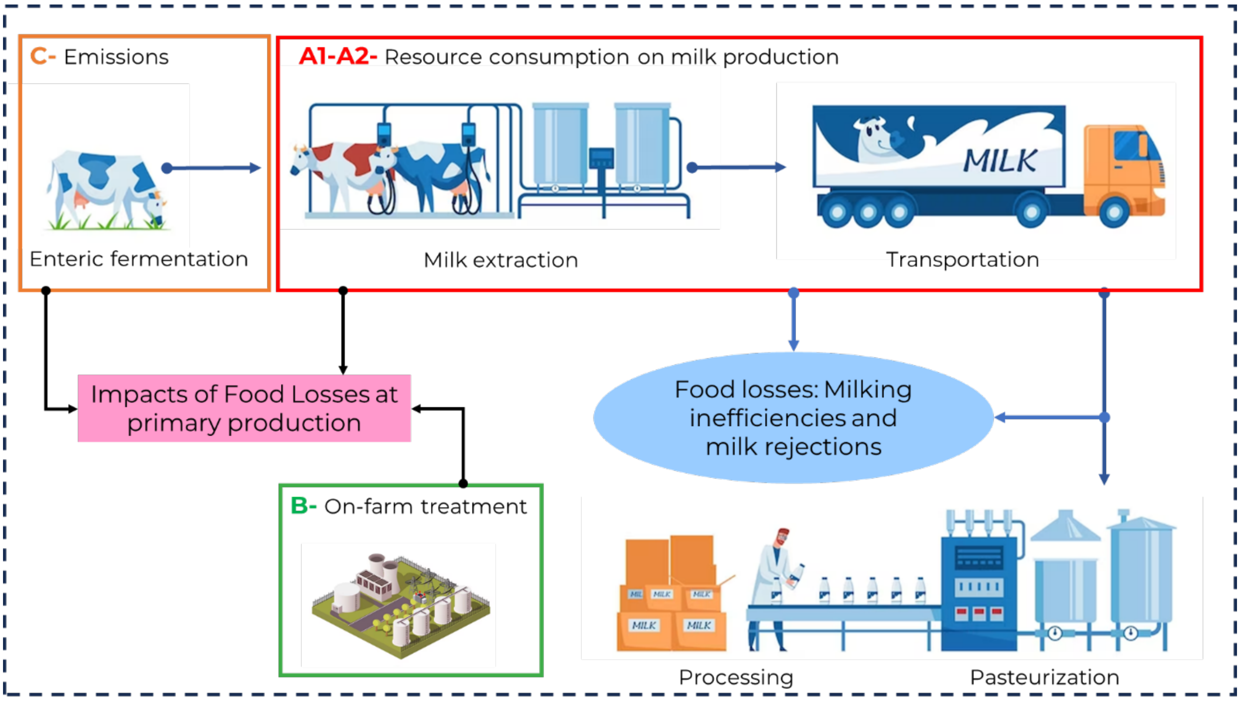

Figure 17- System boundaries for milk products and impacts to be considered at primary production.

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Eggs:

Egg production, like other agricultural activities, can have several environmental impacts that are associated with different stages of the production process. Egg production is associated with greenhouse gas emissions, primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Methane is produced by the digestive systems of laying hens, and nitrous oxide is released from manure management and the application of fertilizers. These emissions contribute to global warming and climate change. The fraction of FL will use the same resources used as commercialized product and will emit the same GHG. The impacts associated to the eggs FL will be divided as follows:

A1- Impacts associated to resource consumption for eggs production.

A2- Impacts due to machinery and farm operations.

B- Impacts associated with the treatments of spoiled and broken eggs.

C- livestock emissions (digestive system of hens and manure management).

Part of the impacts will be representing the phase of eggs production, from resource consumption to operations, the treatment of lost eggs if not counted as waste, moreover, a fraction of emissions from digestive system of laying hens corresponding the amount of eggs loss at primary production. The impacts associated to the treatment of egg FL, is accounted when the treatment is not licensed as waste treatment within the production site.

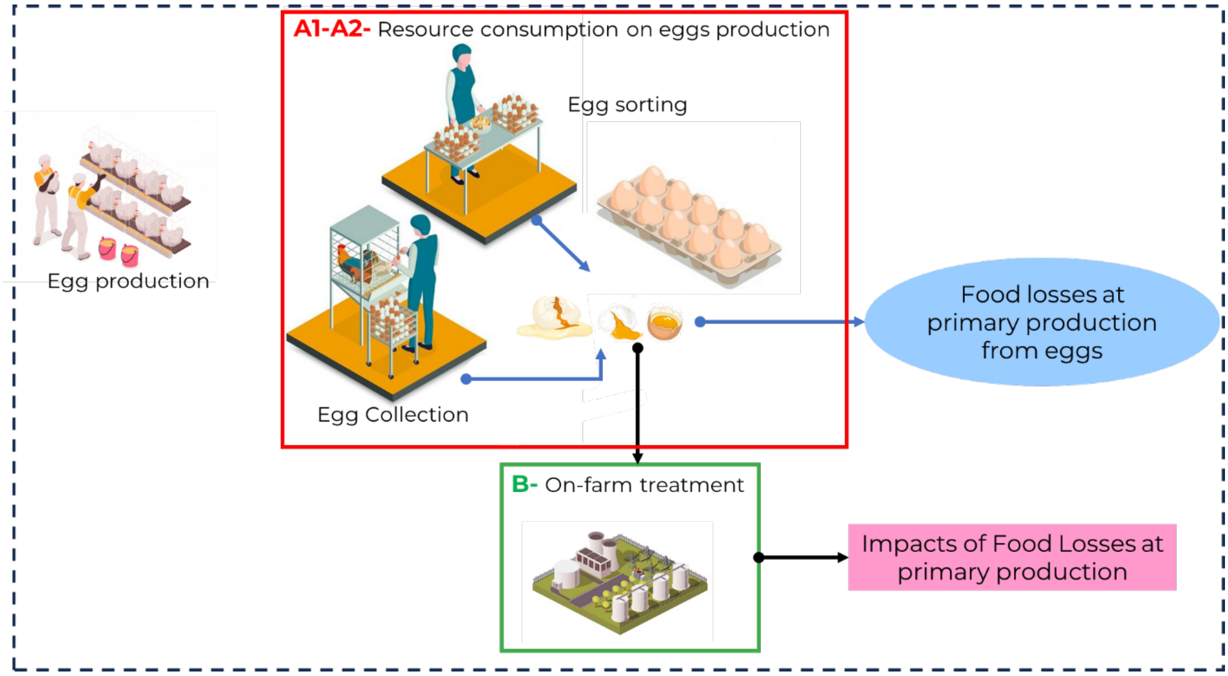

Figure 18- System boundaries for eggs products and impacts to be considered at primary production.

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- **Fish**

Fishery and aquaculture activities can have various environmental impacts that are associated with different aspects of the seafood production process. These impacts may affect marine ecosystems, water quality, and contribute to climate change. When fish are lost or wasted, it represents a missed opportunity to utilize a valuable natural resource. This can contribute to overfishing and depletion of fish stocks, particularly for species that are already at risk. For improving the sustainability of the seafood industry and addressing the associated impacts, we will try through FOLOU, to quantify the impacts associated to fish losses. The impacts associated to fish losses include:

A1- Impacts associated to resource consumption for fish production (case of aqua-culture).

A2- Impacts due to machinery and operations at primary production.

B- Impacts associated to the treatments of fish losses if not considered waste.

In case of fishery, the life stages of primary production and processing may occur at the same moment on fishing boats before arriving to the port. And the fish loss will be returned to the sea without being quantified. These will be taken into account at the moment when performing the LCA, and all limitations and assumptions made will be reported with the results.

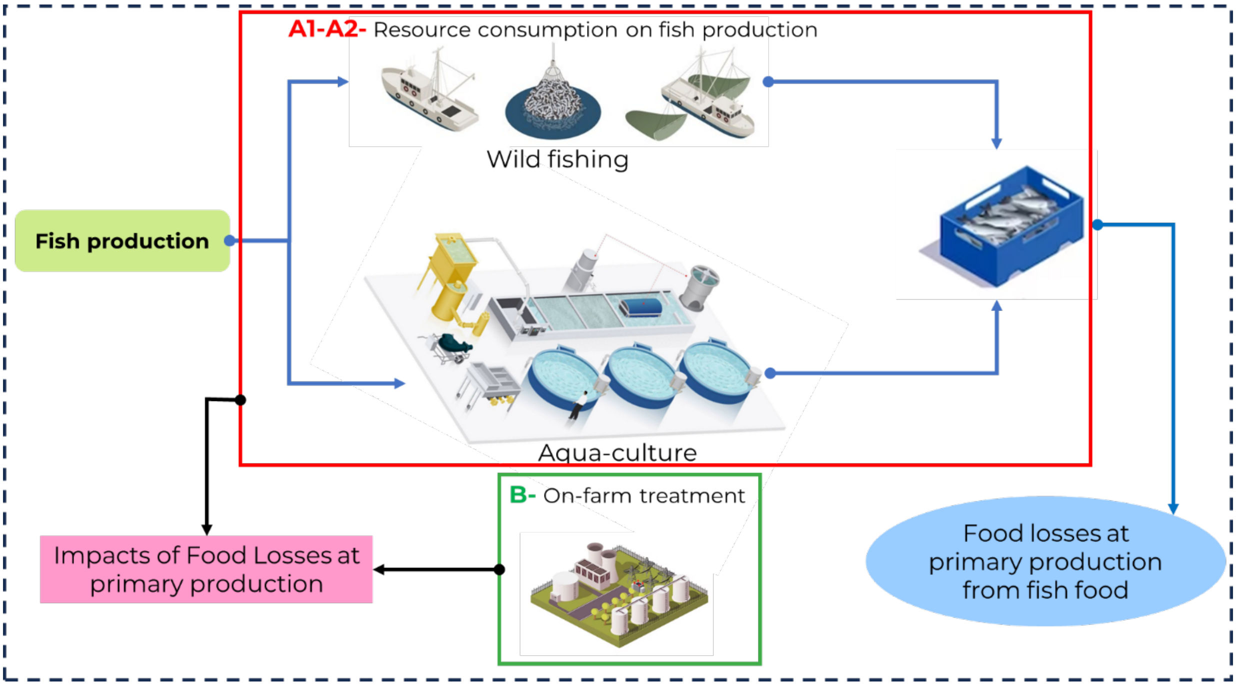

Figure 19- System boundaries for fish commodity and impacts to be considered at primary production.

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7.2.4 Product system

A product system in LCA is a collection of materially and energetically connected unit processes, which perform one or more defined functions. In other words, it is a model of all the processes that are involved in the life cycle of a product, from the extraction of raw materials to the disposal of the product at the end of its life. Figure 20 visualizes the product system adapted in this work, where the link between the food production process (for the five commodities), the inputs to the process, the emissions due to different activities and the disposal of FL is modeled.

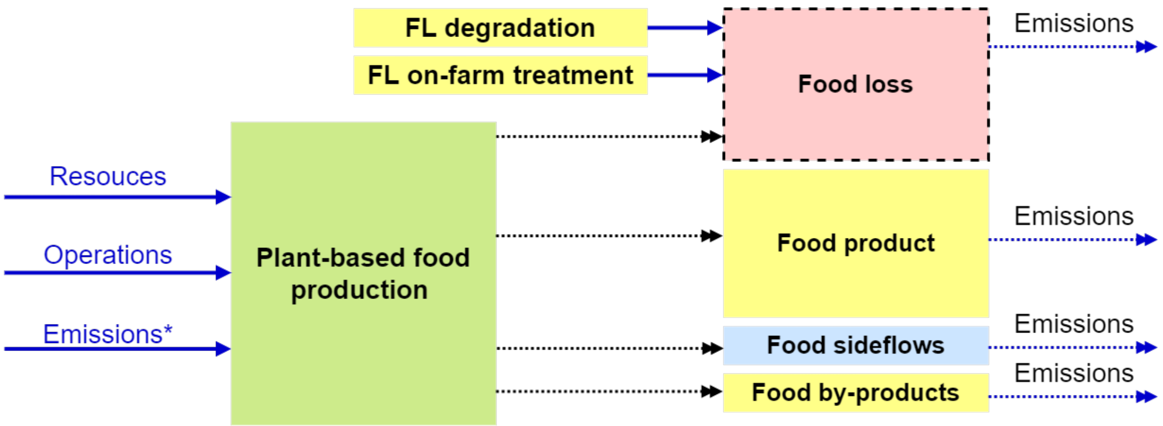

Figure 20- Product system for modelling food loss impacts adapted by the FOLOU project.

7.3 Life Cycle Inventory:

7.3.1 Life Cycle Inventory (LCI)

Collecting data for LCA studies is a critical and often challenging part of the process. The quality and reliability of data significantly impact the accuracy and credibility of LCA results. The optimal approach to be followed is to clearly define the data requirements for the LCA study for each commodity group, including the specific parameters, processes, and life cycle stages to be assessed. Up to today, there is a lack of primary data for various food products at MS level, thus, we will be considering a variety of data sources, including primary data, secondary data, LCA databases data and modeling techniques. Due to a lack of specific data for certain products per country, it is recommended to utilize average values for the EU region as a proxy. It should be noted that regional variations may exist and could influence the accuracy of the results. Following, a detailed description of the source of data for each impact considered for the five commodities. Ideally, the impacts of FL per food product can be added to the existing impact to deliver an integrated impact that includes the side flows generated during the production phase (Figure 21).

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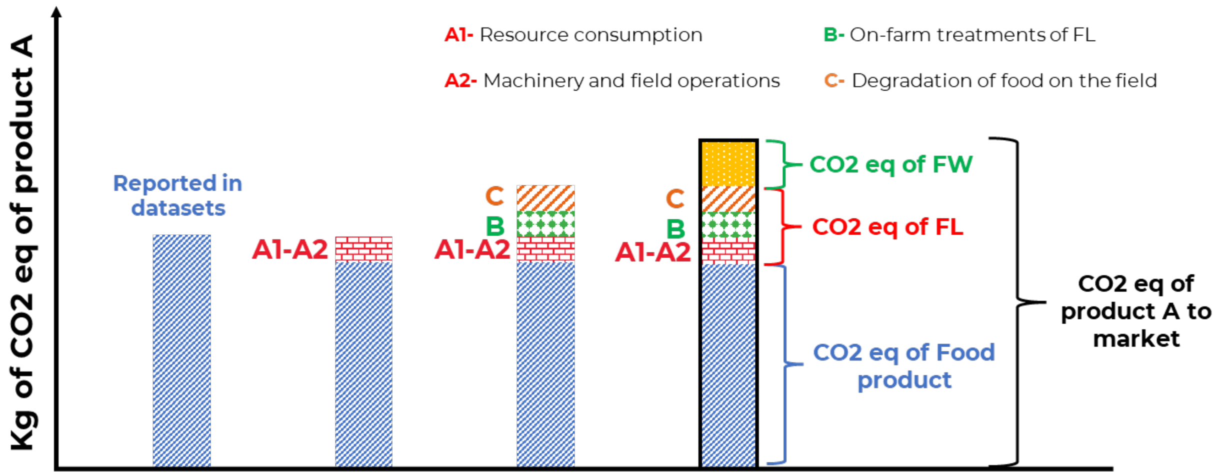

Figure 21- Actual food product impact allocation and proposed impact after accounting the impacts of side flows.

7.3.2 Mandatory and optional FL specific data:

7.3.2.1 Plant-based food products:

The approach presented below is developed for three commodities: C1, C2 and C4. To assess the environmental impacts of food losses for plant-based food products, the pre-defined impacts in Section 7.2.3 are to be considered. Currently, the impacts associated with yield, agricultural practices and land use are allocated to the commercialized food product and do account for the impacts of FL. This information is confirmed with two database developers (Ecoinvent and Agrybalis). In some datasets we can find an output flow named "crop residues left on the field" that refers only to remaining branches and leaves from some crop production and does not represent any food losses left on the field (Figure 22). The following Figure illustrates what is considered FL under the framework of FOLOU of which the environmental impact will be calculated.

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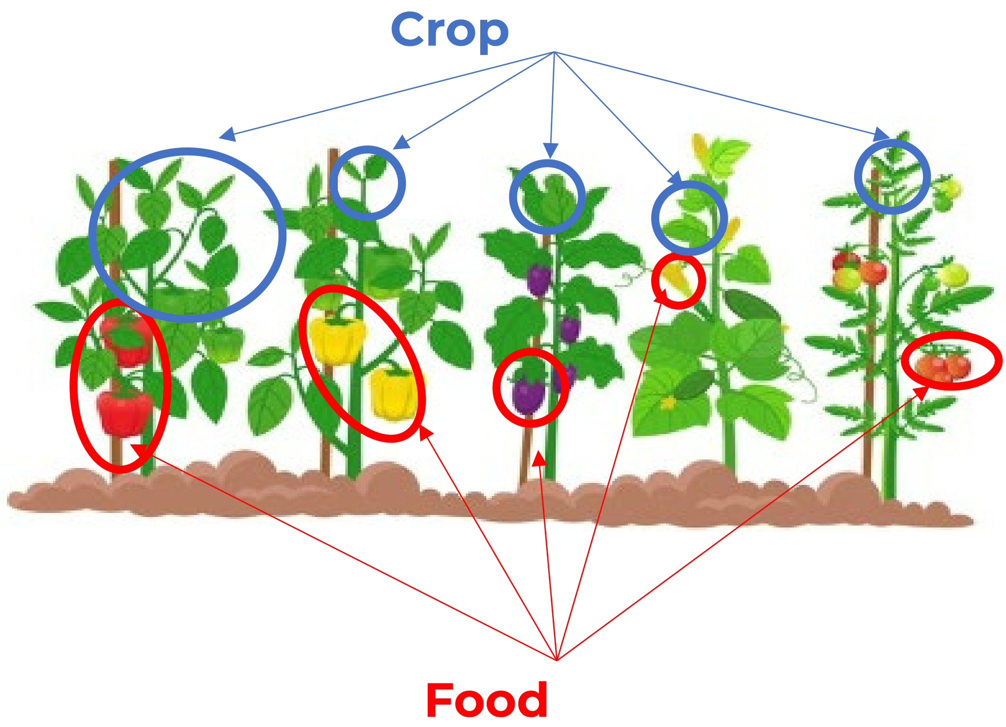

Figure 22- Differentiation between food losses and crop residues left on the field considered by some datasets.

A1- Emissions associated with resource consumption.

Environmental impacts associated to resource consumption from the fraction of food that was lost before leaving PP, is already accounted for in the existing datasets of food products, however, allocated to the food product without considering the fraction destinated to producing the amount of food loss. In this exercise, we aim to extract these impacts by allocating the resources (fertilizers, water, and pests) to food products, FL and FW at farm. The emissions associated with applying the resources are also to be considered. The methodology and source of the emissions are given in Table 2. The impacts associated to resource consumption are determined by 1kg of food and discussed in terms of inputs per unit of farm. The data for the calculation will be extracted from various sources covering many European regions.

A2- Emissions due to machinery and field operations - On-farm handling.

Environmental impacts associated with emissions due to machinery and field operations can be represented by the use of fuel for seeding, harvesting and irrigating, besides the use of energy for storing and other activities. These impacts are following the same approach of allocation as the impacts associated to resource uses. The impacts will only represent the allocated amounts and emissions responsible for producing a fraction of FL. The emissions to be considered and the corresponding methodology are given in Table 2.

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B- Emissions associated with on-farm treatments for the fraction of FL.

These impacts are associated to in-farm treatment of the fraction of FL that was not licensed as food waste. The fraction of food losses that can be treated on-farm to deliver fertilizers (composting) or biofuels (incineration) will be considered among the impacts associated to FL at PP for the plant-based commodities. The fraction of FL to be treated on-farm will be extracted from case studies, surveys, interviews and technical WPs of FOLOU project. The methodology and source for on-farm treatment is given in Table 2.

Table 2- Environmental impacts to be considered for plant-based commodities and their sources.

Impact	Source	Minimum requirement (primary data)	Optional (secondary data)
A2	Fuel use	Depending on available dataset. Use fuel and country specific heating values and emission factors. Amount of fuel consumed	
A1-A2	Fertilizer and crop residue leaching, runoff, and volatilization	Amount of N multiplied by emissions factors.	IPCC
	Fertilizer application and site conditions	Amount of fertilizer applied.	IPCC: Tier 2: As tier 1 but with country specific emission factors. IPCC Tier 3: Utilizes alternative estimation methods based on country-specific methodology.
	Fertilizer application on mineral		
	Organic fertilizer application		
	Synthetic fertilizer application		
	Lime application	IPCC Tier 1: Amount of lime (limestone or dolomite) applied multiplied by default emission factors.	IPCC: Tier 2: As tier 1 but with country specific emission factors. IPCC Tier 3: Utilizes alternative estimation methods based on country-specific methodology.
	Urea application	IPCC Tier 1: Amount of urea applied multiplied by default emission factors.	IPCC: Tier 2: As tier 1 but with country specific emission factors. IPCC Tier 3: Utilizes alternative estimation methods based on country-specific methodology.
B	On-farm treatment	Use amount of FL treated on farm and not licensed under FW category.	Depending on available dataset. Use treatment and country specific emission factors.
C	Crop residues left on field	Amount of food products left on field	IPCC and literature depending on substance

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C- Emissions due to degradation of food on the field (fraction left on the field).

Field losses occur when crops are not harvested, collected, or fully utilized, resulting in the loss of edible food. These losses can occur for various reasons and at different stages of agricultural production, from the point of harvest to post-harvest handling. Many reasons can lead to field losses, namely, quality standards, overproduction, inefficient harvesting techniques and weather conditions. Field losses has environmental consequences including greenhouse gas emissions from unused or decomposing crops, as well as potential nutrients leaching into the soil and water, besides affecting local ecosystems and biodiversity. The emissions from this FL fraction are calculated as shown in Table 2. The data on the fraction of FL that remains as field loss is calculated or estimated from case studies, surveys, and technical WPs of FOLOU project.

7.3.2.2 Meat and animal derived products:

To assess the environmental impacts of food losses for fish commodity, the pre-defined impacts in Section 7.2.3 are to consider.

A1- Emissions associated to resource consumption for meat and animal derived product production.

These impacts correspond to the amount of resources used on the production and handling of the livestock before entering the slaughterhouse gate, from feed, energy, water, and other inputs. In case of meat as well as animal derived products, these impacts are fully allocated to commercialized food or not accounting for. The determination of impacts of resources that lead to producing meat and animal derived products will allow to extract the impacts associated to FL from datasets from the existing numbers.

A2- Emissions due to machinery and farm operations.

Environmental impacts associated to emissions due to machinery and farm/manufacturing operations can be represented by the use of fuel, use of water and, and use of utilities. These impacts are following the same approach of allocation as the impacts associated to resource uses. The impacts will only represent the allocated amounts and emissions responsible for producing a fraction of FL. The emissions to be considered and the corresponding methodology are given in Table 3.

B- Emissions associated with the treatment of dead animals.

The specific treatment may vary depending on the size and type of the animal besides the country or region where it is held. The adequate treatment to be included in this exercise will be selected based on each country or region under study. The fraction of meat loss is represented by the dead animals from the farm gate to the entrance of the slaughterhouse, the latter being excluded. Depending on local regulations and the specific circumstances, there are several disposal options for dead animals. The decision on the fraction of dead animal to be treated and well as the adequate treatment will be made based on case studies, surveys, interviews, and regulations. In case of animal derived products, the treatment adapted will be defined based on different scenarios of the available

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treatments. The methodology to follow for calculating this impact is given in Table 3.

C- Livestock emissions (digestive system and manure management).

The digestive systems of animals, particularly ruminants like cattle and sheep, can have significant environmental impacts due to the natural digestive processes of these animals. Livestock emissions associated impacts are grouping the environmental impacts due to manure management, digestive system emissions (enteric fermentation) and excretion. These impacts are also being counted in the case of animal derived products as a representative fraction corresponding to the amount of milk and egg loss. As with other commodities, FL from meat and animal derived products will be modelled as modelling a food product, then the impacts will be allocated to the amount of FL. The methodology adapted for these impacts is given in Table 3. the inputs data to a farm unit or 1kg of liveweight meat, 1kg of milk or 1kg of meat will be extracted from case studies, surveys, and technical WPs of FOLOU project.

Table 3- Environmental impacts to be considered for meat and animal derived product commodity and their sources.

Impact	Source	Minimum requirement (primary data)	Optional (secondary data)
A1-A2	Fuel use	Depending on available dataset. Use fuel and country specific heating values and emission factors. Amount of fuel consumed	
	Energy supplies	Amount and type of energy consumed	Utilizes alternative estimation methods based on country specific methodology.
	Feed	priority should be given to specific data, whenever possible. Feed production shall be handled in conformance with the requirements from the PEFCR on "Feed for food producing animals" and country of origin of each feed material should be specified.	
B	FL treatment	Use amount of FL treated on farm and not licensed under FW category.	Depending on available dataset. Use treatment and country specific emission factors.
C	Enteric fermentation	IPCC Tier 2: Animal numbers and animal feeding type (e.g. feedlot cattle, cattle grazing) are taken into account. It is based on emission factors (Ym) per animal types and on Gross Energy intake (GE). Emission = GE x Ym	IPCC Tier 3 (considering national specificities): Total dry matter intake (DMI) and digestibility of feed are added to equation used in Tier 2 or utilize alternative estimation methods based on country specific methodology.
	Manure management (storage and application)	EMEP/EEA Tier 2 IPCC Tier 1 or IPCC Tier 2: depending on the substance and process.	EMEP/EEA Tier 3I PCC Tier 2: As tier 1 but country-specific emission factor used. IPCC Tier 3: Utilizes alternative estimation methods based on country-specific

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		methodology
Excretion on pasture	IPCC Tier 1: the total amount of nitrogen excretion in each type of manure management system is multiplied by an emissions factor for that type of manure management system (default values used).	Country-specific data. Alternative estimation methods based on country-specific methodology.

7.3.2.3 Fish:

Aquaculture, which is the farming of aquatic organisms such as fish, shrimp, and shellfish, can generate several types of emissions that contribute to environmental impacts. These emissions may include greenhouse gases, nutrients, and organic matter.

A1- Emissions associated to resource consumption for fish production (case of aqua-culture).

These impacts correspond to the amount of resources used on the production and maintenance of the aquaculture sites, accounting for the corresponding amount to the fraction of fish loss only, from feed, energy, water, and other inputs. These impacts are calculated for the case of aquaculture and not wild fishing. The data will be extracted from case studies, consultations, surveys, and interviews. The methodology used to calculate the environmental impacts associated to resource uses for the fraction of FL is given in Table 4.

A2- Emissions due to machinery and operations at primary production.

These emissions are due to use of fuel and energy supplies in aquaculture facilities, during the production and transport to feed the fish in the sites. The data to calculate these impacts will be extracted from interviewing aquaculture manufacturers, case studies, published technical report, and statistics. The methodology and to calculate the corresponding emissions are given in Table 4.

B- Emissions associated to the treatments of fish losses if not considered waste.

The appropriate treatment of dead fish in aquaculture is essential to prevent the spread of disease, maintain water quality, and minimize environmental impacts. The specific treatment may vary depending on the scale of the aquaculture operation and local regulations. The data for these impacts will be extracted from case studies, through interviews, consultations, and surveys. The methodology used to calculate the environmental impacts are given in Table 4.

C- Emissions associated with aqua-culture.

Aquaculture can generate several types of emissions that contribute to environmental impacts. These emissions may include greenhouse gases, nutrients, and organic matter. Methane (CH4) is a potent greenhouse gas that can be emitted from aquaculture ponds, particularly in systems that involve the culture of anaerobic organisms like certain bacteria, CH4 is emitted from water to the

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atmosphere. Carbon dioxide (CO2) is released during the respiration of farmed aquatic organisms, and Nitrous oxide (N2O) is emitted from aquaculture ponds, especially when organic matter, such as uneaten feed or waste, accumulates and undergoes denitrification. Aquaculture operations generate nutrient emissions, including nitrogen and phosphorus, through the excretion of aquatic organisms, uneaten feed, and the decomposition of organic matter.

Table 4- Environmental impacts to be considered for fish commodity and their sources.

Impact	Source	Minimum requirement (primary data)	Optional (secondary data)
A1-A2	Fuel use	Depending on available dataset. Use fuel and country specific heating values and emission factors. Amount of fuel consumed	
	Energy supplies	Amount and type of energy consumed	Utilizes alternative estimation methods based on country specific methodology.
	Feed	priority should be given to specific data, whenever possible. Feed production shall be handled in conformance with the requirements from the PEFCR on "Feed for food producing animals" and country of origin of each feed material should be specified.	
B	FL Treatment	Use amount of FL treated on farm and not licensed under FW category.	Depending on available dataset. Use treatment and country specific emission factors.
C	Aquaculture	Emissions to air from digestion	
	Aquaculture	Nutrients in water	

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7.4 Life Cycle Impact Assessment:

7.4.1 Impact categories

The environmental footprint impact categories provide a comprehensive framework for assessing the environmental impacts of various systems, helping stakeholders make informed decisions and take actions to reduce the environmental footprint of products, processes, and services. The specific choice of impact categories depends on the goals, scope, and context of the LCA study.

Table 5- Impacts categories recommended by the EC for the LCA.

Impact category	Units
Acidification	mol H+ eq
Climate change	kg CO2 eq
Freshwater ecotoxicity	CTUe
Freshwater eutrophication	kg P eq
Human toxicity, cancer effects	CTUh
Human toxicity, non-cancer effects	CTUh
Ionizing radiation E (interim)	CTUe
Ionizing radiation HH	kBq U235 eq
Land use	kg C deficit
Marine eutrophication	kg N eq
Mineral, fossil & ren resource depletion	kg Sb eq
Ozone depletion	kg CFC-11 eq
Particulate matter	kg PM2.5 eq
Photochemical ozone formation	kg NMVOC eq
Terrestrial eutrophication	mol N eq
Water resource depletion	m3 water eq

7.4.2 Geographical coverage

Geographical coverage in a LCA study refers to the spatial extent or geographic boundaries within which the assessment is conducted. It defines the region or area for which environmental impacts and resource consumption are analyzed. Geographical coverage is an important consideration in LCA because it can significantly influence the results and relevance of the assessment. As the objective of WP5 is to deliver the impacts per country and EU level, national data are the most relevant to be collected for this exercise. Depending on the existing data by the time of the LCA assessment, limitations in terms of product, commodity or country will be faced. In this case, an average value will be provided per commodity and country for the assessment as illustrated in Figure 23.

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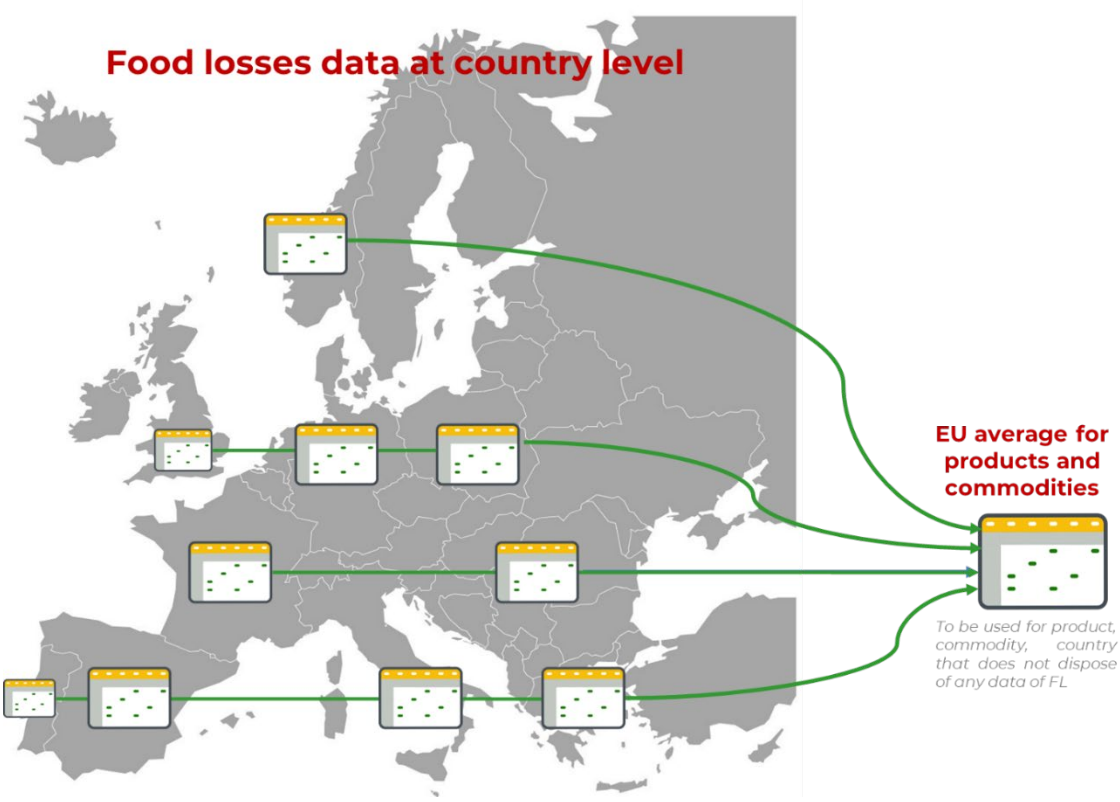

Figure 23- Concept of data coverage among MS and the EU average

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7.5 Consequential Life Cycle Assessment of Food Losses:

Consequential LCA allows for a dynamic and forward-looking analysis, which is particularly important when assessing food losses at primary production. It takes into account the consequences of adopting various strategies to reduce losses and the resulting changes in the food supply chain. Although the losses are happening at PP stage, the resulting changes are affecting further stages in the food supply chain and other connected markets. FL reduction strategies or prevention actions may influence market dynamics, affecting the production, distribution, and consumption of food. In this exercise we will be considering how these changes can impact the environmental and social performance of the food system.

different scenarios will be compared, consequential LCA helps identify potential trade-offs and unintended consequences of food loss reduction strategies. In the following sections, a description of the steps to perform CLCA and the methodologies corresponding will be provided. The systems and the scenarios to adapt at the moment of modeling will be defined.

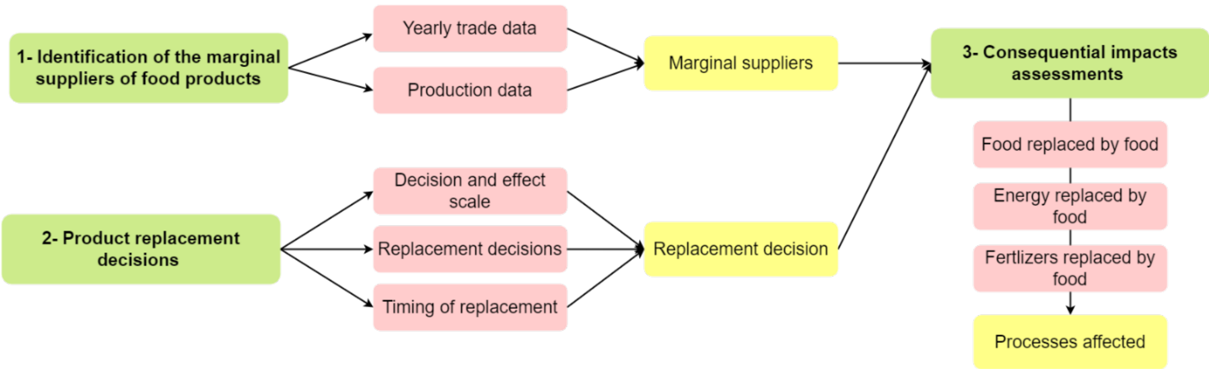

Figure 24- Consequential LCA steps to be followed for conducting the assessment for food loss at primary production stage.

CLCA will be performed considering some percentages of FL reductions. These reductions will be extrapolated from the advancement of SDG 12.3 estimating the yearly achievement of the target.

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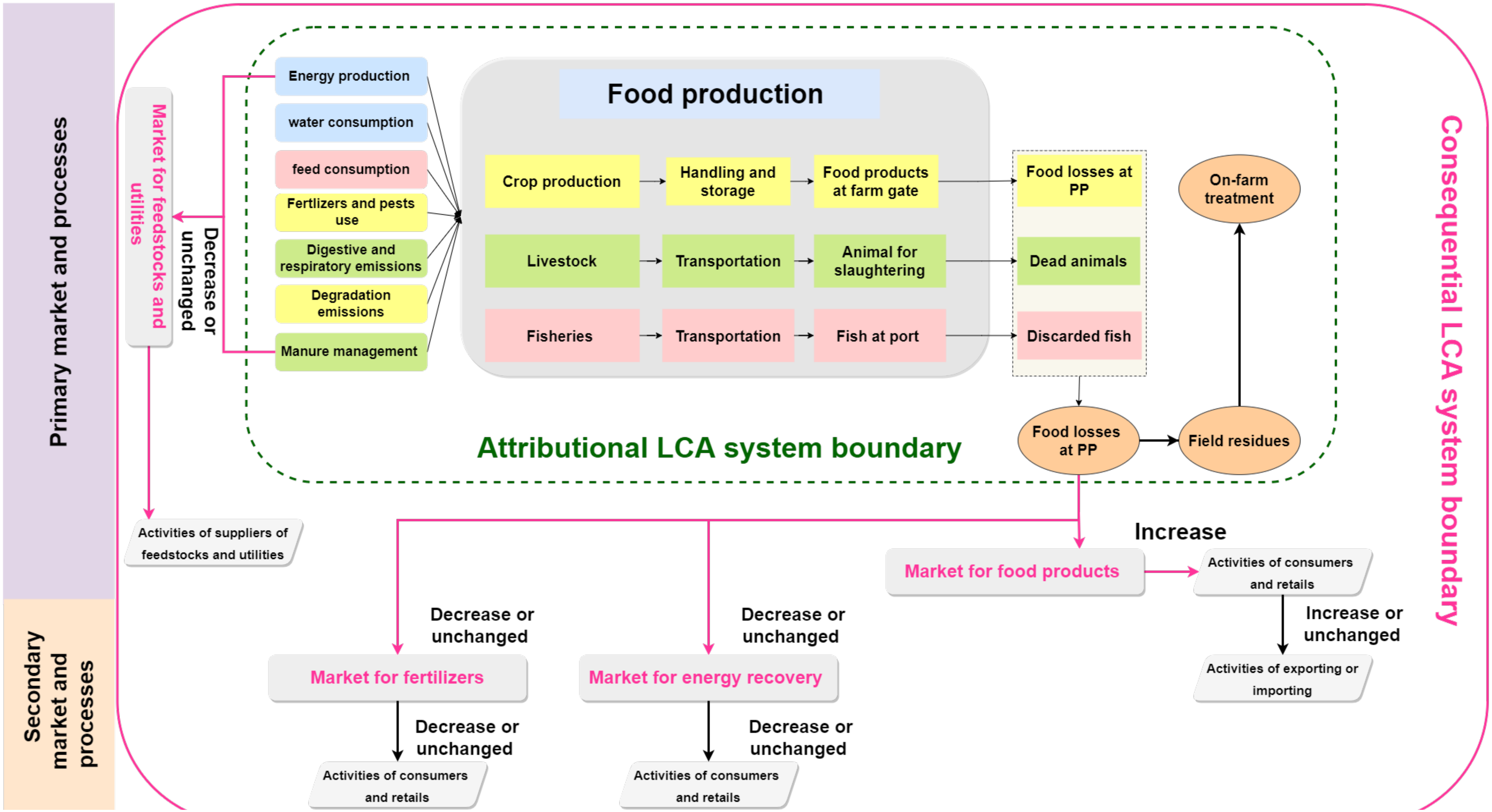

Figure 25- Consequential LCA system boundary in comparison to attributional LCA for food loss at primary production stage.

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7.4.1 Consequential LCA to assess the changes resulting from FL reduction at PP.

7.4.1.1 Identification of the marginal suppliers of food products

The consequential inventory modeling approach for LCL implies that an increase in the demand for a specific product is met by the marginal suppliers within the market (Ekvall and Weidema 2004). Reflecting the statement for food products, an increase in food production, by reducing FL, will decrease the dependence on the marginal suppliers within the food market. The identification of marginal suppliers is a key element of consequential LCA and defines which activities and relative inputs and outputs should be included in the life cycle inventory, thus determining the final environmental burden of the product system. The purpose is that constrained suppliers should be identified and removed from the list of potential suppliers, as they cannot respond to a change in demand.

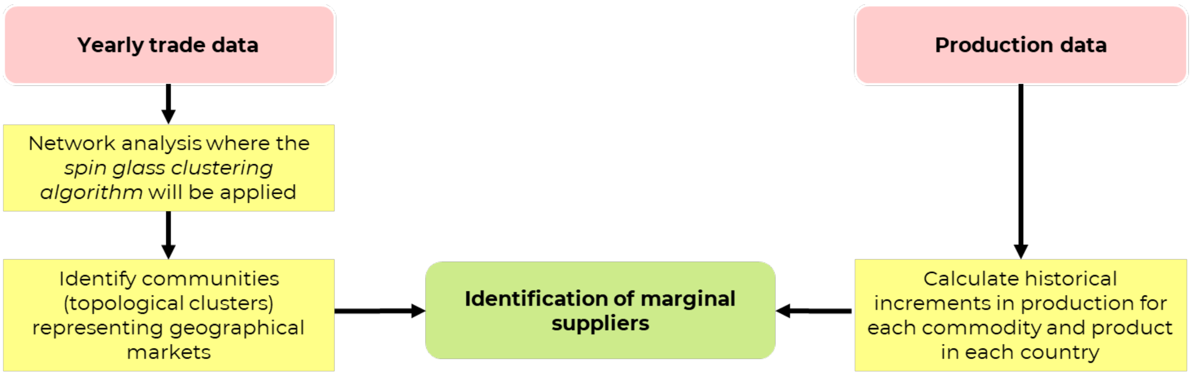

Figure 26- Example of steps to follow for the identification of marginal suppliers of food products at country and EU level.

- **Network analysis of food communities:**

Network analysis can be a valuable tool for identifying food communities or groups of organizations, individuals, or entities within the food system that are interconnected based on their activities, collaborations, or common goals. This analysis will be performed using the yearly trade data of food products for each MS extracted from statistical databases relying on a variety of clustering algorithms. The network analysis will allow identify the trade network of food for the last five years and conclude a pattern for the five commodities under study. Ideally, the food communities (or topological clusters) will be representing geographical markets for commodity groups.

- **Calculation of historical increments in production for food production**

Production data for country extracted from FBS and CBS for products representing the five commodities at country level. The historical increments in production for each commodity and product will allow conclude the pattern of the domestic supply quantity for each product and country. This will allow detect the amount of food that can be traded for each year.

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- **Identification of the marginal suppliers**

Combining network analysis results with historical increments in production in each country will allow build a trade system consisting of several scenarios of possible marginal suppliers for food products. Besides food market trade, other markets will be discussed as well in the CLCA. For instance, the reduction of FL will result in reducing the amount of FL valorized as fertilizers or biofuel, thus these markets will subject also a change.

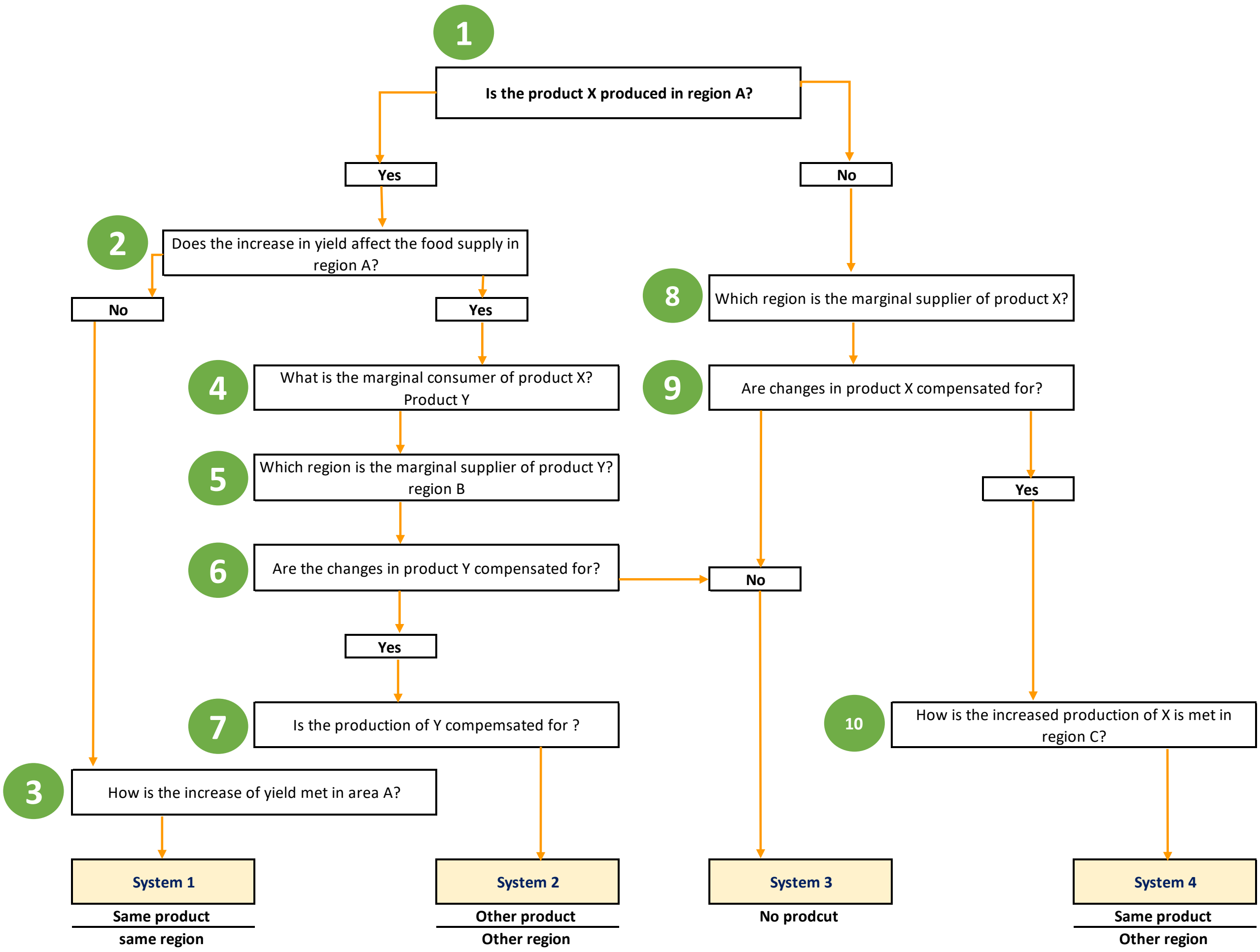

Figure 27- Decision tree structure answering consequential changes due to food loss reduction per product and country.

7.4.1.2 Product replacement decisions

According to the definition of CLCA in Section 7.1, different decisions can be assessed for the same "consequence", this can lead to an overlapping of the consequential effects. Tracking all the causal relationships between these effects is challenging and requires combining various methodologies and models to perform the CLCA. For this reason, a focus on only one aspect will be adapted for the CLCA in FOLOU project. Relevant aspects to be discussed in case of reducing FL at primary production stage are price-market effects, related marginal suppliers' specification and socio-economic behavior influence. The recommended approach to avoid the overlapping is to frame

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the product system under study over time (Ekvall and Weidema 2004; Weidema et al. 2013). This means that we have to specify which processes to consider in case of avoiding FL while specifying and fixing the time of the decision. The steps for this exercise are given below:

- **Decision and effect scale:**

The concept of consequence is always related to the result of an action performed, in this study, we will be focusing on consequence of having more food in the market resulting after reducing FL at primary production stage. Above-mentioned, the aspect of time is crucial and more precisely, the characterization of the cause-effect chain over time which implies forecasting. Thus, the timing of the decision and its effect are to be defined. Reflecting on our goal of reducing FL and delivering more food to the market, when replacing a food product resulted in avoiding FL for another, lowers the use of resource used, but this will require a different supply rate of products within a set timeframe.

To select which activities to include following a decision, we adhere to the guidelines of the UNEP-SETAC Life Cycle Initiative (2011) on CLCA product systems: "***activities are included in the product system to the extent that they are expected to change as a consequence of a change***". The description states that any process occurring before the decision is made shall be excluded. This can lead to confusion with the system boundaries between ALCA and CLCA, the latter we will be defining "products systems" for each commodity and decision instead of "product life cycle".

In order to propagate the consequential effects of any decision requires specifying the scale of the decision itself as well as the scale of the effects caused by the decision Ekvall et al. (2016). For our exercise, the consequence of having more food in the market requires a decision to be done at most of FSC stages, an option is to replace a product in the market and affect its production, export the excess of food (if applicable) to other regions, reduce the production rate of some food products and more options. Depending on the decision made, many or few processes can be affected, the magnitude of the change will allow classify the decision as small-scale decision or large-scale decision.

The decisions and the different scenarios will be defined along with their scale effects for all the CLCA to be performed for FL at PP of the five commodities.

- **Replacement decision framework:**

The main framework that is applied for the propagation of the process chain in CLCA is the one provided by Weidema et al. (2013), called the "substitution, consequential, long-term" (SCL) approach. The SCL framework focuses on a particular type of decision, namely, that of a marginal increase in demand of a product or service marginal increase in demand of a product or service in the market of interest. Our focus will be on different decisions other than the SCL, where proposed decision types with a specific scale will be discussed for each food commodity. Different modelling choices will be used to make the

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distinction between different scenarios and product systems. The replacement of a decision along with its effect scale will be shaped by a replacement timing.

7.6 Net environmental savings due to food loss reduction

Previously in a work published by the JRC entitled "***Assessment of food waste prevention actions***", a framework for the evaluation of food waste prevention actions and its use in assessing the effectiveness and efficiency of such actions was developed. The work was developed jointly by the Directorate-General for Health and Food Safety and the JRC of the European Commission in cooperation with the Platform's 'Action and Implementation' subgroup. A total of 91 actions were collected and assessed under the developed framework, where the net environmental savings and net economic savings were calculated using a developed calculator for each action.

In this sense, one of the major outputs of WP5 of FOLOU project, is to extend the approach developed for food waste by the above report to the primary production stage where FL is generated. The purpose is to be able to join the two approaches and link the calculator with results obtained through FOLOU for FL at PP.

The reason behind such assessment is to estimate the efficiency of the developed prevention actions as well as following up the existing ones and optimizing with new strategies. The purpose is to calculate two indicators for each prevention action defined, namely, net economic saving and net environmental saving. Regarding net environmental savings, a calculator will be developed where information on pre-defined prevention actions, which will be identified during the project, information on environmental impacts associated with activities to be included, impacts associated to FL treatment, required transportation, and additional information as shown in Figure 28. The results will be given in CO2.eq saved using a defined prevention action for each 1kg of FL per commodity group.

Moreover, calculating the net economic savings resulting from the implementation of defined prevention actions (separately) to highlight the importance of saving FL in an economic point of view, more details about this indicator will be elaborated in Section 8.

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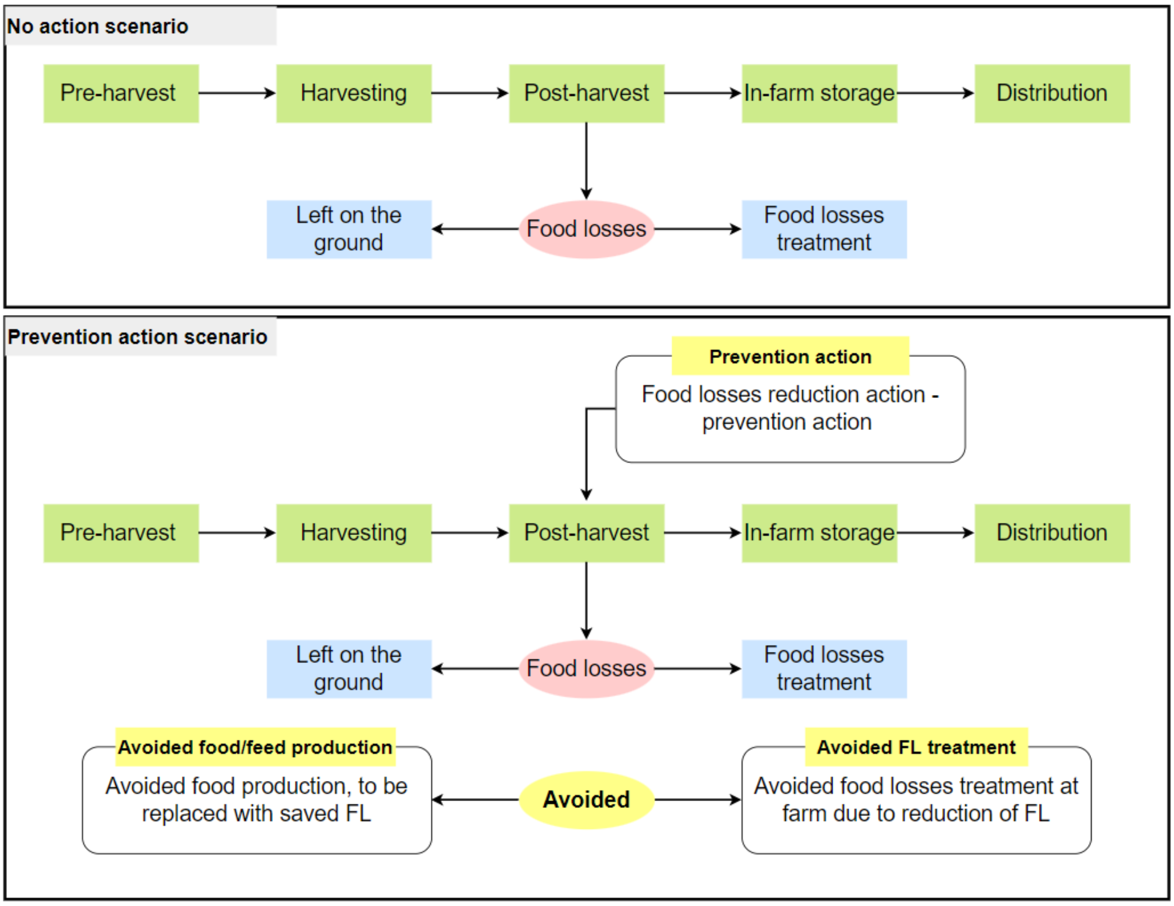

Figure 28- Visualization of prevention action framework to calculate the net environmental savings resulting the reduction of food loss at primary production stage.

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8. Life cycle costing (LCC)

8.1 Introduction to LCC

To quantify the economic impacts associated with FL at primary production stage, it is mandatory to quantify the amount of FL generated to expect the associated cost and expenses. For the sustainability assessment of FOLOU project to be performed in T5.3 will use the results obtained in T5.2 for the quantification of FL and PL at primary production stage.

8.1.1 Definition of LCC

Life cycle costing (LCC) is a comprehensive financial analysis and decision-making tool used in various fields, including project management, asset management, and product development. The primary purpose of performing life cycle costing is to assess and compare the total cost of ownership or operation of an asset or project over its entire life cycle. This approach helps organizations and individuals make informed decisions about investments, product choices, and project management by considering costs beyond the initial acquisition cost. This approach takes into account not only the initial acquisition or construction costs but also the costs associated with operating, maintaining, and, in some cases, disposing of the asset or system.

8.1.2 Types of LCC

Hunkeler et al. (2008) provided a classification of LCC into three main approaches: Conventional (C-LCC), Environmental (E-LCC) and Societal Life Cycle Costing (S-LCC) – mainly differing in terms of perspective, costs included, and potential uses. In summary, Conventional LCC has narrow boundaries, primarily focused on individual stakeholder perspectives and specific products or investments. E-LCC extends the boundaries by aligning with LCA standards, considering the entire life cycle, and accommodating multiple stakeholders. S-LCC goes even further by assessing the overall societal costs, incorporating broader economic and environmental considerations, and taking a societal perspective.

8.1.3 LCC of FL at primary production stage seen by FOLOU.

In the context of FOULOU, performing a life cycle costing (LCC) analysis of food losses at the primary production stage serves several important purposes, particularly in the context of agriculture and the food supply chain. These purposes are crucial for decision-making, policy development, and sustainable agricultural practices. Here are the key purposes behind performing an LCC of food losses at the primary production stage:

- **Economic Assessment:** LCC helps quantify the economic impact of food losses at the primary production stage. It considers the costs associated with crop or livestock loss, including production inputs, labor, and equipment. This information is vital for farmers, policymakers, and stakeholders to understand the financial implications of food losses.

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- **Resource Allocation:** By assessing the life cycle costs of food losses, it becomes easier to determine where resources are being wasted and how they could be better allocated. This helps optimize resource management, reduce inefficiencies, and improve overall productivity in agriculture.
- **Sustainability Evaluation:** LCC considers the environmental and social costs associated with food losses, such as wasted water, energy, and land resources. It provides a comprehensive view of the sustainability impacts, aiding in the development of more sustainable agricultural practices and policies.
- **Decision Support:** LCC assists farmers and producers in making informed decisions about crop selection, storage methods, and handling processes. It helps identify cost-effective strategies to reduce food losses, such as investing in better storage facilities or pest management techniques.
- **Policy Development:** Governments and international organizations can use LCC data to develop policies and initiatives aimed at reducing food losses at the primary production stage. These policies may include incentives for farmers to adopt sustainable practices or regulations on waste disposal.
- **Supply Chain Efficiency:** By quantifying the costs of food losses, LCC can reveal inefficiencies in the supply chain. This information can lead to supply chain improvements, better coordination among stakeholders, and the reduction of losses during transportation and distribution.
- **Risk Management:** LCC also considers the financial risks associated with food losses, providing insights into the potential impact on farmers' livelihoods and the stability of food supply chains. This is crucial for risk management and resilience planning.
- **Food Security:** LCC helps address food security concerns by identifying critical points of loss and developing strategies to minimize them. Reducing food losses at the primary production stage can contribute to improved food availability and affordability.
- **Consumer Awareness:** Publicizing LCC findings on food losses can raise awareness among consumers about the value of food and the need to reduce waste. This can influence consumer behavior and promote responsible consumption.
- **Research and Innovation:** LCC can drive research and innovation in agriculture and food production, encouraging the development of new technologies, practices, and storage solutions that reduce losses and improve resource efficiency.

Within WP5 of FOLOU project, LCC will be performed taking into account the abovementioned aspects to be addressed and discussed, aiming to deliver a proper clear assessment of the food losses at primary production stage at each MS, and EU level. The assessment will conclude useful economic practices among the MS that can help improve the supply chain of a commodity/product in a different region. Potentially, the assessment of the

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three classes of LCC will be covered by FOLOU, the system boundaries will be enlarged from C-LCA to SLCA, and multiple stakeholders will be involved to bear the different costs. The quality and accessibility of trustworthy cost data is another important factor in LCC as a whole and food losses in particular. As Hunkeler et al. (2008) pointed out, confidentiality concerns may frequently restrict access to necessary cost data. Moreover, even high-quality cost data may be highly fluctuating and have a limited validity period. Therefore, there will always be certain obstacles in the establishment of LCC databases and enlarging the system boundaries to perform one type of LCC or another.

8.2 Goal and scope

8.2.1 Goal and scope

The goal of the LCC assessment is to evaluate the economic impacts associated to the fraction of food losses generated at primary production stage at each MS and at EU level. The purpose is to quantify the cost of the operations that take place while the production of the fraction of food lost at primary production, the cost of treatment adapted for the food losses at primary production stage and is not classified as food waste, and the economic burdens associated to the forecasted cost of food losses at PP per country. Another outcome of the sustainability assessment is to calculate the net economic savings resulting from adapted prevention actions to reduce FL at primary production stage. The prevention actions and the scenarios for FL reduction will be defined further in FOLOU project.

8.2.2 Reference unit

Same as LCA, a mass FU is more appropriate to be considered, as FL is more linked to the product and the yield than to Unit land. The same approach was considered for cases where LCC was performed to FW instead of FL.

8.2.3 System boundaries

Initially and mandatory, the system boundary considered for the LCC, is analogous to the one considered for the LCA, meaning that LCC will cover the same stages, and considered the same impacts projected in a cost point of view as adapted from Figure 15 to 19 to the following Figure 29. Furthermore, as mentioned above, the system boundaries will be extended to discuss society impacts linked to LCC.

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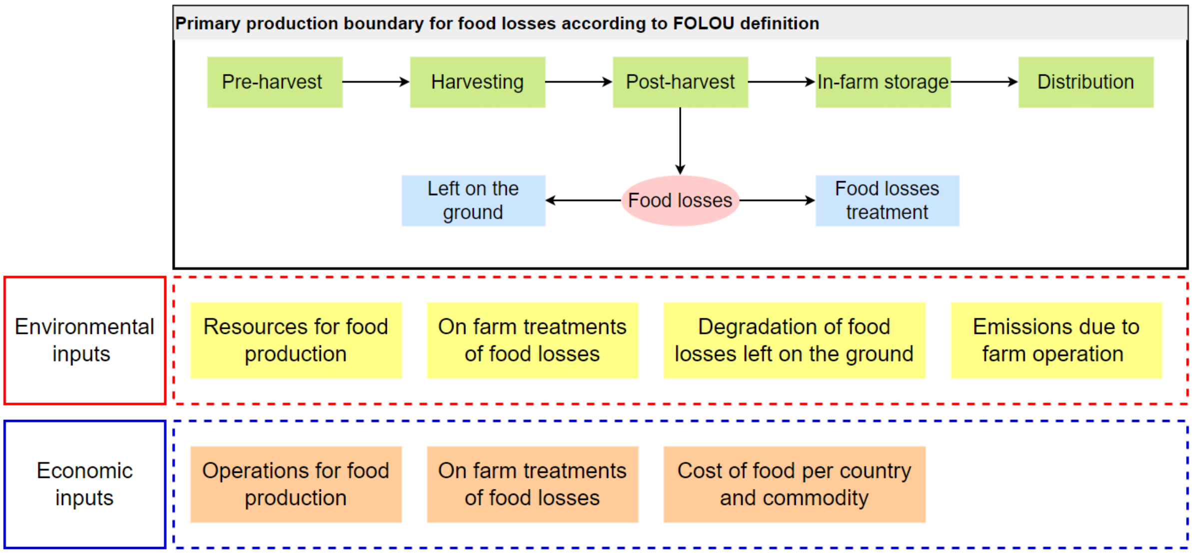

Figure 29- System boundary of LCC of food loss at primary production stage, conducted following LCA system boundary.

Another aspect linked to system boundaries and the integration between LCA and LCC is cut-off. Certain life cycle stages, activities, and processes disregarded by LCA might have a large impact on costs (Hunkeler et al. (2008)), therefore cut-offs criteria might present differences between the two assessments even with consistent boundaries. For LCC assessment of FOLOU boundaries, two cut-off criteria will be applied:

- **Environmental cut-off:** Cash flows directly linked to material flows (energy, materials, emissions) inventoried in the LCA to be considered. The purpose is to identify resource efficiency hotspots (e.g., surplus resource use associated with FL).
- **Semi-financial cut-off:** Further cash flows related to processes (labor, capital, etc.) inventoried in the LCA to be included. The latter could be needed to analyze potential capital or intensive labor measures (e.g., new processing machinery or increased workload to prevent food losses at primary production stage).

8.3 Life Cycle Inventory and LCIA

8.3.1 Assessment framework and required needed information

A Life Cycle Costing (LCC) framework for food losses at the primary production stage involves a structured and systematic approach to assessing and analyzing the total costs associated with food losses in agriculture from the point of production through to distribution. While LCC frameworks can vary depending on specific applications, the below general outline of a framework tailored for analyzing food losses at the primary production stage:

Scope Definition: Clearly define the scope of the analysis, specifying the type of primary production (e.g., crop farming, livestock, fisheries, i.e., classify the commodities to be grouped) and the specific food products or commodities

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to be considered. The assessment will be performed per commodity group as well as per representative products at each MS.

Time Horizon: Determine the time frame for the analysis, which could range from the moment where crops/animal are considered food, ready for harvest or production until the point of transfer to the next stage in the supply chain (e.g., processing or distribution). The time horizon can vary depending on the product and its perishability. The available data found to perform the analysis will mark whether further assessment and discussions will be carried out to complement the life costing assessment associated to food losses at primary production stage.

Cost Categories: Identify the various cost categories relevant to food losses at the primary production stage. According to different classification criteria, there are three methods to classify LCC, which are content dependence, time dependence, and cost dependence (De Benedetto and Klemeš, 2009; You et al., 2012).

Data Collection: collection of relevant data on the cost components within each category. This includes gathering historical data, conducting surveys, and estimating future costs of food products and associated operations.

Analysis and Modeling: adapting financial models, spreadsheets, or specialized LCC software to calculate the present value of future costs, considering the discount rate. Analyzing the data to estimate the total life cycle costs associated with food losses at the primary production stage. At the stage of modeling, we must define variables to represent the different elements of the LCC. These variables might include capital costs, operating costs, maintenance costs, discount rates, and time periods. The defined variables are to be linked by equations that answer economic indicators that will be identified for the LCC assessment of FL at PP.

Sensitivity Analysis: Conduct sensitivity analysis to assess how variations in variables or assumptions may impact the results. This helps in understanding the robustness of the LCC analysis.

Decision Support: The LCC results can inform decision-making processes at the primary production stage. For example, farmers and agricultural stakeholders can use this data to make informed decisions about investments in infrastructure, storage, transportation, and crop management practices aimed at reducing food losses.

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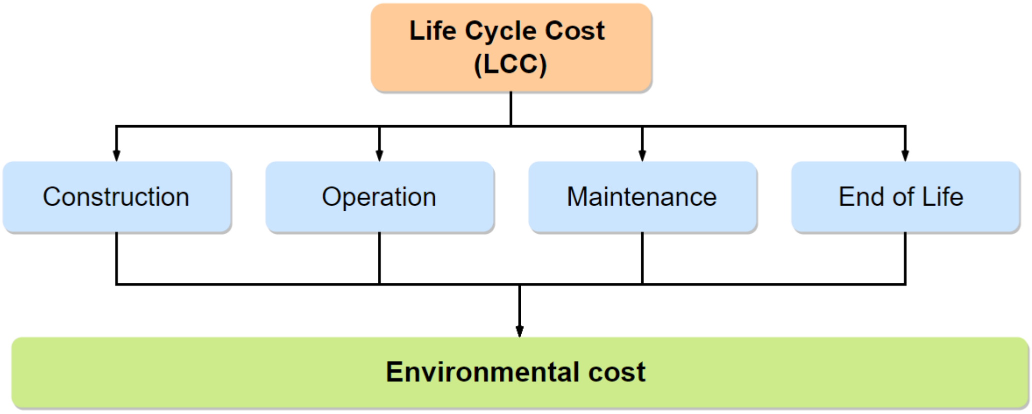

Figure 30- Composition of LCC expenses to consider for environmental boundaries of food loss at primary production stage.

8.3.2 Cost categories

Costs to be included in the LCC assessment can vary depending on its content, time or cost perspective. In some cases, for the LCC of a selected commodity it would be more relevant to choosing one classification or another. Content depends on will allow a deep assessment of different cost categories, namely, operation costs, utility cost, investment cost and others. Time dependence cost will differentiate between initial cost and future cost. Finally, the cost dependence LCC could be divided into the three categories of operation and maintenance cost, alternative cost, and construction cost. Some subclasses are also included in this classification, so that cost function can be defined. The cost classification that will be chosen for LCC assessment of FOLOU project will be defined based on the need of each category group and on the objective of conducting the assessment in each case.

- **Economic burdens associated with food losses at PP stage:**

It is important to note that the specific costs and their magnitude can vary depending on the type of primary production (crop farming, livestock, fisheries), the geographical region, the type of produce, and local conditions. A comprehensive LCC analysis takes into account all relevant cost components to provide a complete understanding of the economic implications of food losses at the primary production stage. These may include:

- **Production Costs:** Costs associated with planting, cultivating, harvesting, and post-harvest handling.
- **Loss Costs:** Costs related to food losses, including perishable product degradation, spoilage, and waste.
- **Logistics and Transportation Costs:** Costs associated with moving the produce from the farm to storage or distribution points.
- **Storage Costs:** Expenses linked to on-farm or off-farm storage facilities and equipment.

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- **Environmental Costs:** Costs related to the environmental impact of food losses, such as greenhouse gas emissions from spoilage or waste disposal.
- **Economic Costs:** Economic consequences of food losses, such as reduced income for farmers and communities.

For the LCC assessment of selected representative products per commodity and country, the following structure will be used as basis (Figure 31). Potentially, and depending on the available data, the different focus of the cost will be discussed while highlighting the economic impacts of FL at primary production stage.

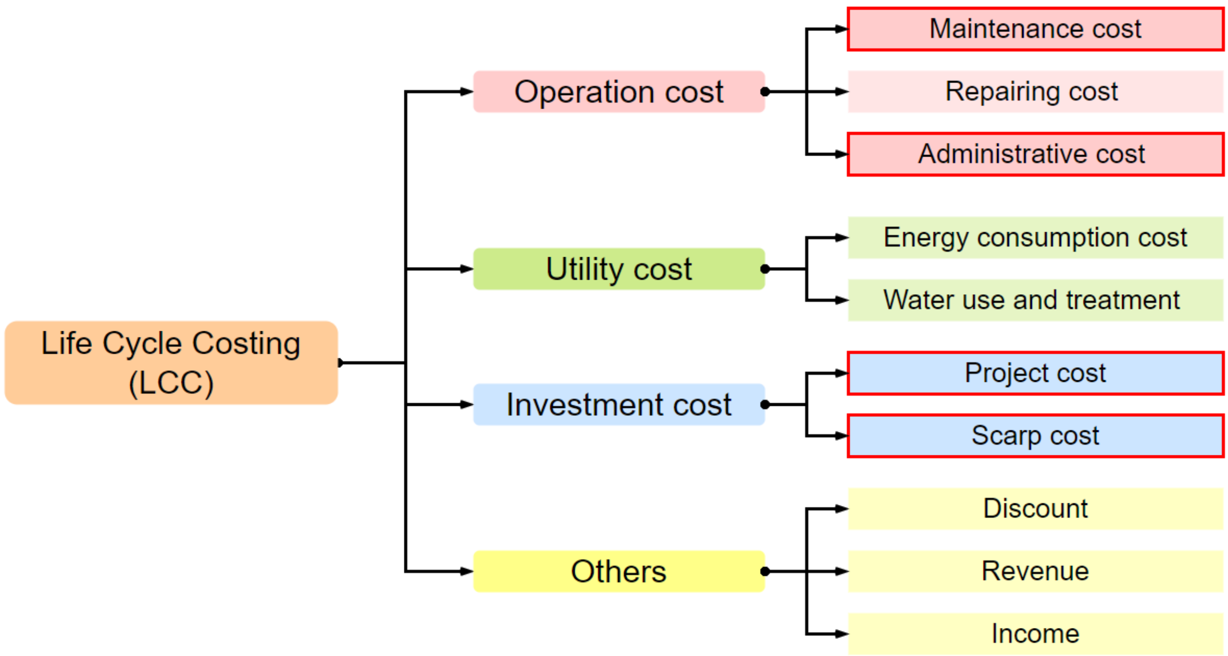

Figure 31- Classification of LCC expenses based on direct and indirect costs (red frame).

8.3.4 Sensitivity analysis

The LCC assessment for FL at PP will be accompanied with a sensitivity assessment, where key parameters will be selected for this exercise for each commodity type. Firstly, an Identification of which variables are most sensitive and could have the most significant influence on the LCC results for each product per commodity and country (uncertain variables or parameters). Then assess whether changes in these variables are likely to occur and what that means for decision-making.

By systematically adjusting the uncertainty of the variables, either manually or automatically if the feature is available in the used tool, an evaluation on how the variables impact the LCC results will be carried out. This helps in understanding the robustness of the model and examine the trends and patterns that emerge from the sensitivity analysis.

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The purpose of performing the sensitivity analysis is associated with the input data quality available for FL quantities at primary production for all products at all MS level.

8.4 Net economic savings for saving a percentage of food losses at PP:

Calculating net economic savings from a prevention action of food losses should consider costs associated with implementing and maintaining the prevention action selected. These costs are essential for determining the overall financial impact of the action.

Analogous to Section 7.6, the economic impacts of the prevention actions to be implemented purposing the reduction of food losses at PP is a relevant indicator to assess the cost-efficiency of the action assessed. The Net economic saving will take into consideration the following costs: 1) Cost of avoided food production, 2) Saving from avoided on-farm treatment of the food that has been prevented from losses and 3) the cost of the implemented prevention action.

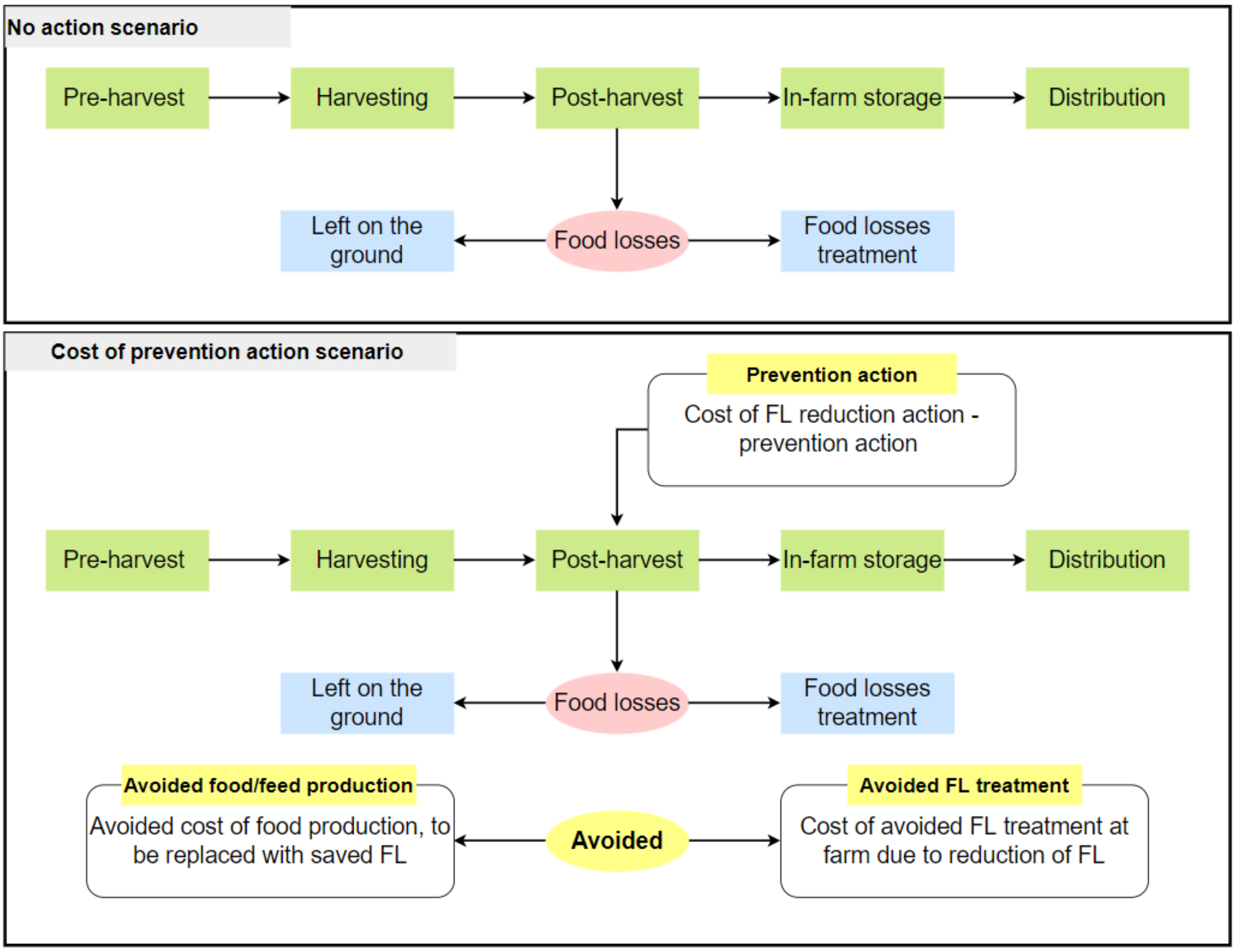

Figure 32- Net economic savings framework applied to prevention actions aiming to reduce food loss at primary production stage.

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Expanding the cost categories above, we can site the following categories:

- **Implementation Costs:** or Capital Investment, this includes the initial costs required to implement the prevention action. It encompasses expenses like purchasing equipment, building infrastructure, or acquiring technology.
- **Operating Costs:** consisting of labor costs, utilities costs, materials and supplies costs, and repair and maintenance costs for regular and unplanned maintenance, repairs, and servicing of equipment or infrastructure.
- **Compliance Expenses:** costs associated with meeting regulatory requirements and ensuring that the prevention action complies with relevant standards and regulations.
- **Environmental and Social Costs:** expenses associated with the environmental impact of the prevention action. Social Costs are related to the social impact of the action, such as community engagement or compensation.
- **Externalities:** Consider external costs, such as unforeseen negative impacts on the environment, health, or society that may result from the prevention action.
- **Financing Costs:** are mostly related to financing the implementation of the prevention action, including interest on loans or other financing charges, and costs associated with managing and overseeing the implementation and operation of the action.

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9. Social life cycle assessment (SLCA)

9.1 Introduction to SLCA

9.1.1 Historical development of SLCA:

Social Life Cycle Assessment (SLCA) is a novel approach that evaluates the social impacts of goods and services throughout their life cycles, building on the established Environmental Life Cycle Assessment (E-LCA or widely known as LCA) methodology. LCA originated in the 1990s when O'Brien and others (1996) first proposed integrating social aspects into LCA. Klöpffer (2003) and Weidema (2006) further contributed to discussions on aligning S-LCA with LCA. Various social indicators, such as employment (Hunkeler 2006), Quality Adjusted Life Years (QALY) (Weidema 2006), and health impacts (Norris 2006), have been suggested. Site-specific assessments have also been advocated, emphasizing the importance of evaluating impacts related to a company's behavior on-site (Dreyer et al., 2006).

A significant milestone in the development of SLCA was the UNEP/SETAC SLCA Guidelines (Benoit and Mazijn 2009; Benoit et al., 2010), created within the Life Cycle Initiative partnership between the United Nations Environmental Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC). These guidelines, the outcome of a global and inclusive process involving stakeholders from various sectors, represent a foundational vision for S-LCA methodology. However, further refinement is necessary to make it a practical tool. SLCA assesses social impacts but does not dictate whether a product should be produced or provide guidance on addressing social impacts; it serves as an informative tool for decision-making.

9.1.2 Definition of SLCA

A social and socio-economic Life Cycle Assessment (SLCA) is a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle encompassing extraction and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal. SLCA complements LCA with social and socio-economic aspects. It can either be applied on its own or in combination with LCA.

Life cycle assessment (LCA) considers mainly environmental impacts along supply chains, from extraction of raw materials to end-of-life of products. Similarly, social life cycle assessment (SLCA) integrates traditional life cycle assessment methodological steps while having social impacts as focus. Coupling the assessment of environmental and socio-economic issues may support more comprehensive sustainability assessment of impacts, benefits, and related trade-offs.

SLCA performed together with environmental LCA helps to understand the intersection of social and environmental issues, better aligning environmental

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sustainability efforts with social efforts (UNEP, 2020). It is an iterative methodology, which means that we can improve the assessment over time, going through several assessment loops and moving from more generic results to more case-specific ones.

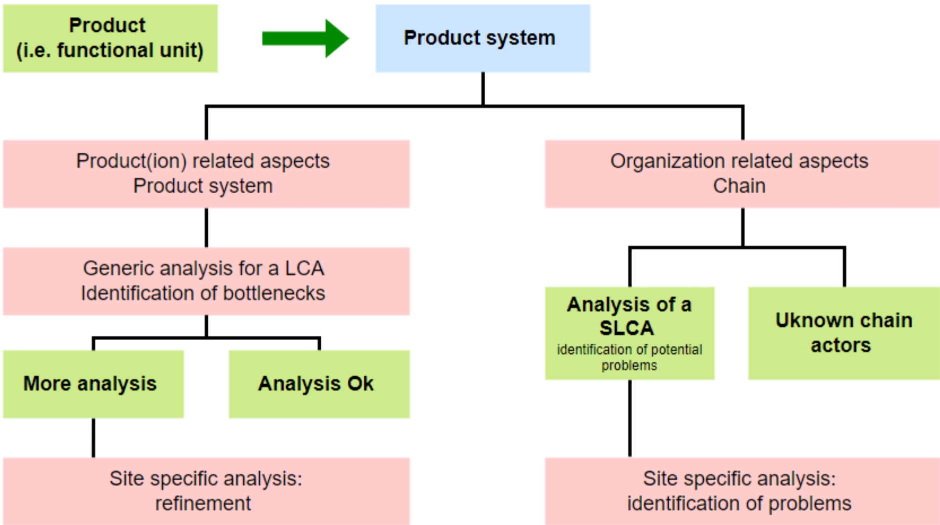

Figure 33- Twofold analysis of the product system (adapted from Mazijn et al., 2004).

Even though SLCA complies with the ISO 14040 framework, certain aspects could change, become more prevalent, or be emphasized depending on the degree of the research. An approach for creating life cycle inventories is suggested by the UNEP Guidelines for Social Life Cycle Assessment of Products. A life cycle inventory is developed for indicators (such as the number of jobs generated) linked to effect categories (such as local employment) that are connected to five major stakeholder groups: workers, consumers, local community members, society, and value chain players. Stakeholders, subcategories, and indicators are all listed in the UNEP (2020) methodology (31 subcategories), according to the stakeholders involved in a product's life cycle. A stakeholder category is a group of stakeholders who are anticipated to share a common interest given their proximity to the systems under investigation. The S-LCA users may additionally develop and apply additional stakeholder categories, differentiations, and/or subgroups (Benoit et al., 2010).

9.2 Goal and scope:

9.2.1 Goal of the assessment

The scope of the assessment will be aligned with the methodology developed under WP4 of the FOLOU project "***Food loss is any harvest-mature plant, animal or living being (including inedible parts) that is not successfully harvested, as well as food removed from the supply chain during post-harvest phase that does not become animal feed, by-product or food waste***." a cradle-to-gate assessment for 1 USD food product at the primary production stage. The input of the model is therefore represented by the list

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of country-specific sectors for a certain product, while the output was set as 1 euro of representative food product.

A stakeholder categorization may be used to classify the subcategories while conducting the aim and scope. To guarantee that the SLCA aligns with the aim and scope is the goal of classifying subcategories according to stakeholder groups. There is speculation that stakeholders might differ at each stage of the supply chain. Figure 34 shows a selection of stakeholder group-specific effect categories and subcategories for food commodities at each MS. The assessment will be performed at country level in case of available data, otherwise, an EU average will be adapted following the same approach for the LCA and LCC (Figure 23).

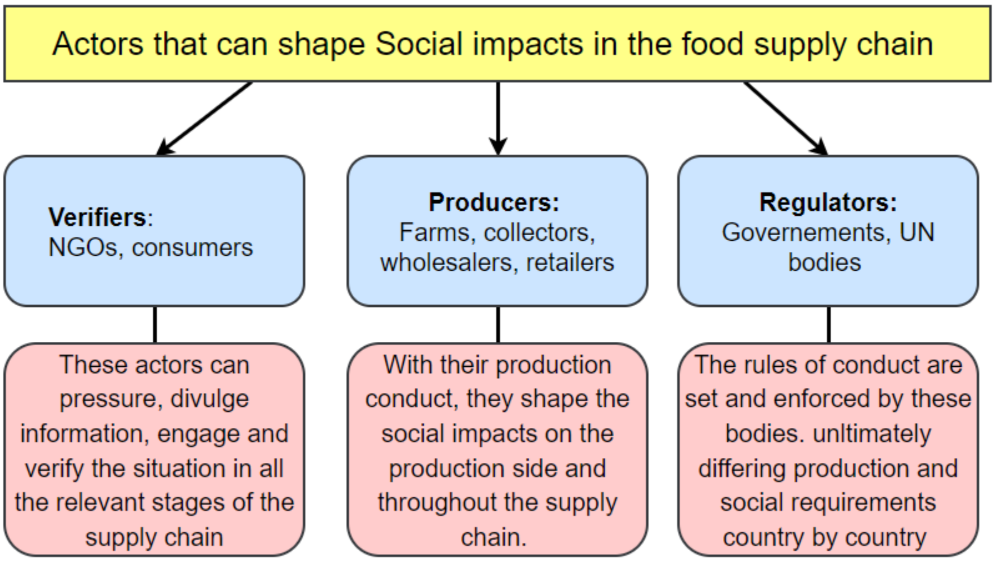

Figure 34- Stakeholders involved in the social aspects of food loss at primary production stage.

9.2.2 Reference unit

S-LCA frequently uses semi-quantitative or qualitative data, which cannot be precisely represented in terms of process output units. Several writers suggested doing aggregation using the activity parameter (UNEP, 2020).

9.2.3 System boundaries

The system boundaries to be used for SLCA is preserved from the one developed for the LCA assessment and aligned with the definition and scope of food losses developed under FOLOU project. The SLCA assessment will take place on a farm (where the food is being produced) and the stakeholders to be taken into account are to be defined for each food commodity group.

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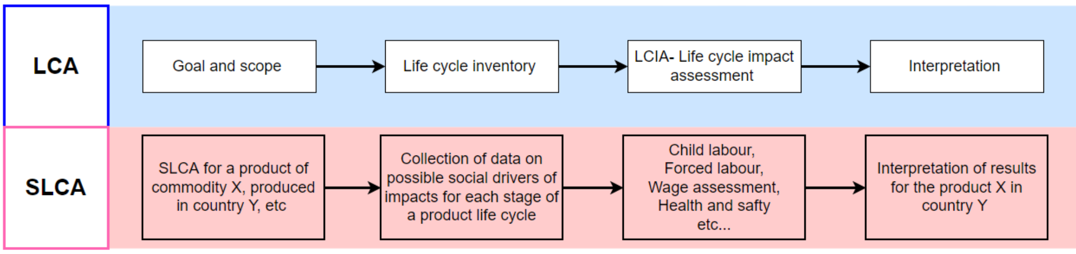

Figure 35- Projecting environmental impacts framework to social aspects for the assessment of food losses at primary production stage.

9.3 Life Cycle Inventory:

9.3.1 Database and Life cycle inventory

PSILCA, or the Product Social Impact Life Cycle Assessment database, was created by GreenDelta as an innovative Social LCA database. PSILCA is based on the connection of a database containing statistics on the many social dimensions covered by the indicators with a multi-regional input/output database, namely Eora (Lenzen et al., 2013). PSILCA, a database of financial exchanges for about 15,000 business sectors and commodities in 189 nations, is based on Eora. Additionally, it incorporates social indicators (country specific sectors, CSS) for each country-sector combination. According to the UNEP's social LCA framework (UNEP, 2020), social indicators are organized into five stakeholder groups and 23 impact subcategories (such as child labor, a fair wage, etc.). Except for the indicator "contribution to economic development" which refers to a positive influence or a social opportunity, 87 indicators speak to social hazards or negative effects.

The majority of the sources included in PSILCA's database for social statistics come from reliable official statistical organizations, including the World Bank3 and International Labor Organization (ILOstat2), as well as other trusted public and private sources. The PSILCA database also provides a data quality evaluation for each data point, which is determined by the technical, temporal, completeness, and geographic conformity of the data as well as its reliability of the data source.

Table 6- Social indicators divided by topics/subcategories, and stakeholders in PSILCA database.

Stakeholder	Topic	Indicators
Local Community	Access to material resources	Certified environmental management system
		Extraction of biomass (related to the area)
		Extraction of biomass (related to population)
		Extraction of fossil fuels
		Extraction of industrial and construction minerals
		Extraction of ores
		Level of industrial water use (related to renewable water resources)
		Level of industrial water use (related to total withdrawal)
	Environmental Footprints	Embodied agricultural area footprint
		Embodied forest area footprint
		Embodied water footprint

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		Number of threatened species
	GHG Footprints	Embodied CO_2 footprint
		Embodied CO_2-eq footprint
	Local employment	The unemployment rate in the country
	Migration	Emigration rate
		Immigration rate
		International Migrant Stock
		International migrant workers in the sector
		Net migration rate
		Number of asylum seekers in relation to the total population
	Respect for indigenous rights	Indigenous People Rights Protection Index
		Presence of indigenous population
	Safe and healthy living conditions	Drinking water coverage
		Pollution level of the country
		Sanitation coverage
Society	Contribution to economic development	Contribution of the sector to economic development
		Embodied value-added total
		Illiteracy rate, female
		Illiteracy rate, male
		Illiteracy rate, total
		Public expenditure on education
		Youth illiteracy rate, female
		Youth illiteracy rate, male
		Youth illiteracy rate, total
	Health and Safety	Domestic and external health expenditure (% of current health expenditure)
		Domestic general government health expenditure (% of current health expenditure)
		Global Peace Index
		Health expenditure, external resources
		Health expenditure, out-of-pocket
		Health expenditure, public
		Health expenditure, total
		Life expectancy at birth
Value Chain Actors	Corruption	Active involvement of enterprises in corruption and bribery
		Public sector corruption
	Fair competition	Presence of anti-competitive behavior or violation of anti-trust and monopoly legislation
	Promoting social responsibility	Membership in an initiative that promotes social responsibility along the supply chain
Workers	Child labours	Children in employment, female
		Children in employment, male
		Children in employment, total
	Discrimination	Gender wage gap
		Men in the sectoral labor force
		Women in the sectoral labor force
	Fair Salary	Living wage Lower bound
		Living wage Upper Bound
		Living wage, per month (AV)
		Minimum wage, per month
		Sector average wage, per month
	Forced Labour	Frequency of forced labour
		Goods produced by forced labour
		Trafficking in persons
	Freedom of association and collective bargaining	Right of Association
		Right of Collective bargaining
		Right to Strike
		Trade union density
	Health and Safety	DALYs due to indoor and outdoor air and water pollution
		Presence of sufficient safety measures
		Rate of fatal accidents at the workplace
		Rate of non-fatal accidents at the workplace
		Violation of mandatory health and safety standards
		Workers affected by natural disasters
		Evidence of violations of laws and employment regulations

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	Social benefits, legal issues	Social security expenditures
	Working time	Weekly hours of work per employee

9.3.2 PSILCA indicators screening:

From the indicators presented in Table 6, a selection will be made for each food commodity highlighting the social impact resulted on the operations during the production of its products (life cycle of the food production process). The assessment will be performed at country level for each commodity represented by several food products, instead of each product individually, as is the case for the LCA. The indicators will be categorized by stakeholders for each impact category/indicator. The actors/stakeholders that are responsible for shaping the social impacts at primary production stage of food production are given in Figure 34.

Once the indicators are defined, the data collection will be done by means of an Excel tool, where each indicator will be qualitatively determined on the scale illustrated in Figure 36.

Calculate the Indicator

Reference scale	Reference scale description	Result
☑ VLR	0 < y < |5|	
☐ LR	|5| ≤ y < |10|	
☐ MR	|10| ≤ y < |20|	
☐ HR	|20| ≤ y < |30|	
☐ VHR	|30| ≤ y	
☐ NR	y = |0|	
☐ N/APP	y = |100|	
☐ N.A.	no data	N.A.

Figure 36- Illustration of the social indicator scale developed for the assessment of SLCA in PSILCA database.

The results obtained by each indicator will be incorporated into the PSILCA model developed in OpenLCA software, which will be used for the social assessment in the framework of FOLOU project.

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9.3.3 Geographical coverage

As adapted for LCA and LCC, the data geographical coverage will follow the same approach and hierarchy. For products, commodities, country disposing from primary data, the assessment will take into account the available data. In case primary data for some products are not available, an average will be defined to represent a commodity per country and another one to represent a commodity at EU for the special cases where no data is available for SLCA (See Figure 23).

9.4 Linking PSILCA indicators with SDGS goals/targets:

9.4.1 SLCA and SDGs

The United Nations (UN) announced an Agenda for 2030, "Transforming Our World," with 17 new sustainable development goals (SDGs), in order to define a worldwide strategic direction for development (UN, 2015). Six of them (1, 4, 5, 8, 10, 11) are centered on social concerns, while two are concerned with governance as a way to go from unsustainable growth to sustainable development (16, 17) (Figure 37).

Figure 37- SDGs classified under three sustainability pillars: economic, environmental and social.

The link between LCSA and the SDGs has been researched and emphasized in literature. Several studies have associated LCA as an environmental impact assessment approach to various SDGs (Sala, 2019; Sanyé- Mengual and Sala, 2022; Kørnøv et al., 2020), including the creation of conceptual models (e.g., in relation to absolute measures of sustainability, Chandrakumar and McLaren, 2018) and the empirical testing on case studies (e.g., Sala and Castellani, 2019).

In this line, and considering the framework of FOLOU project, many social impacts of food production at primary production stage could be stated. In fact, Food losses at the primary production stage can have significant social impacts on various stakeholders involved in the agricultural and food supply

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chain. These impacts can vary depending on the specific circumstances and context, but some common social consequences of food losses at the primary production stage include:

- **Farmers' Livelihoods**: Food losses can directly affect the income and livelihoods of farmers. When a significant portion of their harvest is lost due to factors like pests, diseases, or poor post-harvest handling, farmers may face reduced income and financial instability. This can lead to poverty and food insecurity for farming communities.
- **Rural Communities:** In many regions, agriculture is a primary source of income and employment for rural communities. Food losses can lead to reduced economic opportunities in these areas, potentially driving migration to urban centers in search of employment, which can strain urban infrastructure and services.
- **Food Security:** Food losses at the primary production stage can contribute to food scarcity and increased food prices, affecting not only farmers but also consumers. This can lead to reduced access to nutritious and affordable food, particularly for vulnerable populations.
- **Food Aid and Assistance**: Increased food losses can put pressure on governments and humanitarian organizations to provide food aid and assistance to affected communities. This can strain resources and divert efforts from other development programs.
- **Environmental Impacts:** While the primary focus of food losses is on social impacts, it's important to note that these losses also have environmental consequences. For example, when food is lost due to inefficient farming practices, it may lead to unnecessary resource use (e.g., water, energy, land), which can exacerbate environmental problems and contribute to climate change. These environmental impacts can indirectly affect social well-being by influencing resource availability and sustainability.
- **Education and Healthcare:** Reduced income and increased food insecurity can impact access to education and healthcare services. Families may have to make difficult choices between sending their children to school or allocating resources for medical care when they are struggling to meet basic food needs.
- **Gender Equity:** Food losses can have differential impacts on gender. In many agricultural communities, women play a significant role in food production and post-harvest activities. When food is lost, women may bear a disproportionate burden in terms of lost labor and increased workload, which can affect their well-being and limit their opportunities for education and income generation.
- **Social Cohesion:** Food losses can create social tensions within communities, especially if there is competition for limited resources or disputes over responsibilities for the losses. This can strain social cohesion and community relationships.

These hotspots social screening is general in terms of applicability to the primary production stage, country, and commodity level. Depending on the

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available data by the day the assessment will be carried out, the list may vary according to the commodity, country and available data.

The abovementioned social impacts are associated with the SDG goals illustrated in Figure 37. In the following sections, an extended methodology on how to link the social impacts presented in PISILCA database to goals and targets from SDGs framework.

9.4.2 Linking PSILCA indicators and SDGs

Linking the social performance of the food supply chain, mainly focusing on primary production stage, with the SDGs goals/targets will allow a deep description of the actual situation of the food system in relation to the achievements proposed by SDGs framework. The assessment will serve to identify the hotspot social impacts within the food system that require urgent to no intervention to be done in the food systems (PP). the linkage between the obtained results and the SDG framework will project the situation in another dimension that reflects the EU food performance from an SDG lens.

The method developed to perform the analysis (shown in Figure 38) is based on three major steps to be followed:

i) Mapping PSILCA indicators to the SDGs framework,
ii) Selection of indicators from PSILCA and finally
iii) Implementation of SLCA to the EU food losses at primary production stage.

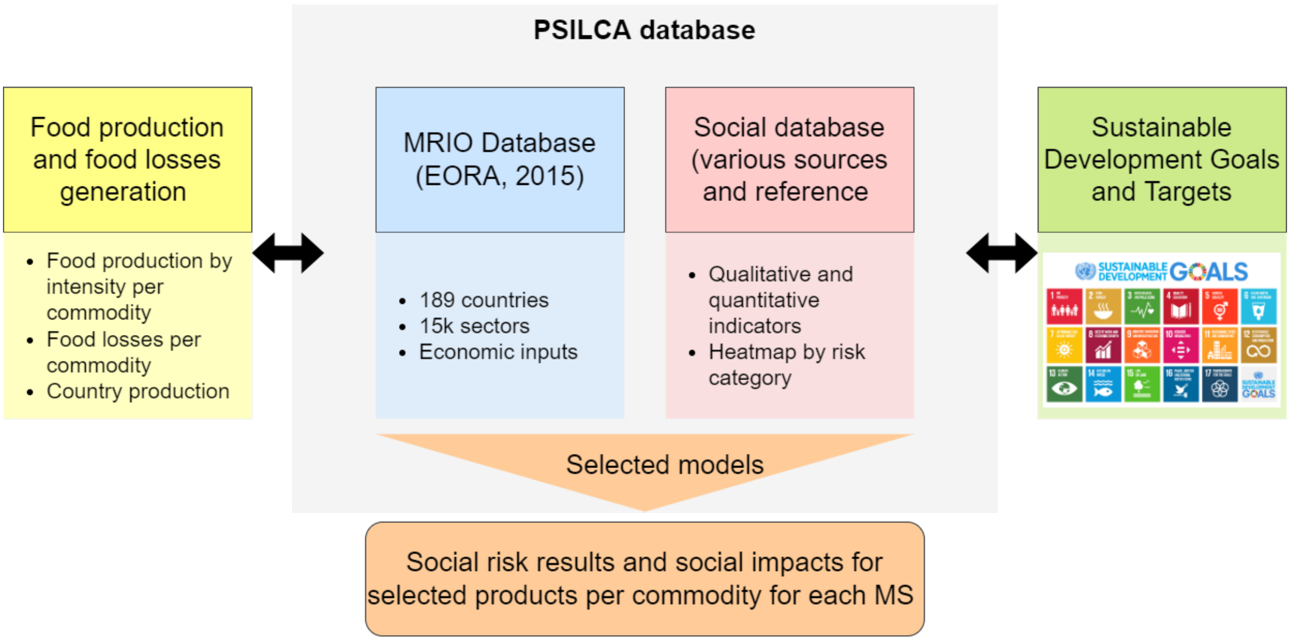

Figure 38- Building block of the framework to be followed for the social assessment linking the models in PSILCA database to SDGs framework.

i) Mapping PSILCA indicators to the SDGs framework

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Mapping the indicators of the PISILCA database to SDGs framework allows understanding how it relates to its goals and targets, as well as current coverage by SLCA.

The SDG mapping will be performed in two steps:

1- Looking in detail at each PSILCA indicator and linking them to the corresponding target of the SDG framework.
2- Grouping the indicators at the level of stakeholders (SLCA category), impact category (SLCA category) and SDG goal level (Figure 38).

ii) Selection of indicators from PSILCA

Data on social risk is provided for the indicators, with a scale ranging from no/very low risk to very high risk (Figure 36). A characterisation factor (CF) is allocated for each risk level, reflecting the risk level in terms of medium risk hours per worker hour on an exponential scale. Using the so-called activity variable, or worker hours, this quantification enables the aggregate of distinct country-specific sector (CSS) throughout the stages of the supply chain. The number of hours a worker puts in to generate one dollar's worth of output for a certain industry.

The CF of the specified social indicator in the CSS is multiplied by the activity variable (worker hours), and the result is accumulated along the supply chain to determine the social risk.

The selection of indicators and subcategories from PSILCA is following the listed criteria:

- **Environmental aspects**: Exclusion of environmental aspects assessed with LCA methodology (section 7)
- **Local level:** The data used for this assessment, as well as related databases, are only available at the country level. This limitation makes it challenging to detect social risks at a local level, such as specific employment trends or migrant worker flows in particular areas tied to specific production activities. Consequently, these country-level averages are not meaningful for evaluating local impacts, particularly in the context of "local employment" and "migration" within the stakeholder category of the "local community." This limitation also extends to some indicators related to environmental aspects.
- **Data completeness and quality**: In the PSILCA v.2 database, the "Consumers" stakeholder category is represented by just one indicator related to deceptive or unfair business practices towards consumers. However, this indicator had to be excluded from the analysis for various country-sector combinations due to the unavailability of data. Similarly, the impact subcategory "social responsibility along the supply chain" had to be excluded from the analysis as it suffers from numerous data gaps and generally low data quality based on the database evaluation.

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The implementation of these criteria will lead to a selected list of indicators and subcategories. A sensitivity analysis can be implemented based on policy relevance and data quality.

The indicators will be grouped by stakeholder group and subcategory for each commodity at country level. The final list of indicators can be modified, reduced or extended depending on the logical links that will be used with the SDGs framework and the available data. A preliminary list will be identified within the FOLOU project and the SLCA will be performed to highlight the social impacts and risk for the same product produced at two different countries. The assessment will be performed meanwhile identifying the drivers behind the food losses occurred in each case, thus a better evaluation of the decision making at country level for the five studied commodities.

iii) Implementation of SLCA to the EU food losses at primary production stage

Social risk associated with an economic unit of output from certain country-sector using PSILCA and taking into account all risks related to upstream phases of the supply chain. The assessment will be applied to a commodity as a food indicator based on the life cycle of representative products. The commodity will be represented by several products based on their production intensity for the last five years. Figure 38 visualizes the main building blocks of the model to assess the social footprint of FL at PP. For each representative produced product, trade and domestic consumption will be calculated following the approach described in Sections 5 and 6 where annual FL and PL were determined.

For this exercise different data sources were employed in the building block (Figure 38), a specific classification system and mapping is required to combine trade data for representative products with the country-sectors combinations available in PSILCA.

The MRIO (Multi-Regional Input-Output) database used in the PSILCA (Product-specific Supply and Use Input-Output Life Cycle Assessment) method, specifically the EORA database, encompasses diverse national sector classifications. These classifications vary in granularity, ranging from highly detailed (with hundreds of sectors for a single country) to more generalized (with 26 sectors per country). To harmonize the data, each representative food product is associated with a specific sector from the available classifications corresponding to the various producing countries. This mapping ensures uniformity in the sector representation across the dataset. The input of the model is therefore represented by the list of country-specific sectors for a representative product, while the output was set as 1 euro of representative food product.

All data on the representative products per commodities are calculated as shown in Section 5 and 6.

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9.5 Unveiling the Social and Economic Dimensions in sustainability assessment of FL at PP

9.5.1 Monetary valuation of environmental impacts of food losses at primary production stage:

The process of turning metrics of social and environmental impacts into monetary units is known as monetary valuation, and it is used to calculate the economic worth of non-market products, or goods for which there is no market (Pizzol et al., 2015). There is value in identifying the order of magnitude of environmental impacts converted into monetary terms in view of placing them in relation to the real economy, and in this way facilitating decision making (Alberici et al., 2014).

Since the first monetary valuation of an LCA was conducted by Finnveden et al. (1999), several approaches and methods have been developed up to today. Several advantages of using monetary valuation in the weighting phase of LCA are to be cited, however, the practical implementation of this approach in LCA were still considered to be challenging (Finnveden et al., 2009; Ahlroth et al., 2011; Ahlroth, 2014).

LCA assesses potential impacts which do not refer to specific situations but are generalizable and aggregated over space and time. Therefore, the monetary valuation of potential impacts should result in monetary valuation coefficients (MVCs) applicable to different contexts (Pizzol et al., 2015), which is not straightforward. It was also recognized how the potential benefits of applying monetary valuation in LCA are constrained by the limited development of MVCs, especially for some impact categories (Arendt et al., 2020).

In the framework of FOLOU project, and as an objective of WP5, the monetary environmental impacts associated to the fraction of food losses generated at primary production stage is relevant outcome.

To perform the monetary valuation of the environmental impacts associated to FL at PP the following steps are to follow:

1- Collection of MVCs: from literature and case studies reporting results that can be used or adapted for the five commodities to be assessed. In case multiple MVCs are available for the same product representing a commodity, the average is to be considered. Ideally, only MVCs directly applicable to the EF will be used.
2- Combination of the MVCs with environmental impact factors: after analyzing the approaches available for the monetary valuation of midpoint impacts according the 16 impact categories assessed by the EF method.
3- Adjusting the MVCs for inflations to the selected reference year: in case the MVCs were provided in euros per year rather than reference year, an adaptation is necessary following the equation below:

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$$\text{Final value (i)} = \frac{CPI\ final, i}{CPI\ initial, j} * Present\ value(j)$$ [23]

where:

Final value: represents the MVCs for the year i adjusted for inflation.

Present value: represents the MVCs in the year j (this is the year set as the "Present year").

CPIfinal,i: represents the CPI value for the year i;

CPIfinal,i: represents the CPI value for the year j (this is the year set as the "Present year").

The values of the CPI indexes will be derived from the Eurostat database and if available other case studies.

4- Converting environmental impacts in monetary terms: by multiplying the environmental impact to the monetary factor corresponding.

9.5.2 Social return on investment:

Social Return on Investment (SROI) is a framework and methodology used to assess and communicate the social and environmental value or impact generated by an organization, program, project, or intervention in monetary terms. It's a way to measure the positive outcomes and benefits in financial or economic terms, similar to how financial return on investment (ROI) measures financial gains. This assessment is one of the relevant and additional objectives of WP5 within the FOLOU project.

Calculating SROI for food losses at the primary production stage involves assessing the social and environmental value created by reducing these losses and assigning monetary values to these impacts. In this case the social impacts will at PP will be the focus. The scope and boundaries will be the same as defined in Section 7.1.2.

To successfully perform the assessment, the following criteria should be considered:

1- Identify Stakeholders: Identify the stakeholders involved, including farmers, local communities, food supply chain actors, and consumers, as well as government agencies and environmental organizations concerned with sustainability.
2- Outcomes and Impacts: Identify the positive outcomes and impacts resulting from reducing food losses at the primary production stage. These can include increased food availability and security, improved

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income for farmers and reduced environmental impact (e.g., reduced resource use and greenhouse gas emissions).

3- Use surveys, interviews, or other methods to gather involved stakeholder input. Evaluate the significance of these outcomes for each stakeholder group.

4- Monetization: Assigning monetary values to the outcomes and impacts. This step is considered to be the most complex one and may involve the following:

- Estimating the value of additional food production and reduced waste.
- Calculating the increased income for farmers due to reduced losses.
- Assessing the cost savings from reduced resource use and emissions.
- Consider the cost of interventions or technologies that reduce food losses.

5- Investment Costs: Calculate the investment or costs required to reduce food losses at the primary production stage. This may include the cost of implementing new technologies, training programs, or infrastructure improvements.

6- SROI Calculation: It's important to highlight that calculating the SROI for food losses at the primary production stage can be challenging due to the need for accurate data and the complexity of monetizing social and environmental impacts. However, it can be a valuable tool for demonstrating the benefits of reducing food losses in terms of improved food security, economic gains for farmers, and reduced environmental impact. SROI is calculated by the mean of equation X as follows:

$$\mathrm{SROI} = \frac{Social\ value\ created}{Investment\ Costs} \qquad [24]$$

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